
ISLS 2023
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ISLS Annual Meeting 2023

Building Knowledge and Sustaining our Community
Montreal, Canada, June 10-15
Workshops: June 10-11
Concordia University & Dawson College

17th International Conference of the Learning Sciences (ICLS)

- Proceedings -

Edited by: Paulo Blikstein, Jan Van Aalst, Rita Kizito, & Karen Brennan

ISLS

Université Concordia University
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The Erindale Academy

International Society of
the Learning Sciences

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17th International Conference of the Learning Sciences (ICLS) 2023

- ICLS Proceedings -

3rd Annual Meeting
of the
International Society of the Learning Sciences (ISLS)

Editors:
Paulo Blikstein, Jan Van Aalst, Rita Kizito, & Karen Brennan

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Preface

This volume contains the proceedings of the Third Annual Meeting of the International Society of the Learning Sciences (ISLS 2023) under the theme "Building Knowledge and Sustaining our Community." The resilience and high cohesion of the ISLS community have prevailed after the turbulent pandemic years. In 2023, our community gathered again at Concordia University in Montréal, Canada. Long-standing members and newcomers came together in beautiful downtown Montréal to share new research, engage in lively discussions, expand their network, and taste the famous *poutine*.

Though this is the 17th time our community has come together for an annual meeting, it is only the third year that we have held an Annual Meeting of the International Society of the Learning Sciences (ISLS) where the International Conference on Computer-Supported Collaborative Learning (CSCL) and the International Conference of the Learning Sciences (ICLS) where held together. At ISLS 2023, in addition to the habitual categories, we again invited submissions in the Technology Innovation category and created two new ones: *Innovative Symposia* (which included, for example, hybrid participation and pre-conference activities) and *Practice-Oriented Papers*. The program also distinguished between empirical, theoretical, and methodological contributions for all submission categories.

The ICLS Proceedings feature long papers, short papers, posters, and symposia, all subject to rigorous double-anonymized peer review. We received an unprecedented 791 submissions, an increase of 8% compared to ICLS 2022. The submissions covered a broad range of ICLS research, design, and technological innovation. In total, 32.5% (105 out of 323) long paper submissions and 34.3% (93 out of 271) short paper submissions were accepted in the category in which they were submitted. In addition, several submissions were accepted into a different category (short papers or posters). As a result, the ICLS Proceedings features 105 long papers, 196 short papers, eight technology innovation papers, 21 practice-based papers, 244 posters, and 19 symposia.

We have had submissions from 44 countries in all continents. Unfortunately, almost 80% of those came from the US and Canada, and only about 7% came from low- and middle-income countries, which hold 70% of the world's population. Interestingly, the overall acceptance rate for South America (48%) is higher than that of the US (44%) and Western Europe (32%). Even though the number of US submissions is more than 20 times higher and covers more categories, these percentages suggest that the quality of the papers from low- and middle-income countries is high and that a larger participation of scholars from these countries would enormously enrich our community.

The program chairs would like to thank the 684 reviewers and 164 senior reviewers who carried out 2334 reviews and 791 meta-reviews. Collectively, we wrote 818,000 words--more than the Bible (788,000 words)! We would also like to thank the numerous people who have spent countless hours ensuring that the program is of high quality and the fantastic ISLS 2023 local organizing team.

ICLS 2023 reflected our collective pursuit to understand learning in its multifaceted contexts and to develop equitable and innovative learning environments. The conference's presentations and discussions underscored the importance of integrating diverse learning contexts to address the challenges and opportunities in a world undergoing intense transformation, diving into complex tapestries of learning processes, technologies, designs, and practices. Our eclectic community is exploring themes and methods that go all the way from machine learning to thick ethnographies, and is becoming, each year, more attuned to different epistemologies, worldviews, and ways of learning. The contributions in 2023 reflect this diversity, exploring topics such as learning in the disciplines (science, mathematics, history, civics, maker education, computer science, and others), equity and justice, artificial intelligence in education, embodied cognition, multimodal learning analytics, teacher learning, and informal learning environments.

ICLS 2023 should not just be a platform for academic discourse but also a catalyst for transformative action. Hopefully, the discussions and collaborations initiated in Montréal will resonate beyond the conference, inspiring new research and practice in the Learning Sciences. We hope that insights from these proceedings will empower participants to cultivate learning environments that are more inclusive, justice-oriented, innovative, and rigorous, enabling learners to realize what Paulo Freire considered to be the ontological vocation of every human: *changing the world.*

Saudações Freireanas,

Paulo Blikstein, Karen Brennan, Rita Kizito & Jan Van Aalst
Conference Chairs, ICLS 2023

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Metacognitive Calibration: A Methodological Expansion and Empirical Application

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Abstract: The ability to judge performance accurately is essential for successful learning. However, statistics or measures to do so are frequently limited to binary judgments and not scalable. Moreover, they primarily assess only one dimension of the metacognitive calibration accuracy. In this methodological paper, we develop and discuss a new set of statistics to determine the calibration accuracy and the direction of miscalibration. Together, they indicate the extent of confidence accuracy and whether learners are overconfident or underconfident in their judgments. These statistics are scalable to non-binary judgment data. We then illustrated them in an empirical study with 34 doctoral students' performance judgment data which were assessed when answering domain-specific conceptual questions. Results from traditional measures were calculated, serving as a reference for the new measures' reliability. In addition, we developed an *R*-package implementing and visualizing the latter. The theoretical and practical implications are discussed.

Introduction

The concept of *metacognitive calibration* describes the idea of a learner's ability to correctly judge their task performance (Keren, 1991). In other words, learners that are able to judge their correct performance as correct and incorrect performance as wrong display a high metacognitive calibration. Since the seminal literature review by Lin and Zabrucky (1998), the importance of metacognitive calibration became a highly acknowledged concept in the field of educational psychology and the learning sciences. Metacognitive miscalibration through overconfidence regarding the own performance appeared to negatively influence learning by reducing cognitive processing efforts (Lin & Zabrucky, 1998). Inadequate underconfidence, on the other hand, might negatively impact self-confidence, which is essential for successful learning as through the affected intrinsic motivation (i.e., through perceived competence). Similarly, it might influence potential ability-grounded failure attribution (Bandura, 1986; Dweck, 1975; Ryan & Deci, 2000). As such, empirical studies provided evidence for the predictive power of anxiety and reduced self-confidence (i.e., underconfidence) on lower test performance (Barrows et al., 2013). Furthermore, failure-driven problem-solving (e.g., Productive Failure; Kapur, 2014), in contrast to success-driven problem-solving, was shown to partly increase students' metacognitive calibration, potentially due to greater opportunities for self-evaluation (Sinha & Kapur, 2021a). In other words, the failure to successfully solve a problem might be beneficial to increase calibration accuracy, next to all other alleged positive effects of initial struggle as effective preparation for future learning (Sinha & Kapur, 2021b). In conclusion, high accuracy in the judgment of performance appears to constitute often a beneficial prerequisite for knowledge acquisition in any domain. The inability to accurately assess the own metacognitive calibration might hinder learning.

Whereas one major field of research is concerned with the analysis of metacognitive calibration in different situations, as presented above, another research branch aims to explore various possibilities of enhancing learners' calibration accuracy to ultimately facilitate learning. For instance, Xia and colleagues (2019) could show that students' reflections on their own performance contributed to a more accurate metacognitive calibration. In contrast, the calibration assessment after repeated judgments of learning revealed enhanced underconfidence, indicating that students who are continually asked to judge their performance might become less confident about their responses over time (Koriat et al., 2002). Yet, providing feedback on the actual performance might play an important role in an individual's performance judgment improvement, as empirical evidence suggested (Callender et al., 2016). Similarly, delayed conceptual summarizing (Thiede & Anderson, 2003) or strategy training for assessing calibration (Nietfeld & Schraw, 2002) supported students' calibration accuracy. Hence, next to the suggested significance of metacognitive calibration for learning, there is substantial empirical evidence on how to promote calibration accuracy.

However, to profit from theoretical and empirical work that investigated various ways of improving metacognitive calibration accuracy to positively affect learning, it is irrevocable to have a well-substantiated statistic to estimate this accuracy.

Theoretical background

In a recent explorative calibration accuracy comparison study, Schraw and colleagues (2014) evaluated the most commonly used statistics (e.g., *d'*, *gamma*, *G*-index). They found that the appropriate metrics of choice depend on the research question. One measure alone was shown to only be rarely sufficient to establish an estimation of calibration accuracy (Schraw et al., 2014). A particular reason for this conclusion is, however, inherent to the different measures themselves. Whereas *d'* measures the standardized difference between correctly judging the correct answer and wrongly judging a wrong answer as correct, this measure alone mainly indicates whether learners are rather over- or underconfident, hence the direction of the miscalibration. Additionally, the standardization of this measure does not allow for a direct comparison of calculated indices from different studies, as the results will depend on the measured variance in the specific sample population. The *G*-index, in contrast, looks at the proportion of correct judgments to incorrect judgments. Thereby, this index determines the accuracy of individuals but does not make any statement regarding the direction of the miscalibration. In other words, a low accuracy result does not indicate whether participants are rather underconfident or overconfident, despite the essential difference between these two concepts regarding learning. Lastly, *gamma* follows a similar approach to the *G*-index by subtracting the product of the wrong judgments from the product of the correct judgments, over the sum of both products. Whereas the weighting of over- and underconfidence is different from the *G*-index, also in this case, it remains impossible to determine the direction of the miscalibration. Overall, and in agreement with the suggestion from Schraw and colleagues, it appears that no measure drastically outperforms the others but that they are rather covering different aspects of the concept of calibration accuracy.

A further limitation of some of these statistics for performance judgment assessment is their restriction to dichotomous data sets. Calibration estimations can then only be determined if the judgments are assessed in a yes-or-no format (i.e., “Are you sure about your response?” with answer options “yes” and “no”). However, in practice, an individual’s judgment of their own answers might not always be so straightforward, and more fine-grained answering options could yield more accurate approximations of the calibrations. One way to increase the sensitivity of calibration analyses is by asking a similar question but assessing responses on a 4-point Likert scale (yes / rather yes / rather no / no). Having four items to choose from still forces the participant to decide but allows them to indicate uncertainties. Nonetheless, the currently available statistics for examining calibration accuracy do often fail to come up for the need for greater sensitivity. Thus, the generally used statistics might answer specific research questions very well but not coherently report accuracy and the miscalibration direction. Also, they are often limited to binary data sets, thus restricting their application in empirical studies.

In this paper, we propose a novel set of statistical measures for assessing calibration accuracy and the direction of a miscalibration. Moreover, we demonstrate the applicability of these statistics for binary data as well as data assessed in 4-point Likert scales, thereby taking into account the non-binary nature of actual performance judgments. Thus, we aim to advance the methodological standards of determining and interpreting metacognitive calibration. Lastly, we present and apply an *R*-software package to easily calculate and plot the calibration accuracy and miscalibration direction on empirical data from a study with 34 doctoral students to illustrate the suggested methodological advancements and compare the results with conventional measures for reliability.

Methodological expansion of calibration accuracy and miscalibration

As previous research showed, scholars mostly focused on binary confidence judgment data (Schraw et al., 2014). Thereby, students’ judgments are evaluated based on whether they correspond to the actual performance. These different combinations of performance and judgment can be visualized in a 2×2 matrix (Table 1, left). However, if working with non-binary data, this matrix must be expanded, for example, to a 2×4 matrix in the case of a 4-point Likert scale-based performance judgment (Table 1, right). Consequently, new statistics are needed.

A starting point for establishing new statistics comes from defining a robust measure for a binary system, which then can be scaled up, for instance, to a 4-point scale system. Of primary importance are thereby measures for overconfidence (1–sensitivity; Feuerman & Miller, 2008) and underconfidence (1–specificity; Feuerman & Miller, 2008). Simply put, the overconfidence ratings indicate the frequency with which a learner wrongly judges their answer as correct when they are wrong, thus being overconfident in their abilities. Likewise, underconfidence describes the frequency of correct answers that are wrongly judged wrong, thus indicating a learner’s lack of recognizing their abilities (Table 2). The accuracy of one’s metacognitive calibration depends on these two measures. High underconfidence and high overconfidence, as well as a combination of these two, must be reflected in such a value. Additionally, the frequency of their actual occurrence must be considered as well. If this is neglected, a participant with all judgments and performance correct beside one obtains the same calibration accuracy score as a participant with all judgments wrong. Thus, the values for under- and overconfidence must be considered in relation to their actual frequency. The resulting formula for the calibration accuracy is shown in Table 2.

Table 1
Performance-evaluation matrices for dichotomous and 4-point-based confidence judgments

Confidence Judgment	*Performance* Correct	Incorrect
Yes	a (true positive)	b (false positive)
No	c (false negative)	d (true negative)

Confidence Judgment	*Performance* Correct	Incorrect
Yes	a	b
Rather Yes	c	d
Rather No	e	f
No	g	h

Note. Letters a to d (left) and a to h (right) indicate the variables needed for the formulas used for the calculations displayed in Table 2. *Performance* specifies whether a specific problem was solved correctly or not. *Confidence judgment* indicates students' judgments of their own answers' correctness, either collected in dichotomous format (yes / no) or on a 4-point Likert scale (yes / rather yes / rather no / no).

Like the limitations of the statistics *gamma* and *G*-index, this new calibration accuracy measure does not make any statement regarding the direction of the miscalibration. However, it is possible to apply the same theoretical and mathematical reasoning to determine whether any calibration inaccuracy is due to over- or underconfidence. By relatively subtracting the false positive (b) from the false negatives (c), one obtains a similar statistic to *d'* that allows investigating the miscalibration direction (Table 2). Additionally, this miscalibration value is not based on standardization, as is the case for *d'*, but yields relative and comparable miscalibration estimates. Combining these newly established statistics (i.e., calibration accuracy and miscalibration), we can assess the accuracy of a performance judgment and the cause of any inaccuracy.

Table 2
Calibration calculation formulas for dichotomous confidence judgments

Statistic	Formula	Explanation of the formula
Overconfidence O	$O = b/(b + d)$	This value explains how often a student wrongly answers a question while wrongly believing to have answered it correctly.
Underconfidence U	$U = c/(a + c)$	This value explains how often a student correctly answers a question while wrongly believing to have answered it wrongly.
Calibration accuracy C	$C = 1 - \left(\frac{1}{a+b+c+d}\right) \cdot \left(\frac{b^2}{b+d} + \frac{c^2}{c+d}\right)$	The metacognitive calibration accuracy value is based on the relative occurrence of a students' over- and underconfidence judgment. 1 indicates perfect calibration, and 0 indicates full miscalibration.
Miscalibration M	$M = \frac{1}{a+b+c+d} \cdot (b - c)$	The miscalibration value explains the cause of any metacognitive calibration inaccuracy. $M = 1$ indicates full overconfidence, and $M = -1$ indicates full underconfidence.

Note. The variables a to d correspond to the participant-specific count values established as described in Table 1. If the nominator of any fraction is equal to 0, this specific fraction must be set to 0. For instance, if a student never judges an incorrect answer as correct (b), the overconfidence value must be set to 0. In this case, the calibration and miscalibration values remain dependent only on the underconfidence statistic.

Generally, there are two major advantages of using these statistics instead of a combination of the commonly used ones. First, the obtained measures are mathematically based on the same underlying construct and are, thus, directly comparable within and across studies. And second, both are directly scalable to any dimension of interest. Being able to estimate calibration for not only binary response judgments but those of a higher level might deepen the understanding of learners' actual calibrations. As such, we derived the formulas for performance judgments of a 4-point Likert scale (Table 3). The exact calculations to obtain the formulas in Tables 2 and 3 can be found in the supplementary materials on OSF (see methods).

Table 3
Calibration calculation formulas for 4-point-based confidence judgments

Statistic	Formula	Explanation of the formula
Overconfidence *O*	$O = \frac{xb+yd}{x(b+h)+y(d+f)}$	This value explains the weighted ratio of how often a student wrongly overestimates their performance in case the given answer is incorrect.
Underconfidence *U*	$U = \frac{xg+ye}{x(a+g)+y(c+e)}$	This value explains the weighted ratio of how often a student wrongly underestimates their performance in case the given answer is correct.
Calibration accuracy *C*	$C = 1 - \frac{1}{\text{tot}'} \cdot \left(\frac{(xb+yd)^2}{x(b+h)+y(d+f)} + \frac{(xg+ye)^2}{x(a+g)+y(c+e)}\right)$ with $\frac{1}{\text{tot}'} = \frac{1}{x(a+b+g+h)+y(c+d+e+f)}$	The calibration accuracy describes the inversed relative sum of the weighted overconfidence and underconfidence values. *C* = 1 indicates perfect calibration, and *C* = 0 indicates full miscalibration.
Miscalibration *M*	$M = \frac{1}{\text{tot}'} \cdot (x(b-g) + y(d-e))$	The miscalibration score describes the relative difference between the weighted incorrect answers (overconfident – underconfident). *M* = 1 indicates full overconfidence, and *M* = –1 shows full underconfidence.

Note. The variables *a* to *h* correspond to the participant-specific count values established as described in Table 1. If the numerator of any fraction is equal to 0, this specific fraction must be set to 0. For instance, if a student never judges an incorrect answer as correct (*b*) or as rather correct (*d*), the overconfidence value must be set to 0, and the calibration and miscalibration values remain dependent only from the underconfidence statistic. The factors *x* and *y* indicate the relative weighting of the individual values from the performance-evaluation matrix to come up for the different judgment certainty levels (*x* for "yes" and "no"; *y* for "rather yes" and "rather no"). The generalized formulas are described in the supplementary materials on OSF (see methods).

Weighting confidence ratings

Suppose working with a non-dichotomous performance-judgment matrix, as in those cases in which the response confidence was assessed with 4-point Likert scales. The weighting of the individual confidence judgments then gains importance. Not differently weighting the answers would reduce them again to a binary measure. Thus, introducing the weighting factors *x* and *y* could overcome the shortcoming of presently available measures that categorize judgments in a binary manner (Table 3).

Founding the weighting ratio ($w = x/y$) in theoretical elaborations, we propose one specific solution for this problem: attributing a three times higher weight to those ratings with greater confidence ($w = 3$). The rationale for doing so is motivated by the literature on and common practice of interpreting Likert-based data as interval data despite its ordinal nature (Wu & Leung, 2017). To understand why ordinal-scaled Likert data can be treated as interval scales in some instances, Boone's and Boone's (2012) distinguishment between Likert-type and Likert scale data comes into play. Whereas the first describes situations in which single items are compared, the latter is based on multiple items that describe together one characteristic. Thus, when having multiple items that constitute one composite characteristic, there is evidence in favor of analyzing them on an interval scale (e.g., Boone & Boone, 2012; Sullivan & Artino Jr, 2013).

Having concluded that interpreting Likert scales on interval data might be appropriate in specific situations, we need to assign values to the individual judgment options. On a 4-point Likert scale from "no" to "yes," the interval is set around the value 0 ("neither yes nor no"), whereby 0 is not a selectable option, aiming to enforce students' decisions. Looking at the two intermediate values ("rather no" and "rather yes"), it appears that they are mathematically twice as much represented on any interval scale than the border values ("yes" and "no"). In other words, if a student selects the option "rather yes," this answer implies that the student's decision of performance judgment was either in the interval of (0; "rather yes"] or ["rather yes"; "yes"). In contrast, a student's answer of "yes" suggests that the student's decision was only in the interval of ("rather yes"; "yes"]. Expanding this train of thought, we find the numerical decision interval of (0, 1.5) for the answer "rather yes" (at the interval value of 1) and [1.5,2] for the answer "yes" (at the interval value of 2). The absolute decision interval of the answer "rather yes" is thus three times as large as the interval of the answer "yes." Consequently, we can only mathematically account for this double representation if the weighting is set to 3 (see endnotes 1 & 2).

Empirical application

Methods

All data sets and annotated *R*-scripts used for the present analysis are openly available in an OSF online repository (https://osf.io/6pdjt/). The various functions of the novel *R*-package for the metacognitive calibration analysis can be directly installed as *R*-package (https://github.com/samueltobler/mcc).

Participants

The participants of the application study were 34 doctoral students in natural sciences at a highly-ranked European university. The participants were, in average, 27.1 years old (*SD* = 2.3), whereby 41% indicated to be female, 59% male, and 0% non-binary. Participation in the study was voluntary, and three vouchers from a local grocery store were raffled among all participants. The university's ethics commission approved all studies before their conductance.

Materials

The test materials consisted of nine multiple-choice questions that covered a fundamental concept of the participants' study field and were published as part of a validated concept inventory (α = 0.69; 95% CI: 0.54-0.84) (Tobler et al., 2023). The students' self-reported performance judgment was assessed for each question by asking them, "How confident are you with your response?" on a 4-point Likert scale with the descriptors *very unconfident, rather unconfident*, *rather confident*, *very confident*.

Metacognitive calibration R-package

The for this purpose developed *R*-package directly calculates metacognitive calibration accuracy *C* values and the miscalibration *M* estimations for data sets with performance results and performance judgments on a 4-point Likert scale. The calculations are based on the proposed formulas in Table 2. Moreover, conventional measures, including *d'*, *gamma*, and *G*-index are functionally integrated to directly compare the different statistics. Eventually, the package allows plotting the results for more informative analyses of the data set. The extensively annotated *R*-package can be directly installed in the *R* software environment from GitHub (see link above).

Procedure and analysis

The participants were recruited through university-internal mailing lists and asked to complete the online test alone and without further resources. There was no time limit for taking the test. However, we excluded participants who showed statistical duration outliers (*n* = 3) and those who were faster in finishing the test than it would take to read the individual questions (*n* = 4). The final sample size consisted of 27 participants (Age: *M* = 27.2, *SD* = 2.3; 30% female, 70% male, 0% non-binary).

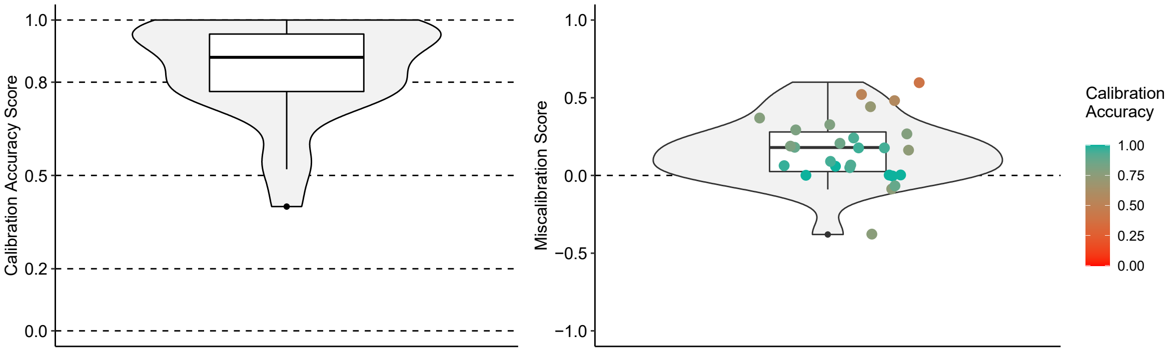
The test results were descriptively analyzed. The metacognitive calibration accuracy and miscalibration values were analyzed and plotted using the hereby introduced metacognitive calibration *R*-package. Additionally, we compared the results from the newly proposed calibration accuracy statistics with the results that would have been obtained by applying the commonly used calibration accuracy measures (i.e., *d'*, *gamma*, and *G*-index). Moreover, we investigated the correlation between calibration scores and actual performance. All analyses were conducted in the *R* software environment (R version 4.2.1; R Core Team, 2022). A list of all *R*-packages used for the analysis can be found in the supplementary materials on OSF.

Results

The normalized performance score analysis indicated that the participant understood the tested concept relatively well ($M = 0.72$, $SD = 0.21$, $min = 0.11$, $max = 1.00$). Furthermore, the results from the empirical application of the novel statistics revealed that most doctoral students answered the performance judgments with relatively high accuracy ($M = 0.84$, $SD = 0.16$; Figure 1, left). The miscalibration scores further indicated that most of the students, if demonstrating some calibration inaccuracy, were somewhat overconfident regarding their performance ($M = 0.16$, $SD = 0.22$). This finding is in line with the color-coded miscalibration scores demonstrating that those students with lower calibration accuracy rather were over- or underconfident but not both (Figure 1, right).

Figure 1

Metacognitive calibration and miscalibration values; Note. The dots in both sub-figures indicate the individual participants. The miscalibration scores (Figure 1, right) are color-coded according to the individual calibration accuracy. Green indicates perfect accuracy; red indicates complete inaccuracy.



Looking at the Pearson's correlation values determined for each comparison of newly proposed and priorly discussed measures, the results showed significant correlations between the new statistics and the *G*-index, but fewer between the new ones and *d'* or *gamma* (Table 4). Additionally, the correlation of *gamma* or *d'* accuracy values with the 4-point calibration accuracy and miscalibration scores were weaker compared to the binary values of the new measures. These results indicate that the 4-point-based calculations contain more information that the other measures cannot capture, explaining more variance and, thus, revealing more precise estimates. Lastly, we found no significant correlation between performance and calibration accuracy C ($r(25) = 0.26$, $p < .18$). Instead, the calibration results obtained by using the *G*-index statistics on the artificially binarized data set revealed a significant correlation with performance ($r(25) = 0.57$, $p < .01$). No significant correlations were found between performance score and *d'* ($r(25) = -0.01$, $p = .97$) or *gamma* ($r(25) = -0.37$, $p = .06$). However, a performance score-dependent visual breakdown of calibration accuracy and miscalibration descriptively indicates greater variability in accuracy and miscalibration with lower performance (Figure S1 in the supplementary materials).

Table 4

Statistic comparisons with empirical data

Measure	*M*	*SD*	1	2	3	4	5	6
1. Calibration accuracy *C* (4-point)	0.84	0.16	–					
2. Miscalibration *M* (4-point)	0.16	0.21	-0.64^{***}	–				
3. Calibration accuracy *C* (binary)	0.84	0.13	0.86^{***}	-0.62^{***}	–			
4. Miscalibration *M* (binary)	0.21	0.17	-0.56^{**}	0.89^{***}	-0.73^{***}	–		
5. *d'*	0.00	1.46	0.41^{*}	–0.19	0.43^{*}	-0.30^{*}	–	
6. *Gamma*	0.48	0.33	0.34	–0.29	0.46^{*}	–0.34	0.18	–
7. *G-index*	0.14	0.75	0.72^{***}	-0.42^{*}	0.89^{***}	-0.65^{***}	0.47^{*}	0.29

Note. The performance judgment ratings have been transformed to binary values to calculate the various statistics (*d'*, *gamma*, *G-index*). The newly proposed statistics have been evaluated with both the binary-transformed and the original 4-point Likert scale data. Statistically significant correlations are marked with an asterisk sign ($^{*}\ p < .05$; $^{**}\ p < .01$; $^{***}\ p < .001$). $N = 27$.

General discussion and conclusion

The significance of being metacognitively well calibrated and, thus, able to accurately judge the performance has been repeatedly shown to positively affect learning (Lin & Zabrucky, 1998). Moreover, prior work has documented and compared various statistical approaches to accurately estimate a learner's metacognitive calibration (Schraw et al., 2014). By comparing different statistics, they investigated which of them might show the best suitable measure for accuracy. Regrettably, they did not find a one-size-fits-all statistic to measure the latter but concluded that the appropriate measure must be chosen based on the research question. Furthermore, some of these measures can only be applied to dichotomous data but are not directly scalable to judgment data assessed on higher order Likert scales, for instance.

We developed a methodology that compensates for these two shortcomings. Our novel approach is grounded in two complementary statistics that are based on the relative occurrence of false positive and false negative performance judgments. These two statistics, the calibration accuracy and the direction of any miscalibration, yield a direct estimate of an individual's metacognitive calibration. Furthermore, they explain any deviation from a perfect calibration in terms of underconfidence or overconfidence. Additionally, these two statistics are directly scalable from binary judgment inputs to 4-point Likert scale ratings, and generalizable beyond that as well. Thus, it appears that the newly developed methodology to estimate metacognitive calibration accuracy might overcome the major limitations of commonly used statistics. Also, it presents easily applicable measures that might be valuable for researchers in and outside the field of the learning sciences when working with calibration measurements. Nonetheless, triangulating the results with other metrics such as d' or G-index, recommended by Benjamin and Diaz (2008) or Schraw (1995), might provide supplementary validity of the calculated accuracy estimates.

Moreover, we empirically tested the new measures to demonstrate their performance. Statistical comparisons with the established measures revealed significant correlations in most cases, indicating that the new statistics assess a similar construct to conventional measures but explain more variance. Lastly, we developed a freely available and directly implementable R-package to apply the proposed formulas as well as more conventional ones to calculate calibration accuracy and visualize the results for facilitated interpretation.

Limitations and future directions

One limitation of the current approach is that the ordinal nature of Likert-scale data is ignored and interpreted as interval data. However, treating the data as ordinal data would not allow determining a calibration score, which emphasizes the different extent of judgment certainty. Instead, it would lead again to a dichotomous data set. Furthermore, assessing calibration accuracy over multiple items was shown to approximately resemble an interval scale (Boone & Boone, 2012). Nonetheless, the technical advancements as present in online conducted studies (Evans & Mathur, 2005) would allow collecting performance judgment data directly on true interval scales. Yet, the herein presented statistics could easily be expanded for higher degree matrices.

Future work could focus on applying these statistics in classrooms where most participants are novice learners and not experts in the field. Whereas students at the end of their educational career (i.e., post-graduate students) might have learned well over the years to accurately judge their own capabilities, learners at lower educational levels might struggle more to do so. Thus, using these measures to continuously investigate the students' metacognitive calibration accuracy and the impact of success or failure on it might reveal more detailed insights regarding the development of calibration accuracy throughout their education. Similarly, future studies could emphasize assessing calibration accuracy with the proposed measures when testing new educational interventions to investigate their impact on this trait.

Endnotes

(1) Intervals are described according to the general notation standards for mathematical intervals. Round brackets indicate that all values until but without the start- or endpoint are included, and square brackets indicate that all values until and with the start- or endpoint are included. Mathematically expressed, this means $(0,1] = \{x \mid 0 < x \leq 1\}$.

(2) A weighting of $w = 2$ might appear more logical at first glance. To explain why this might be less exact, let's reconsider the interval of [-2; 2] on a 4-point Likert scale. This interval would then result in the values of [-2; -1; 1; 2] for ["no"; "rather no"; "rather yes"; "yes"]. Like before, we have three 0.5 interval steps for the answer "rather yes" (0, 1.5), but only one for the answer "yes" [1.5, 2]. Suppose we now set the weight of "yes" answers to be double as high as that for "rather yes" answers. In that case, the relative weight of the different answers with respect to their abundance on the interval scale corresponds to $1 \cdot 1.5$ for the "rather yes" answer and $2 \cdot 0.5$ for the "yes" answer. Thus, the "rather yes" answer option still weighs more than the "yes" option $((1 \cdot 1.5)/(2 \cdot 0.5) = 1.5 \neq 1)$. Only if we set the weight to $w = 3$, we get an equal ratio (i.e., 1) for the weighting of "yes" and "rather yes" answers.

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“When We’re in Spaces Among People of Colour, Your Ideas Just Flow”: Politicized Trust and Educational Intimacy in Activist Spaces

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Abstract: This paper examines how relationships of educational intimacy and politicized trust were constructed in an activist community. Bridging theories of politicization and activist becoming with emerging research on the significance of relationships for identity development and solidarity, this paper brings micro-interactional data of how relationships are constructed and why they matter. Tracing a group debrief by members of colour within the Fossil Free UofT activist group allows us to see how humour constructed intimacy alongside intense disclosure and collectivized grievance construction. This contributes to work in the learning sciences to demonstrate the political contexts and consequences of learning and provides tools for activists to organize learning ecologies for educational intimacy and politicized trust.

On relationships and learning

The question of how relationships shape learning has animated many of us in the learning sciences over the last decades, and particularly in recent years as attention in our field has shifted to attend more closely to the political and ethical dimensions of learning. Recent research has examined how relations of educational intimacy (Uttamchandani, 2021) and politicized trust (McKinney de Royston & Vakil, 2019) have made specific forms of learning possible, and this work, alongside other interventions toward understanding relationships and politicization is vital in understanding how other possible futures are imagined and enacted through the joint work of community members. This paper theorizes political transformation through a sociocultural lens, arguing that politicization is a learning process, one that unfolds not in the minds of individual participants, but rather as co-constituting processes of development involving the political concepts, practices, epistemologies, and identities of learners as they transform through their engagement in building new possible futures (Curnow, et al., 2020).

These theoretical and analytical questions align closely with questions emerging from social movements, where the need to understand how, when, and why some relationships support learning and collective action to change social systems toward more just futures (and why some do not). This question was a persistent undercurrent in the work of FossilFree UofT, a campus-based climate activist group. In their campaign to push the University of Toronto to divest the endowment funds from the 200 fossil fuel companies with the largest reserves, many of the young people engaged in this work dramatically shifted their political orientations. So often, young activists in the campaign wondered why some people “wouldn’t learn” and why, by contrast, other spaces felt so nurturing of their political engagement and growth as climate justice activists.

In this paper, I take up those questions, asking how relationships of educational intimacy enabled politicization. I use one particularly rich interaction as the basis of analysis, looking at video of an impromptu debrief of people of colour after a tense meeting. In this debrief, we can hear explicit talk about the value of relationships of trust and shared experience, and also see the ongoing unfolding of educational intimacy. Building from Uttamchandani (2021) and Vakil & McKinney de Royston (2019), I argue that the relationships of intimacy and politicized trust enabled participants in the debrief to become politicized, and that the politicization process further entrenched and reinforced their relationships.

To make this argument, I begin with a brief overview of recent research on relationships, politics, and learning from sociocultural perspectives. I then provide more detail on the context of Fossil Free UofT before describing the participatory action research project we undertook, the data collection, and the methods of analysis. I then pivot to an analysis of the debrief, highlighting the sensemaking happening in real time, and identifying how the relationships of politicized trust and intimacy make that learning possible.

Literature: Relationships, politics, and learning in the learning sciences

Research that interrogates learning as a sociocultural and interactional accomplishment is foundational to the learning sciences. Within that broad framing, we can look more specifically at work that attends to the affordances for learning that relationships enable. There has been work investigating how friendship shapes learning processes and outcomes among students (Takeuchi, 2016; Jackson, et al.; 2020; Vakil & McKinney de Royston, 2019), among social movement organizers (Curnow, et al., 2021; Teeters & Jurow, 2018; Uttamchandani, 2021; Vea, 2018), between teachers and students (Boaler, 2008; McKinney de Royston, et al., 2017), between research collaborators (Vakil, et al., 2016), and among researchers (Jackson, et al., 2020). All of this work recognizes that learning is social, and that who learners are surrounded with matters for what they learn, how they learn, and how they feel about learning. This work also identifies that a focus on relationality is a political act within a system of racial capitalism, but the political interventions they highlight are diverse. In this section I highlight the important contributions that have been made in this area to situate my work and to celebrate the web of relationships my analysis is entwined in. Through the process, I orient readers to the invitations and directions that emerge when these papers are read alongside each other.

For McKinney de Royston, Vakil, Nasir, Ross, Givens, and Holman (2017), a focus on politicized care means that interactional dynamics of support for Black boys from teachers, and in particular Black men, shapes the terrain of learning through kinship networks that extend beyond the classroom and are rooted in shared experiences of racialization. The use of "politicized trust", then, signals a shared experience within racialized relations, and the ways adults hold space for young people to be valued. This is political in that it works against normative anti-Black discourses that devalue and dehumanize Black children and centres their brilliance. Also working from the idea of politicized trust, Vakil & McKinney de Royston look at the ways politicized trust is enacted in STEM classrooms, examining how students come to understand and respect each other and enact solidarities (or not). Their use of the concept centres on the idea that relationships between students must be premised on good faith and solidarity when people are working across difference. When examining an explicit conversation about race in a classroom, they note how the conversation devolves in the absence of shared experience, politics, and identities, and how the absence forecloses opportunities for learning (predominantly for the White boy student). The trust that is politicized is premised on a shared understanding of the nature of racialization and racial injustice and a willingness to learn alongside each other in service to racial justice. This is a theoretical stance against work that takes up colour-blind approaches to learning and relationships (ie. Boaler 2008) and insists that learning relations must grapple with the lived experience and dominant social relations of white supremacy rather than elide them.

Teeters & Jurow (2018) look at how community promotoras build relationships of trust, commitment, and reliability that also extend beyond the bounds of their official work. Through creating spaces for shared stories which built convivencia, a sense of communalism, they built relationships that allowed them to surface experiences of domestic violence and create educative spaces for women to share their experiences, decreasing their sense of isolation, and building networks of support when women took legal action against their abusers. These relationships were consequential and political, embodying care and facilitating safety through listening and building programs from needs revealed to them in confidence—led by and for Latina im/migrant women.

For Vea's investigations of animal rights activists (2020), friendships are both a learning target and process for enabling learning. For these activists, being friends, building relationships of care and intimacy, and making activism fun and social creates incentive structures that attract people to vegan activism and keep people in. These relationships are instrumentalized in service to the political goals, and drive identity development as animal rights activists. Here the relationships are politicized in that they incentivize and sustain political engagement, fostering a sense of community and empowerment in contradistinction to meat eaters which keeps people involved in the fight for their shared vision.

Finally, in his work with LGBTQ2S+ youth, Uttamchandani draws our attention to the way relationships make political work possible. He argues that educational intimacy focuses on noticing the spaces that are created and how they prefigure relations of care, focusing on the discursive patterns of support created through joking, ribbing, gentle correction, and practiced facilitation strategies that were gender affirming and fluid. While Uttamchandani did not set out to theorize politicization, we can see ways that the youth in Chroma prefigured a queer social space that was affirming in the face of cis/het normativity/queerphobia in their schools and communities—which was and is a political act. This kind of work that draws attention to the mechanisms of spaces that stand outside the mainstream and in tension with mainstream politics and practices is exactly the type of work I take up as well, looking to see how the people made marginal through hegemonic masculinities, trans- and queer-phobia, and white supremacy, etc. make their own spaces and how those spaces then re-make them.

Across this emerging work, the attention to learning as collective, as always political and in service to political projects of liberation is vital—this learning is consequential (Jurow & Shea, 2015). These relationships are framed as political interventions in the context where learning itself is political, and where learners are engaged in counter-hegemonic action to build space for themselves in opposition to systems that devalue their existence. They show us that trust, in many forms, including felt trust and empowerment, politicized trust, and confianza and solidarity, make it possible for people to learn and work together to contest inequitable relations.

Conceptual framework: Politicization

I orient here to theories of learning as becoming (Lave, 1996). Situated learning and legitimate peripheral participation (Lave & Wenger, 1991) describe processes through which new members become centrally recognized and enmeshed participants within communities of practice. Full participation unfolds not only by learning skills or discourses, but more holistically by developing the ability to participate in the full practices of the community. Alongside this growth, new members come to identify with and be recognized as members of the community.

Politicization is a process of becoming; one where transformation toward collective action in the shared repertoires of social movements is critically important, and where ideas about what futures are possible (Gutierrez & Jurow, 2016) shift and expand based on the shared ideas, identities, practices (Curnow, et al., 2020). Politicization is a multidimensional shift in the political concepts/cognition, the practices, the epistemologies/ways of knowing and being, and the identities of learners (Curnow, et al., 2020). In our conceptual framework, these pillars cannot be disarticulated from each other, they continually reinscribe the development of each other as participants become increasingly politicized. This work builds on popular education (Horton & Freire, 1990; Arnold, et al., 1991) theory and practice and theorizations of sociopolitical development (Watts & Guesseous, 2006; Kwon, 2014) that attend to how people's understandings of their worlds shift toward systemic political analysis and drives them toward collective action to remake their worlds in more just and equitable ways. Politicization is a highly consequential learning process, and is a process of making and remaking ones' self, community, and larger social relations.

Within the framework of politicization, though, many questions remain about the when, the why, and the how of politicizing processes. Why do some members of a community of practice become more radical in their politics while others do not? What are the mechanisms that support politicization in learning ecologies? These questions animate social movement organizers whose aim is to expand the base of people engaging in politicized practices, and for whom political education work is a core focus. For this reason, I bring together the emerging work on relationships, to examine in micro-interactional detail how the relational practices of a subset of youth organizers within the Fossil Free UofT demonstrated the politicization of members while creating space for further politicization. In analyzing the relational construction of educational intimacy and politicized trust as it unfolds, we gain tools for understanding how space was held to enable politicization.

Context: Fossil free UofT

Fossil fuel divestment was the most common student campaign to address the climate crisis. The campaign works with students on campuses to their leadership bodies to divest their endowments from the 200 fossil fuel companies with the largest reserves of fossil fuels (Fossil Free, 2015). It is a kit-based campaign, coordinated by 350.org. At the University of Toronto, the fossil fuel divestment campaign was coordinated by undergraduate and graduate students. From October 2014 through May 2016, Fossil Free UofT met weekly to coordinate the divestment campaign. Between 15 and 35 people attended regular meetings. The group tended to be majority white, with roughly even numbers of men and women attending, and no openly identified (at the time) non-binary or trans students participating. Racial and ethnic make-up shifted over the course of the campaign, but the group remained predominantly white, even as Indigenous, Black, Latino, South Asian, and East Asian students became increasingly involved, in terms of numbers and leadership in the group.

This paper is based on a participatory action research project that examines how student activists learned about race, colonialism, and patriarchy through their involvement in environmental activist campaigns. We situate our work within militant ethnography. This approach anchors researchers within the social movements we are part of and argues it is inadequate for researchers to merely observe political contestation, but that researchers must be engaged in shared struggle (Scheper-Hughes, 1995). We enacted our commitments to relational accountability through a participatory action research campaign (Maguire, 1987) that resulted in the co-creation of the Rad Lab. This writing is a product of the RadLab analysis. The ideas that alternative spaces shaped their political development came out of those very spaces, and through the articulation of the shifts we were seeing. RadLab members were involved in bringing these ideas into the world, and as they have moved on from the project, I continue documenting findings and reaching out for feedback from the team (thus, when I use "we" I am talking about the collective work at the time (as part of FFUofT) or the collective analysis (we the RadLab), and when I use "I" I speak to my analysis here that draws from the collective work but isn't collaboratively written.

Methods

We started from the broad question: how do participants in the fossil fuel divestment campaign become politicized around racial justice, feminism, anticolonialism, and other radical politics? In the process, we worked collectively to theorize from below and articulate what we meant by politicization (Curnow, et al., 2020), and then to figure out when we became politicized, and when others who took up more radical politics became politicized, what enabled that? What could we recreate in other organizing spaces that would be useful to help develop critical consciousness, radical repertoires, a counter hegemonic worldview, and shared identity? From that question, we narrowed our scope to the impact that "alternative spaces" had in enabling the learning that we were interested in.

To answer these questions, video was collected with the University of Toronto (UofT) fossil fuel divestment campaign. Video was collected at meetings, actions, some caucus spaces, and debriefs over the two-year campaign, resulting in over 15,000 minutes of video. Videos last from 60-240 minutes and were captured from one to four angles and stacked so streams are visible and coded simultaneously.

After video was collected, it was content-logged and pre-coded using codes based on the research question (including race, gender, and colonialism). The first substantial analytic pass of coding was conducted by the RadLab members, including five women participants from the group, one white, one South Asian, two East Asian, one Indigenous, and one Black man. We watched segments of videos from across the year together and coded "interesting" segments, asking the broad question of how race matters in our group, discussing every instance someone raised and making extensive notes. After conducting "interesting" coding on three segments from the beginning, middle, and end of the year, we reviewed the "interestings" and consolidated them into codes that were most present in the video we reviewed and in our experiences of the group. From this collaborative data analysis, we established early coding domains which were applied to the video and other data.

In coding for moments where racialization, colonialism, and gender were discussed directly, I generated a condensed transcript of relevant talk from the content logs and transcripts. I then iteratively coded that looking for what enabled that talk. In this coding, specific instances that were particularly meaningful, where I could see learning reflected and unfolding simultaneously became examples of particular interest. In these instances, I found that the mechanics of educational intimacy were significantly different. I coded for humour, intimacy, and disclosure, as well as something harder to count, but which was deeply felt when watching the video; the significance of trust, the network of support, and the assumptions of shared experience/shared values/shared goals. These were identified through interactional practices, in tone, facial expressions, gesture and use of space, and in the context of the talk.

Findings

One example of learning is shared here, where politicization simultaneously unfolded and is demonstrated as an accomplishment as Black members and members of colour from the group expressed and constructed politicized trust, built consequential relationships where grievances were collectivized, enacted educational intimacy, and through the process sustained their ability to participate through rich relations of solidarity. I focus on a selection of talk by activists of colour where teasing, laughter, and intense disclosure and grievance construction are woven together. This choreography of levity and intensity created the conditions for politicization and reflected the ongoing learning of the community. This moment came during Winter Term in the second year of the campaign. At this point in time, the political dynamics in the group were growing increasingly polarized, as one set of group members became increasingly committed to working through bureaucratic structures toward a technocratic approach to addressing climate change, while another group became increasingly politicized around ideas of climate justice, where addressing colonialism, racism, and capitalism were central to their aims. As part of this polarization, the uneven racialized, gendered, and classed dynamics of who spoke in meetings, for how long, and to whom became problematized, as white men spoke an overwhelming majority of the time, creating a space that members of colour and white women described as problematic after it became clear how endemic the problem was. In the meeting, the Women's Caucus presented their concerns about womens' experiences in the campaigns and the ways their voices rarely broke through, and when they did, how they were not affirmed (Curnow, et al., 2020). In the large group discussion of the problems raised, people of colour bridged the gendered experience in Fossil Free UofT with the racialized experience, noting that people of colour were systematically marginalized and "underappreciated". The response from the members of Fossil Free UofT was mixed; some were grateful to learn the critiques, while others reacted angrily. The meeting included yelling, tears, and storming out.

An impromptu debrief happened after the meeting, as members of colour gathered in the back of the room to affirm the contributions several of the members of colour had made in the meeting, where their racialized positions and experiences were discussed explicitly, which almost never happened in the large group contexts. The debrief conversation lasted for over an hour, as at first a small group, and gradually almost all the members of colour in the group joined the huddle in the back of the room. There was other activity in the room and hallway, as several members (who had been unhappy about the content and process of the gendered grievances) gathered in the front corner of the room to discuss strategy that they said had not been adequately discussed in the meeting because of the fight over the Women's Caucus. Others gathered in the hallway around someone crying. What unfolds here is a snapshot of the broader trajectory of politicization and the relationships that fostered that politicization, but it is emblematic, and demonstrates sensemaking as it unfolds, the ways that consequential relationships were constructed, and how those relationships made transformational learning possible.

Constructing politicized trust

In a small circle of five people of colour, Cricket tells Dawood what he appreciated about Dawood's powerful interventions in the meeting while Jade nods enthusiastically, with Jade adding "No, I totally know, it's amazing." Over the course of the debrief, participants shared experiences and went into more detail about the kinds of discrimination that they had experienced on campus and had only hinted at in the large group meeting. As they talked, they were all affirmed, with Amil snapping, Jade nodding vigorously, and lots of verbal continuers, like "yeah", "mmmhhmmmmm", etc.

Standing around in the corner in a tight circle, as others moved in and out of the room, and as others dealt with the aftermath of the conflict-riddled meeting in the hall as well, the immediate processing was an extension of the sensemaking that was happening in the meeting, as people took up arguments that had been initiated in the meeting. The circle discussed the content of the meeting in serious and in mocking ways, noting the problematic nature of demands that women get permission to meet outside of the large group space. They discuss shared experiences of struggling to be heard in the group and the racialized experiences of being shut down that impact their participation in the group, especially when the White men were acting aggressive. Referring to one of the sticking points in the meeting where one of the men accused the women's caucus of not speaking up in meetings or raising their concerns in the moment, Jade took up this line of reasoning:

> Jade: Also, y'know sometimes, it's not that we don't want space to say it — sometimes we have nothing to say, because we're like internalizing all the thought (Wiggling fingers near head). And it takes a while for some people to like think of something to say from the brain and the (Gestures from head to heart space). Like some people just, like, whip it out (Snaps). Where for me it takes like 15 minutes, to like think of something. So yeah, different for everyone.
> Amil: (Snapping for Jade as affirmation) How much of that is being in spaces where your ideas are being shot down. It's like a mechanism to preserve…
> Jade: (Nodding) A lot, yeah.
> Amil: This is like something I find surprising. When we're like in spaces among people of colour, pretty sure for women (Gesturing widely around to this group of people), your ideas just flow, right?
> Tresanne: Yeah (Laughs)
> Amil: … but when you're in the space, how are you going to judge me…
> Jade: Yeah
> Amil: Cuz I've been in spaces where people shut down your ideas (Whipping gesture) and then you're like, OK. You shouldn't say anything.

There is consequential sensemaking happening across this exchange, all read through the relationships of politicized trust that are assumed in the circle. First, we can see Jade critiquing both the demand that women (and by her own extension, other people of colour) respond to men's requirements for how they participate in the space. She takes up the assumption that participants must think quickly and respond verbally for their feedback to count. This links up with two of the ongoing critiques that had circulated in the Women's Caucus and the People of Colour Caucus: the logic of being quick on your feet as a classed, gendered, and racialized performance, and the idea that the only valid criticism was explicit and verbal, which effectively ignored the embodied feedback, the withdrawal, and the refusals that were more common among women and people of colour in the group. Jade is bringing those arguments into the space, linking them to this context and problematizing the ideas yet again. Amil takes these up and extends to another idea that the People of Colour Caucus had discussed widely at this point in the campaign — their experiences of being shut down and the overall experience of being minoritized on UofT's campus. The political analyses are being rearticulated and collectivized again here, using the space of community to validate their experience, and to share these political critiques with Cricket and Jennifer, who were newer to the campaign and had been less involved in other alternative spaces. While these were pedagogical expressions, which I believe Amil intended to shape how others read the field, they also seem to be seeking validation and building solidarity among others who were likely to have experienced similar (though distinct given the expressions of anti-Blackness at UofT and in the world) things. His frank discussion of the strategic moves he makes to protect himself from racist responses was an invitation and a starting point for solidarity. It was a practice of invitation that made space for politicization and deepened politicized trust through vulnerability and shared marginalization. We see the significance of that relationship when he says, "When we're like in spaces among people of colour, pretty sure for women (gesturing widely around to this group of people) ... your ideas just flow, right?" Naming the dynamics of this small group, he notes the significance of politicized trust in relationships among people of colour, showing how they were flowing, as they riffed on each other's ideas in response to the problematic meeting, and noting that the relationships of support allowed them all to do that work without fear of being shut down. The ongoing construction of politicized trust enabled space to collectivize grievances, similar to what Teeters and Jurow found and what McKinney de Royston, et al. described. The relations of trust rooted in shared experience iteratively politicized members and reinforced feelings of belonging and shared identity within the People of Colour Caucus.

Consequential relationships

Relationships made the space possible; the intimacy that was created was expressed in the context of friendship, trust, and shared experience. This was made explicit as Dawood spoke. He was a newer member who was almost always silent at meetings, and who hadn't participated in many of the activities outside of large group meetings.

> Dawood: I feel so much more connected and appreciated in the group just by communicating myself. I don't even need a response from everyone.
> Jade: (Nods enthusiastically) Yeah, I know.
> Dawood: Just communicating it makes me feel more comfortable.
> Jade: Exactly
> Dawood: This is probably the first time you noticed me talking.

In this space, the validation from sharing their stories seemed impactful, further entrenching the shared identities, politicized trust, and the sense of accountability to one another, and the kinds of communalism that Teeters and Jurow note in their work. In this exchange the interactions feel transformed from that of the meeting. Where the meeting had been tense and the members of colours' gestures seemed fearful and quieter, this space looked different, filled with big gestures, smoother movements, and constant affirmative continuers, verbal and physical. The comfort that was built through articulating a different politics and a non-dominant experience that was shared clearly built the foundations for sustained engagement in what was otherwise a hard environment.

Fostering educational intimacy

Another dynamic in this impromptu debrief was the warmth and affirmation, the laughter and teasing, and the moving between very heavy conversation and joking. In this short example, we can see all of these at play, echoing Uttamchandani's findings around the construction of educational intimacy.

> Tresanne: But I think this is a really nice — yeah, this is a meeting I'll remember forever.
> Jade: (Nods vigorously) Yeah, I'll die remembering it
> Amil: What?!! (laughs)
> Jade: I mean on my deathbed. (All the participants are laughing about the different meanings.)
> Amil: (Laughing hard, looking at the faces everyone else was making in response to Jade's slip) Everyone's reaction!
> Jade: (Buries her head in arm) Sorry! I know, really dramatic.
> Amil: We, um… Yep. Yeah yeah. This is a sidebar, it's like, sorta like, learning to be people of colour, while dealing with all these historical oppressions while being in solidarity with Indigenous people. In a system of weird complicity
> Tresanne: Yeaaah
> Jade: Yeah, yeah.

In this exchange the sense of familiarity and friendship comes through strongly, as Amil teases Jade, everyone laughs, but in a way that is inclusive and builds relationship, rather than making fun or isolating. The moment in the video is so warm, and it's hard to demonstrate that feeling of intimacy through a transcript. Given the context of a very hostile and harmful meeting, the fact that this space emerged which was community-affirming, pleasant, and joy-filled was a meaningful and powerful thing. Centring relationships among members of colour was an active intervention to build belonging, to carve out a shared identity within this broader space. And then we see the fluid move back into one of the more challenging political questions that Amil had been dealing with, navigating white supremacy and settler colonialism as a Black person. This moment may seem like a non-sequitur, but it could only have emerged out of this shared space of racialized community, where politicized trust was being actively enacted and where shared practices of affirmation existed alongside educational intimacy and joking, as a place where the shared experience of members of colour was assumed and appreciated. In the context of those relationships, this broader political struggle around identity and accountability could be voiced and affirmed.

Redeeming and incentivizing participation

In this informal debrief, as people stand around in their coats, then take their coats off to stay longer, there's teasing, there's laughter, there are these very quick moves between intensity and levity, with learning and community. Across the room, during the entire exchange, three White men had gathered across the room to strategize around the governing council and seemed to act like there had not just been a big drama, or to acknowledge that other people were still out in the hall crying. When the White men walked past the debrief and said goodbye awkwardly, there was a collective exhale in the circle. One of them whispered "that's fucked," a shared acknowledgement of the trauma. Nothing else was said for a beat, and then they turned to levity, talking about setting up a potluck and discussing the Canadian Minister of Environment. The relief, the community, the relationship, and the space to just…be… is palpable in this small community where shared experience is understood and cherished. This is the kind of emotional intimacy that Uttamchandani points our attention to, except in this context it is hard won through conflict and micro and macro aggressions within the group rather than in a supportive learning community. In this way, educational intimacy was a tool for redeeming an otherwise hostile space and for incentivizing friendship, to echo Vea's findings, which kept participants active in this movement space. This debrief was the real time construction of community that was otherwise missing, and they carved out space for politicization through relations of intimacy that sustained their participation in the campaign.

Discussion

This relatively short instance of politicizing and politicized talk among activists of colour is highly generative for understanding both the what of politicization — that is, how it unfolds in real time as participants make sense of the testimonies of their comrades, the conflicts of the campaigns, and the shifting political commitments in the group — and the ways that relationships among the participants of colour held space for that learning through constructing educational intimacy rooted in expressions of politicized trust.

Looking to the learning sciences literature on sociocultural processes of learning and relationship, this study draws several pieces into focus. First, this analysis brings more texture into Uttamchandani's ideas of educational intimacy, we can see in living colour the ways that the participants here moved in and out of joking turns, and how teasing created space for difficult articulations of marginalization and made space for fun that sustained participation. While Uttamchandani's discourse analysis paints beautiful scenes of LGBTQ young people building spaces of educational intimacy, this work offers additional analysis into the interactional accomplishments that create that space (the gestures, the proximity, the facial expressions) and how the interactional practices related to the talk/learning/politicization. Second, speaking to McKinney de Royston and Vakil's theorization of politicized trust, this work brings another site of learning to bear, showing how shared experience is articulated and used to build that relationship, and how that trust becomes actively politicized. Trust, in this space, goes from being more than an assumed shared experience to being an articulated shared experience and an affirmed experience, moving people from lingering questions about whether they were the problem (so to speak) and into a politicized understanding of white supremacy and how it worked in the group and beyond the group. Finally, for studies of politicization or sociopolitical development, we can see how relationships facilitated the process of becoming more radical, how relationships served as an accelerant, throwing lighter fluid on the hot takes and making them collective/shared, important, and valid. This is important for the field, because while relationships make all learning possible, the kinds of counter-hegemonic transformations that we document across our work with the RadLab are often hard, both because they go against normative descriptions of how and why the world works as it does, and because it relies on naming difficult experiences of minoritization. Thus, having a community that welcomes that, holds space for it, and can sustain participation in that work is critical for staying in that learning and transforming it into collective action.

Conclusion

For participants in Fossil Free UofT, and particularly for the people of colour whose sensemaking we trace, relationships were consequential. The intimacy they constructed through their joint sense making, shared experiences, and emergent politicization opened possibilities for growth and created avenues for politicized participants to practice leadership and scaffold a pedagogical space for others to become politicized within. For organizers and designers, these moments of refuge show how important alternative spaces can be for minoritized participants to build community, to heal, to build political analysis, to laugh and to breathe. Designing intentional space can be a strategy for sustaining engagement in hegemonic spaces and forging politicized trust and educational intimacy that travels across spaces of participation.

For social movement scholars of learning, this work points us, again, to the significance of relationship, not as a fluffy or simply nice-to-have additive, but as an essential, prefigurative political process that enables and produces sense-making in ongoing ways. For theorists of learning, relationship needs to be at the core of what we examine to understand when, why, and how people learn, as well as whose learning is fostered or constrained through relationships that reinforce or contest hegemonic participation. This analysis brings texture to the conversation and expands the scope of political learning. Where others in the field have theorized politicized trust, educational intimacy, and other related concepts, the case explored here shows us again how important these relations are and what they make possible. In examining the interrelatedness of joy and grievance construction, we can see new avenues for future analytic work, to examine the choreography of learners and facilitators in making sense of tense conflict situations and finding levity within them that is rooted in shared experience and politicized trust.

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Investigating the Role of Kindergarten Children's Constructed Models as Tools for Modeling-Based Inquiry

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Abstract: A growing body of evidence highlights the added value of Modeling-based Learning (MbL) in science when incorporated into kindergarten science education. This descriptive case study seeks to add to the literature by describing the ways two groups of kindergarten children engaged in MbL. The study focuses on the ways that these children used their constructed models as tools for investigations and knowledge development. Findings across the two cases suggest that participating children productively engaged in authentic MbL activities, while they (a) were able to use their own models as tools for further investigations of and knowledge development; and (b) have modeling resources for using their own constructed models as theoretical structures that can be applied in a (new) phenomenon to explain new (parts of the) phenomena. Implications of these findings suggest the dynamic nature of the kindergarten children's models and children's understanding of their models' functions.

Introduction

Extensive research has influentially advocated Modeling-based Learning (MbL) as a productive means for teaching and learning science (e.g., Louca, Zacharia & Constantinou, 2011; Louca & Zacharia 2015; Clement, 2008; Halloun, 2016; Jackson et al, 2008; Khan, 2007; Schwarz et al., 2009; Windschitl et al, 2008; Justi & Gilbert, 2016). NGSS (2013) defines modeling as a practice involving the construction, evaluation, revision, and use of models aiming at predicting and explaining physical phenomena (Louca & Zacharia, 2012). In this respect, models and modeling are considered integral parts of science learning, primarily because they provide the means for students to represent, describe, examine, and explain phenomena (e.g., Justi & Gilbert, 2016). Externalized in various ways, a student-generated model becomes a tool enabling students to understand how a phenomenon takes place and use it to make predictions related to this phenomenon (Schwarz et al., 2009).

Modeling-based Learning (MbL) takes place within the process of constructing models. During MbL the emphasis is placed on the modeling journey and the modeling processes rather than simply focusing on the model as the end product. Thus, MbL directs science learning beyond acquiring science facts, engaging learners in figuring out the mechanism that underlies science facts and phenomena (e.g., NRC, 2012; Krist et al, 2019).

Theoretical framework

The study I report here concerns the application of MbL with kindergarten children. Research suggests that children as young as kindergarten have sophisticated ways of thinking about the natural world around them, which is translated in the K-12 Science Education Framework as the effort to engage them in the development of explanations about natural phenomena (NRC, 2012). Towards this direction, the NRC (2012) framework includes the practices of students developing and using models, and students constructing explanations for natural phenomena. The construction of models may use a wide range of different types of modeling tools, such as everyday language, drawings, diagrams, gestures, dramatic play, 3D structures, computer simulations, and mathematical equations (Giere, 1990; Schwarz et al., 2009; Windschit et al, 2008; NASEM, 2022; NRC, 2012). The development of a model requires the use of representations of the elements included in the phenomenon at task, and, the corresponding underlying mechanism which entails how these elements work and interact with each other (NRC, 2012) resulting in the natural phenomenon.

Despite its added value, the research community has yet to have a clear, detailed picture of MbL in kindergarten science education, related to the fact that it is not clear how effective implementation of MbL in these ages look, posing considerable challenges to e.g., teachers and curriculum designers (e.g., Tobin et al., 2017). At the same time, modeling-based reasoning and practices tend to be considerably underemphasized in school-based science teaching and learning, mostly in the younger grades (Forbes et al., 2015; Schwarz et al., 2009; Windschitl et al., 2008). All these raise questions related to the modeling practices and processes that kindergarten children use when engaged in MbL.

In a very recent report about science and engineering in preschool through elementary grades, NASEM (2022) suggests that developing and using models and constructing explanations about natural phenomena should be part of learning in Science in early grades. The report suggests that models can be viewed as artifacts through which young learners can externalize their ideas about natural phenomena, which could be one main way of allowing children to communicate their thinking in science. NASEM (2022) also points to the fact that preschool children have been observed exhibiting substantial representational proficiencies within the context of MbL. I contend that these proficiencies are related to what Louca (2020) call "modeling recourses" from a variety of areas such as free play (during which they manipulate objects), storytelling (during which they describe things happening in particular order), drawing during which they make, recognize and interpret representational choices and intentions (e.g., DeLoache, 2004). There is also evidence that suggests that children may work with a range of representation types (with of course some support), along with abilities to comparatively discuss the advantages and disadvantages of different representations of the same phenomenon (NASEM, 2022).

In a series of studies, Author and colleagues have contributed to the literature about how kindergarten children engage in MbL. Louca & Zacharia (2015) compared the ways young modelers worked within the modeling process as highlighted by the literature (e.g., Louca, Zacharia & Constantinou, 2011; Louca & Zacharia, 2012; Mendonca & Justi, 2014). They reported that kindergarten modelers follow similar practices but in a different manner. For example, revising their constructed models occurs within the context of investigation and construction phases, suggesting that the model revision phase of the MbL might not be independent. In line with Stratford, Krajcik, and Soloway's (1998) work, the Louca & Zacharia (2015) also highlighted that the constructing-a-model phase is quite complex. The development of a model includes processes such as decomposing the phenomenon under study into smaller parts, identifying elements to be included in the model, and synthesizing (which involves inductive reasoning and requires that children mentally bring the model's elements together). This is also in line with what Krist et al (2019) proposed: during MbL learners may need to move between different scalar levels of the observed phenomenon in order to productively describe the mechanism underlying the phenomenon.

While research in kindergarten MbL has slowly gained some momentum, there are aspects of models (such as the nature of models, the existence of multiple models, the purpose of models, the process of testing models, and the process of changing models (Upmeier zu Belzen and Krüger, 2010)) that have not been studied yet with these ages. While prior research has highlighted differences and similarities in which kindergarten and older children engage in MbL, it is reasonable to seek to investigate the ways that kindergarten children may use models as tools for further investigation and learning, which is related to their understanding of the nature, the role and the purpose of models they construct through MbL.

Purpose

This is a descriptive case study (Yin, 2017) seeking to provide detailed accounts of the ways two groups of kindergarten children engaged in MbL, focusing on the ways that these groups of children use their own constructed models as tools for further learning in the context of MbL. In the first case, students developed models of a simple ecosystem (food chain), and then, they used their models to collect data to develop the concepts of ecosystem balance and the ecosystem web. Children in the second group (case 2) developed models of heat transfer between a stone ice cube and water, and then by using their models, they developed the concept of thermodynamic equilibrium, which led to a new revised model to include the idea of thermodynamic equilibrium.

With an emphasis on the representation of the mechanism of the natural phenomena, in this study, I analyze evidence from these two case studies to describe the process of model development for these phenomena for these groups of children and then, describe the ways that kindergarten children may use their own constructed models as tools that support further learning through using their models for new science investigations. Evidence from the two case studies at hand seeks to add to a growing body of research that children as early as kindergarten are able to engage in MbL. I also use this evidence to argue that (a) children are able to productively use their own models as tools for further investigations of the phenomenon, which can lead to the development of new concepts; (b) kindergarten children have modeling resources (Louca, 2020) that can activate and use in order to consider and use their own constructed models as theoretical structures that can be applied in a (new) phenomenon to explain new (parts of the) phenomenon (Upmeier zu Belzen & Krüger, 2010); and (c) highlight the dynamic nature of the children's models and children's understanding of their models and their functions within the context of children modeling discourse.

Design and procedures

Following a descriptive case study approach (Yin, 2017), this study involved two groups of kindergarten students (age range: 5-6) in Cyprus taught by 2 different teachers (19 and 21 children respectively). Both teachers participated in the same professional development (PD) program for MbL in kindergarten science organized by the author over a school year. The cases selected for this study were the teachers' final teaching unit of MbL in science for the school year, taught in April-June, after a year of developing, applying, and reflecting on MbL units of kindergarten science. Along with the author and the rest of the teachers participating in the PD program, the two teachers developed their units from scratch in a series of online, bi-weekly, 90-minute reflective meetings, and data-driven (video, and photos of children's work) reflections.

For this study, all lessons (about 40-minute duration) in each case study were videotaped and transcribed for analysis. Children's work was also collected for analysis. To facilitate the analyses, for this study I adopted the approach of drawing-based modeling in which students use annotated drawings to represent their model (Fretz et al, 2002), resulting in a children-constructed model that is accompanied by children's descriptions of their models. Thus, I analyzed student-developed models (artifact analysis) along with their presentation and discussion (discourse analysis), seeking to provide rich, detailed descriptions of the characteristics of these models.

Transcripts of student conversations served as the primary source of data. For the analysis of children modeling conversations, I used two complementary approaches for analyzing student conversations. The first analysis of children's conversations in science (e.g., Ball, 1993; Gallas, 1995) builds on the long-standing interest of the science education research community in classroom discourse (e.g., Kurth et al., 2002; van Zee et al., 2001). This analysis uses transcribed children's conversations as a gateway to children's reasoning and learning experiences (Edwards & Mercer, 1995). I used discourse to develop detailed accounts of the context and the content of the modeling conversation describing the student contributions toward MbL, which I describe in the findings section. To support this analysis, I also coded the same discourse data using Russ et al's (2008) coding scheme for mechanistic reasoning in students' discourse. Given that the main purpose of the MbL is to develop accounts describing the process of how a phenomenon takes place, the heart of MbL is the development of the mechanism underlying the phenomenon. In this study, this process was captured by analyzing discourse data by Russ et al's (2008) coding scheme of 7 components of mechanistic reasoning (see Tables 1 and 2 for details).

To support the discourse analyses above, I also analyzed student-constructed models using artifact analysis adopted from Louca, Zacharia, Michael & Constantinou (2011). Codes included the ways that children represented different elements in their models: physical objects, entities, processes, and interactions.

Findings

In this section, I present an overview of each of the two case studies and then turn into a discussion about common emerging themes. The descriptions of the findings below seek to cover the complete unit as it was enacted by the teacher and the children, seeking to give a detailed picture of how the children reached their final model and then use that as a tool for further learning.

Case study 1: A food chain in a simple ecosystem

The first lesson started with children in a whole classroom setting, discussing ways of organizing a number of different organisms to "live in a house". Children ended up with three different categories (plants and trees, insects and mammals). Then the teacher presented another grouping that she came up with, which included one organism from each category, asking children whether this was a possible categorization. Following a discussion about this, the children suggested revising their grouping to include 5 groups, based on the dietary relationships of the organisms involved (organisms that would not eat each other but prefer to eat organisms from other groups were put by the children in the same group). I consider this as the children's model 1 which, based on the artifact analysis, included physical objects (the organisms), physical entities (the organisms' dietary habits), and physical interactions (organisms eating other organisms). Figure 1 provides examples of children's constructed models.

The teacher started lesson 2 by asking children to explicitly represent on a single paper the relationships of the organisms from the different 5 groups. Each child developed their own model (model 2). In a discussion about the subsequent evaluation of those models, the children identified a variety of different representation approaches used in different models by different children. Some models included the organisms (physical objects) on a continuous, straight line connecting them (which I consider to be a form of representation of physical interaction), while others connected organisms with arrows showing the pray->predator relationship, and others putting numbers to show the linear relationship between the organisms. Children used those different ideas to collectively develop a revised representation (model 3).

In lesson 3, the teacher asked children to compare their model 3 with a model she provided in the form of a food pyramid with the same organisms. The children agreed that the two representations had some differences. In the food pyramid, as we moved to a higher level, children suggested, the number of organisms decreased, whereas in the food chain only one organism from each category was represented. However, children were unsure about the significance of the latter representation rule in the food pyramid. From a research perspective, this is related to a more detailed/advanced representation of the physical process in the phenomenon (Louca, Zacharia, & Constantinou, 2011).

In lesson 4, the teacher asked the children to develop their own food pyramid (model 4), from the food chain that they developed during lesson 2 (model 3). During this process, a number of children noticed that the organism on the top of the pyramid was not eaten by any other organism and brought that observation into the discussion. This was the first instance in this unit, that their own models became a tool to think and reflect about the phenomenon represented, providing children with opportunities to think about the phenomenon more deeply, identifying issues absent from their models but deemed important parts of the phenomenon. While discussing this observation in a whole class setting, children suggested that while this could be true, any organism may die from natural causes. Thus, they suggested that this could also be the case for the rest of the organisms. A child suggested that dead fruits, leaves, and vegetables could be eaten by organisms living on the ground such as worms. Thus, they collaboratively decided to include worms at the bottom of their food pyramids, although they were unsure how to convey the information about the role of the worms.

In lesson 5, the teacher proposed to represent their food pyramid using dramatic play (model 5). To do so, the children agreed that each of them will undertake the role of one organism. They spend considerable time discussing the rules of their dramatic play that included physical objects, physical entities, and physical processes involved in the phenomenon. They agreed that the play will include only 1 fox, 3 chickens, a lot of grass (10 children), and 5 worms (physical objects). They talked about different organisms' behaviors and relationships: the fox eats chickens, chickens eat worms, and worms eat dead organisms in the soil (physical interactions). They also discussed physical objects' behaviors such as the plants do not move, the worms move very slowly, the chickens move a bit faster, and the fox being the fastest one (physical entities). They also developed a rule to simulate what happens to one that has been eaten (sit still on the floor) (physical process): when touched by another organism of the same species, the organism could re-enter the game, simulating the birth of new individuals (physical process).

Figure 1

Examples of models from case study 1; (a) Model 1: Grouping (Group model), (b) Model 2: Diagram (Individual model), (c) Model 3: Diagram (Individual model), (d) Model 4: Drawing (Individual model), and (e) Model 5: Dramatic play (Group model)

(a) (b) (c) (d) (e)

In lesson 6, children tried their dramatic play model (model 5). The teacher suggested trying this out with different numbers of individual organisms at the beginning just to see what would happen. They run this with various number combinations as decided by the children. The results were puzzling for the children, because, e.g., a large number of foxes resulted in at some point no chickens alive, and a large number of chickens resulted in no worms alive. The latter also resulted in a round with a decreased number of worms at the beginning of the dramatic play. In a subsequent discussion about the results that children collected, they focused on the results which were different from the results of their initially agreed numbers. Based on the data collected from the various iterations of their model, children suggested the idea of "optimal" numbers of the organizations in their model, which in turn contributed to the development of the conceptual idea of a "balanced ecosystem" and its characteristic of "sustainability" facilitated by the teacher. In that discussion, the children also discussed the results of round 4. Although they suggested that the initial numbers were different (the amount of initial grass was 2 vs. 10), the results between the initial numbers and the final numbers for each round were not that different. During that discussion, children suggested adding a rule that they had not thought of before related to the notion of organisms starving to death if no food was available. Taken all together, children ended up describing that there is an "optimal" number of organisms within a particular ecosystem, which results in steady numbers of organizations overall during the time that the dramatic play is in action. There were not sure how this number would be different in other ecosystems, but they were able to relate this idea with the representation in the food pyramid, in which they previously identified that as we moved to a higher level, the number of organisms decreased. Although not explicitly addressed, children seem to imply that different types of model representations convey different information about the phenomenon, with each model having its own advantages and limitations.

Table 1 presents the coding of the children's modeling discourse based on Russ et al (2008), as I described above, suggesting that over time, children's modeling discourse became more "mechanistic" by including more components of mechanistic reasoning, which resulted in more advanced mechanistic models, and probably facilitated in part for the development of the concept of a sustainable balanced ecosystem.

Table 1
Discourse analysis based on Russ et al's (2008) scheme from case study 1

	Model 1	Model 2	Model 3	Model 4	Model 5
description of the target phenomenon	yes	yes	yes	yes	yes
identification of the set-up conditions	yes	yes	yes	yes	yes
identification of physical or conceptual entities	yes	yes	yes	yes	yes
identification of the entities' activities		some	yes	some	yes
identification of the entities' properties	yes	yes	yes	some	yes
identification of the entities' organization	some	yes	yes	yes	yes
Chaining (what happens prior and after)					yes

Case study 2: Water freezing (heat transfer)

Prior to this unit, this group of children investigated the phenomenon of an ice cube melting (8 weeks in total) developing and revising a total of 6 models in their effort to represent the mechanism underlying the phenomenon.

The teacher started the unit on water freezing by bringing in the classroom ice cubes made of stone and wondered what would happen to the water if she added one cold stone ice cube. In a whole-class setting, the children designed an investigation of measuring the temperature of the water with the stone ice cube every 2 minutes and creating a record of their measurement. The investigation took place in 5 groups. In a subsequent whole-class discussion, the teacher facilitated a process during which children transferred their data to graphs. I consider the children's representation of the data collected as their model 1 (Figure 2 presents examples of children's constructed models), which was a mathematical representation of the data in a graph. Based on the artifact analysis it only included physical entities (records of the temperature). From the data collected, the children noticed that at the beginning, the water temperature increased for a number of measurements until one point, at which it remained unchanged for the following measurements. After a short discussion, the children agreed that these data indicated that the water become colder until one point that the ice cube and the water reached the same temperature, at which point the water temperature stayed the same. Although not explicitly addressed by the children, this implied that the stone ice cube was becoming hotter.

In the next lesson, the teacher reminded the children of their representation (model 1) and asked them how this happened. Looking for a possible explanation, the children suggested using the final model they developed in their previous MbL unit, representing the mechanism of melting. That model consisted of a set of rules for a dramatic play model, in which each child laying on the floor represented a water molecule and showed over time how they moved away from each other (during melting) starting from the outside of the ice cube, as per their observations. Without discussing the rules for this model, children asked their teacher to "play out" this model to explain how cooling happened. This model included physical objects (water/ice molecules), physical processes (movement of the molecules), physical entities (velocity of the molecule movement), and physical interactions between the different molecules. During the application and the subsequent evaluation of their model 2, the children realized that the model could not explain what was going on in the phenomenon currently under study (how the water gets colder because of the ice), due to the fact that their model explains how an ice-cube made of "water melts" (pieces of ice getting detached from the ice cube and become water) and had no information about the change of the temperature, and what was causing this change. Thus, this model could not provide an explanation as to how the phenomenon of heat transfer takes place. In a sense, children realized that although this model was explaining a similar phenomenon (ice melting), it failed to explain the temperature change under study. Although children did not talk about the reason for that failure, this failure was due to what Krist et al (2019) refer to as the two models at hand requiring different scalar level explanations: the ice-melting model stopped at a lower scalar level, lacking information about how the ice-melting (molecules moving) was related to the process of heat transfer that caused the ice melting.

In lesson 3, the teacher gave the children a piece of paper to draw what they thought happened in the water with the stone ice cube. Children developed a third model that in most of the cases showed that the stone ice cube was giving (physical process) "coldness" to the water (physical entity) when the two physical objects (water and stone ice cube) were in touch in the water (physical interactions). Through their models, almost all of the children started talking about the idea of thermal equilibrium. For instance, one child suggested that the ice cube was giving "coldness" to the water, and the warm water was giving "warmth" to the ice cube until they [their temperature] became equal. A second child suggested that the ice cube gave half of its "coldness" to the water until its temperatures become equal. While most of their models 3 included (as in the case of model 2) physical objects, physical entities, physical processes, and physical interactions (and thus the artifact analysis coded similarly these 2 models), children's models 3 were in a higher scalar level compared to model 2, explaining how the phenomenon of heat transfer took place.

Figure 2

Examples of models from case study 2; (a) Model 1: Diagram (Group models), (b) Model 2: Dramatic play (Group models), (c) Model 3: Drawing (Individual model), (d) Model 4: Dramatic play (Group model), and (e) Model 5: Dramatic play (Group model)

(a) (b) (c) (d) (e)

In lesson 4, the teacher reminded the children of their previous models. During a discussion for evaluating model 3, children focused on the idea of "giving and taking", and the idea of the thermal equilibrium at the end of this process. During this discussion, the teacher proposed to develop a new dramatic play model like a two-player game, that would consist of a number of rules that would result in the phenomenon under study. Children discussed the rules of the game: two players, one representing the stone ice cube and the other the water. Both players had several plastic cubes. The children decided that the ice cube should have blue plastic cubes (representing "coldness") and the warm water should have grey plastic cubes (representing "warmth"). At each iteration of the dramatic play model (model 4), each child should give the other one plastic cube of his/her own color and get a cube from the other color from the other child. Children played the game twice with different players, only to notice that the model was not representing what they have observed in the phenomenon: at the end of the dramatic play, the cold entity became warm, and the warm entity became cold. Their model did not end in thermal equilibrium. The dynamic nature of their model enabled children to observe how it simulates the phenomenon and whether the simulation fit their observations of the phenomenon under study.

In lesson 5, the teacher reminded children about the difficulties they had with their model 4 and asked them to think about the phenomenon of warming water in a kettle, as well as the opposite phenomenon of a glass of water colling off in a refrigerator (children have studied both phenomena in the previous unit, without, however, discussing the idea of heat transfer). She then asked children to represent this change in each of the phenomena using a number of plastic cubes. Children proposed having a series of representations of instances for each phenomenon, with the cold water heating having first 1 plastic cube (representing the heat gained), then 2, then 3, and then 4, and the other way around in the warm water case that cools off. Based on this, the teacher reminded them of their model 4 and asked them to think about revising it accordingly. A child proposed having different colors of plastic cubes, based on the examples they considered at the beginning of the lesson. This suggestion took into consideration the number of plastic cubes that each body should have based on their temperature, and highlighted the fact that both bodies should have the same types of plastic cubes. After a long discussion, the children agreed that for model 5 the two bodies should have similar colored plastic cubes, and the warm water had more plastic cubes than the ice cube. They also agreed that both bodies should give cubes to each other, but the warm should give more plastic cubes (2) since it had more plastic cubes than the cold one (1). They also agreed that the game should stop at the point at which the two bodies had the same number of cubes. Children played the game (model 6) several times, changing the number of starting plastic cubes. Taken all together, the dynamic nature of children's model 4 helped them realize that it did not provide a representation of the mechanism of the phenomenon. They then developed a 5th model, that would include the idea of thermodynamics equilibrium (although this was in a crude form requiring refinement). This model is probably a very different solution from what the children first thought in model 4 (exchange of warmth and coldness), and simply the evaluation of the model they constructed leaded students to think about this possible idea. Similar to case 1, the development of the concept of thermodynamics equilibrium in case 2 took place during the process of model development, evaluation, and revision. At the same time, in both cases, the concepts started to develop based on data collected through their models, allowing student-constructed models to function as simulations of the phenomena at hand.

Table 2 presents the coding of the children's modeling discourse of case 2 based on Russ et al (2008). The findings suggest that over time, children's modeling discourse became more "mechanistic" by including more components of mechanistic reasoning, which resulted in more advanced mechanistic models, and probably facilitated in part the developmet of the concept of thermodynamics equilibrium.

Table 2
Discourse analysis based on Russ et al's (2008) scheme from case 2

	Model 1	Model 2	Model 3	Model 4	Model 5
description of the target phenomenon	yes	yes	yes	yes	yes
identification of the set-up conditions	yes	yes	yes	yes	yes
identification of physical or conceptual entities		some	yes	yes	yes
identification of the entities' activities			yes	yes	yes
identification of the entities' properties			some	yes	yes
identification of the entities' organization				yes	yes
Chaining (what happens prior and after)					yes

Discussion and significance of the study

In an effort to contribute towards a more clear, more detailed picture of MbL in kindergarten science education, in this study, I have investigated how two groups of children were engaged in the process of MbL. Evidence from the study adds to a growing body of research that children as early as kindergarten are able to engage in MbL (Louca & Zacharia, 2019; accepted) in a number of productive ways similar (but also different) to the ways that older children work within MbL. Most of my focus in this study was on mechanistic reasoning as evident from the modeling discourse and the children-constructed models (Russ et al, 2008; Krist et al, 2019). While the literature suggests a number of other MbL aspects (NASEM, 2022; NGSS, 2013), evidence from this study may suggest that directing MbL toward the discussion of the mechanism underlying the phenomenon may provide a productive way of engaging kindergarten learners in developing concepts related to physical phenomena.

At the same time, evidence from this study suggests that children used the models they created (and utilized them to collect simulated data from the phenomenon) in a way that led to the development of new concepts (the idea of a balanced ecosystem and ecosystem sustainability in the first case, and the idea of thermodynamic equilibrium in the second case). In both cases, children-constructed models were used by children as tools for further phenomenon investigation and learning. Interestingly, this use of their own models as theoretical structures that enable them to dive into additional investigations related to the phenomenon at hand was not explicitly taught by the teachers, but rather, was a process that was used spontaneously by the children (with of course the support of the teacher). Thus, I contend that kindergarten children may be seen as having a repertoire for modeling resources (e.g., Louca, 2020) that can evoke and use in order not only to develop and reflect on representations of the phenomena with different modeling tools but also to consider and use their own constructed models as theoretical structures that can be applied in a (new) phenomenon to explain new (parts of the) phenomenon. This has been also discussed in the literature (Upmeier zu Belzen & Krüger, 2010) as an essential part of children's modeling competencies, agreeing with NASEM (2022) report pointing to the fact that kindergarten children have been observed exhibiting substantial representational proficiencies.

Taken all together, these findings possibly suggest a potential dynamic nature of the children's models when used as references in children modeling conversations. Working with their own models, children seem to view them in such a way that they feel comfortable using them as theoretical structures that need to be in agreement with the data collected from the phenomenon and provide plausible as well as possible descriptions of the mechanism underlying the phenomenon under study but also making it possible to use them as leverage for "theoretical thinking" (thinking about theories of the mechanism underlying the phenomenon, assumptions, ideas underlying their models). Additionally, the findings suggest that different types of models may afford different learning opportunities, in addition to supporting children in developing abilities and knowledge to choose which modeling medium would fit better their model plans. Of course, these findings create possible new directions for further investigation in MbL such as the role of the teachers, anchoring activities, and the scaffolding needed to provide kindergarten learners in order to be able to engage in MbL in science in the ways I described in this study.

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Supports and Barriers to the Spread of Learning Sciences Innovations: A Comparative Actor Network Analysis

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Abstract: This study compares the adoption and spread of a learning sciences innovation, a project-based, interest-driven STEAM learning program, in two culturally distinct contexts: a large school district in the southeastern United States and the public schools in Helsinki, Finland. Using Actor Network analysis, we show how and what actors needed to be mobilized for the program to get in, get rooted, and spread (or not) in these two contexts. Our findings have implications for understanding both how to spread and sustain learning sciences innovations and similarities and differences between the Finnish and American school systems.

Introduction

In the learning sciences, many of us share the goal of designing innovative learning environments and helping them succeed in the world. However, too many innovations ultimately fail to be sustainable or scalable because of a lack of attention to or understanding of broader organizational capacity (Penuel, et al., 2011) or needed infrastructure (Penuel et al, 2019). To address this problem, we must better understand the supports and barriers to sustainability and scale-up for the types of innovations produced by our community (Penuel, et al., 2011).

This study addresses this gap by comparing the adoption and spread of one educational innovation in two culturally and organizationally distinct contexts: a large, county-level, school district in the southeast United States and the public schools in Helsinki, Finland. This innovation, FUSE Studios (Stevens et al., 2016), is a project-based, interest-driven STEAM (science, technology, engineering, arts, and mathematics) learning environment. We provide a comparative analysis of the adoption and spread of FUSE in these two settings to identify commonalities in the processes involved in scaling the innovation across these two distinct systems.

Outside of the learning sciences, the scaling of educational innovations has long been an important research topic (e.g., Orlich, 1979) and has proliferated in recent years, fueled by globalization. Within scaling discussions, Finland's education system and its success are highlighted (Hargreaves, Halasz, & Pont, 2008; Hargreaves, et al., 2010; Sahlberg, 2010). Comparative research shows differences between the U.S. and Finnish education systems, along dimensions likely to impact innovation adoption. For example, since the 1980s, as part of the *global education reform movement* (GERM), the U.S. has focused education policy and reform efforts on: (1) standardization; (2) core subjects; (3) low-risk routes to learning goals; (4) transferring educational innovations between contexts; and (5) high-stakes accountability (Sahlberg, 2010). However, these elements of GERM have not been adopted as extensively in Finland (Sahlberg, 2010). The differences between these two education systems suggest value in a comparative, cross-national analysis of the adoption and spread of an educational innovation.

We have grounded our investigation in research arguing that adaptability to local contexts influences an innovation's ability to scale (Coburn, 2003). Fostering scaling by designing for adaptability (Stevens et al., 2018) and focusing on the enactment of core design principles—integrity instead of fidelity—can ensure and even enhance an innovation's impact (Cobb et al., 2003; LeMahieu, 2011; Stevens et al., 2018) by allowing actors like teachers and administrators to adapt innovations to local needs. Conceiving of scale as adaptation also emphasizes the work of local actors, in contrast to the passive metaphor of diffusion of innovations (Rogers, 2003).

Within the growing body of work on adapting innovations, international comparisons are rare, especially comparisons focusing on the process of adaptation in practice. A notable exception is research on the spread of the 5th Dimension afterschool program to several locations across the U.S. and internationally (Cole & Distributed Literacy Consortium, 2006; Cole, 2016; Lalueza, Sánchez-Busqués, & García-Romero, 2019). This work demonstrated how, as the program spread, promising implementations failed, and unlikely ones succeeded, as much through the involvement of unexpected actors as through intentional, coordinated effort. While this work provides insight into the longitudinal processes of scaling, it is largely based on *ex post facto* designs. What is missing are analyses of the processes of adaptation as they happen (Nespor, 2002; Fenwick, 2011).

Analytic framework

To address this gap, we used Actor Network Theory (ANT) (Callon, 1986; Latour, 1987; Latour, 2005). We chose this approach, because distributed perspectives on thinking and learning, like ANT, are well-suited to analyzing 'smaller' processes of implementation (Penuel & Spillane, 2014). This is because ANT treats organizations as dynamic networks of human and non-human actors that come into and out of association with each other, tracing associations between actors over time, and identifying moments of translation within networks (Latour, 2005). Because such translations are the building blocks of innovation, this approach is well-suited to analyzing change.

In our analysis, we drew on ANT's general analytic approach and specific ANT constructs. For example, we attended to *moments of translation* (Callon, 1986)—the processes of change through which networks assembled and extended themselves to adapt to local conditions (Fenwick & Edwards 2010). We explain how our innovation got in and got rooted, in terms of *interessement*—how allies or actors in the network were recruited and locked into place (Callon, 1986). We discuss how actors established themselves as *obligatory passage points* (Callon, 1986) in representing an idea, intermediary or problem and related entities in particular ways and invited other entities to detach themselves from their existing networks and connect to this new representation (Fenwick & Edwards, 2010). We discuss *enrolment*—the process whereby entities to be included in the network became engaged in new identities and behaviors (Fenwick & Edwards 2010)—and the *mobilisation of allies* (Callon, 1986)—"the moment...when the network becomes sufficiently durable that its translations are extended to other locations and domains" (Fenwick & Edwards 2010, p. 14) by representatives of the network (Callon, 1986). Finally, we distinguish between *intermediaries*—who move representations or information without transformation—and *mediators*—who transform the representations and information that move within networks (Latour, 2005). We applied these ANT concepts to answer two research questions: (1) How did FUSE get in, get rooted, and spread in these two contexts?; (2) How did the adoption and spread process differ in these contexts?

Method

Research context

Our focal innovation, FUSE Studios (Stevens et al., 2016), is a project-based STEAM learning environment. It represents a significant departure from the standard package (Becker, 1995) of school in both Finland and the U.S., because it is designed around youth interests and choice. Students choose STEAM challenges from over 30 options on the FUSE website. Each challenge has a trailer video to invite interest, and challenges level up like video games (Stevens, Satwicz, & McCarthy, 2008). Students choose when they are ready to upload evidence of level completion to advance to the next level. Students choose when to start and stop a challenge and whether to work alone or with others. While challenges have specific instructions and parameters, students have leeway in both approach and final product. Students complete challenges with a suite of digital and tangible tools. Finally, students' primary instructional resources are the FUSE website and other students, rather than the teacher, who plays a 'facilitator' role. In 2012, FUSE started as a middle school afterschool program in a large, racially and socioeconomically diverse, suburban school district in the Midwestern U.S. Subsequently, FUSE spread within that district, getting integrated into the school day, first at STEM elementary schools, then at all elementary schools. FUSE has subsequently spread beyond the district, to over 250 sites across the U.S. and seven in Helsinki.

Here, we compare two cases of district-level spread: Marvel County Public Schools (a pseudonym) and Helsinki Public Schools. We selected the Helsinki schools as a critical case (Patton, 1990) for comparison to their U.S. counterparts because of documented differences between the two countries' education systems. Marvel County represents a typical case (Patton, 1990) of within-district spread relative to other U.S. districts and a comparable case to the Helsinki Public Schools in size and structure. For example, both Marvel County and Helsinki have a population of roughly 600,000 served by one large, centralized school district. There are, however, important differences between the two contexts. Most notably, Marvel County is racially and socioeconomically diverse, while Helsinki is relatively homogeneous. School funding is also structured differently. Marvel County schools depend not only on local tax dollars but also on a mix of Federal Title I funds (available to U.S. schools enrolling at least 40 percent low-income students) and private industry grants, whereas Helsinki Public Schools are reliant solely on government funding. However, because these differences are reflective of broader, country-level differences, we believe they support rather than detract from the argument for comparing these two cases.

Data collection and analysis

In both districts, data were collected by researchers who had engaged previously in a year-long, ethnographic study of classroom culture and student experiences in the original U.S. district implementing FUSE. Research in Marvel County was conducted by the first and third authors, who are American-born researchers, fluent in English, and research in Helsinki was conducted by the second author, who is a native Finn, fluent in Finnish. Data collection began in mid-2017 with observations and video-recording of the professional development (PD) workshops for new FUSE facilitators. During the 2017-18 and 2018-19 school years, we conducted retrospective interviews with new and returning facilitators, school principals, and district-level administrators involved in implementation. We conducted onsite observations of FUSE classrooms at implementing schools (documented using video-recordings and field notes). These data were supplemented with observations and audio-recordings of administration meetings regarding FUSE (Helsinki) events where FUSE was showcased (Helsinki) and interviews with students about their experiences (Marvel County).

Consistent with our ANT frame, we used our field notes and transcripts from interviews, meetings, and classroom observations to identify relevant actors and their roles in the network at various time points. At each point, we were able to create a representation of the networks in Marvel County and Helsinki, which included relevant humans and nonhumans involved in implementation and how they were brought into *association* with each another. We then compared across time points to see changes over time. We supplemented this series of comparative snapshots by coding interviews and observation data for explicit mentions or observations of translation in the network (e.g., recruitment or attrition of new actors) and reasons for these changes. The result was a dynamic understanding of the composition of each implementing network and how and why it changed over time. We segmented network activity into three phases defined by their corresponding network goals: *getting in, getting rooted*, and *spread* (Stevens et al., 2018). We then compared the two districts.

Results

Getting in

FUSE came to Marvel County through the district's STEAM Integrator/Magnet Coordinating Teacher, Carol (all names are pseudonyms) and the Project Director of Magnet Schools, Natasha. They encountered the program at the National Art Association Conference in Chicago, in March 2016, where they attended a presentation given by the FUSE Art Director and Program Director. The district, which was otherwise under-resourced, had received a grant to create several STEAM magnet schools. So, Carol and Natasha were seeking STEAM programming (an interessement for FUSE). According to Carol, the primary actors that made FUSE appealing were STEAM and equity. Discussing equity, she said, 'A lot of people talk about STEM in underrepresented groups, but [FUSE] does it so well and naturally and capitalizes on that human curiosity that we all have.' The district piloted FUSE at Elementary School A during the 2016-17 school year as the core curriculum for a required, weekly technology class for grades four through six, run by the technology teacher, Jessica. This school was not a STEAM magnet school but one where Carol said, 'The then principal had a vision. She was going to move ahead as if she was a STEAM magnet.' This school paid for FUSE using Title I funds.

Getting into Marvel County was supported by the enrolment of a local aerospace and defense technology company, Stark Industries. Stark Industries was enrolled in the network after the principal expressed a need to have someone show her teachers how to do FUSE. Their interessement to join the network was a desire to have spaces for community outreach (mentorship) and to encourage a pipeline into the local STEM workforce for diverse students. Stark engineers volunteered to visit the FUSE studio two Fridays a month as mentors. For FUSE to get into Marvel County, it also had to be adaptable to local needs. For example, for Jessica to run FUSE as the core curriculum in her technology class, the administration required that she align FUSE challenges with ISTE (International Society for Technology in Education) standards. To fit FUSE within the school schedule and accommodate all fourth- through sixth-grade students, Jessica and her administration further translated FUSE by: (1) making it 40 minutes per week instead of 90 minutes; (2) assigning desktop computers to students, rather than letting students choose different computers each day; (3) adding non-FUSE activities, like building mazes in Minecraft; and (4) adding a 'Wall of Failure' displaying failed 3D-prints to destigmatize failure.

FUSE's entre into Helsinki also began with a conference. At this trans-Nordic conference, in Oslo, Norway, the third author (the principal investigator (PI) of FUSE) presented on FUSE in an invited keynote. This sparked an attending education professor (Liisa) from the University of Helsinki to invite the PI to give a talk on FUSE at the University of Helsinki in Spring 2015. While in Helsinki, the third author was brought by Liisa to School 1, an elementary school widely known as a local leader in testing educational innovations. During this visit, the school principal, Sanna, the FUSE PI, and Liisa discussed bringing FUSE to the school.

At this time, the Finnish schools were adopting a new national core curriculum, which emphasized multidisciplinarity and 'transversive' ('21st century') skills. Along with the district's upcoming strategy for "digitalization," this built interessement for FUSE. District leadership approved the implementation of FUSE in Fall 2016 in negotiations between district leadership, Sanna, and the FUSE PI. These negotiations brought in School 2, a comprehensive school, because district leadership wanted a second context for implementation. The principal of School 2, Jaana, reflected on this, saying, "Well of course the fact that [Liisa] was so impressed by [FUSE], so naturally it kinda increased my trust that this was a worthwhile thing...and then from what I knew about it, it seemed that many of the things in the then-new curriculum were there. And then of course it was especially a good thing for us…as part of our school's emphasis on design and design learning."

In Helsinki, as in Marvel County, FUSE had to be adaptable or translatable to the local context. For example, prior to implementation, the FUSE PI, Schools 1 & 2, the Helsinki leadership, and Liisa agreed all the materials, except for the instructional videos, would be translated to Finnish. However, in Helsinki, FUSE resisted proposed adaptations too divergent from its core design. For example, School 1 suggested running FUSE on available iPads instead of laptops. However, using iPads would have lowered integrity of implementation, as only a few challenges were accessible on iPads. So, the FUSE team pushed back, and School 1 agreed to obtain laptops.

In comparing the getting in phase in these two districts, we see similarities in what types of actors were mobilised and how. As actors, both districts displayed interessement for FUSE. In Marvel County, there was the need for equity-oriented STEAM programming for newly-funded STEAM magnet schools, and in Helsinki, there was the push for digitalization in primary education, a new national curriculum that emphasized multidisciplinarity, and a school with a history of being an early adopter of innovations. The path FUSE took to get into each district was also similar. In both cases, it came in through a professional conference and subsequent conversations between FUSE team members and district administrators. In both cases, external actors (Stark Industries and Liisa) were enrolled and served as intermediaries and lent credibility to the evolving actor networks. Finally, in both cases, FUSE needed to be adaptable to local conditions.

However, there were also important differences in the mobilized actors and their respective functions. In Helsinki, key non-human actors included “digitalization”, the new national curriculum emphasizing ‘transversal competences’ (skills related to well-being, interaction, multidisciplinary, creativity, society, ethics, the environment, global citizenship, and culture), while in Marvel County, non-human actors included equity, STEM/STEAM, the magnet schools grant, ISTE standards, and Title I funds. In Helsinki, the human actors were the FUSE PI, the University of Helsinki professor, and a school principal; only later were district-level administrators involved. In contrast, in Marvel County, the initial human actors were the two district-level administrators and the FUSE art and program directors, who were later joined by a school principal, a technology teacher, and mentors from Stark Industries. These actors also played different roles. For example, while Stark Industries and the University of Helsinki professor both supported implementation, the former contributed mentors, thus serving as a mediator, by altering the students’ and teachers’ experiences of FUSE, while the latter contributed credibility, thus serving as an intermediary but not significantly altering the form of implementation. Finally, while adaptability was important in both cases, specific adaptations to local context differed.

Getting rooted

As implementation progressed, new actors were enrolled or created, and associations between existing actors were strengthened. For example, prior to year two, Carol and Natasha pursued funding for six additional STEAM magnet schools to run FUSE. Three were funded by Stark Industries, and at one, Stark Industries engineers served as mentors. The other three were funded by a new actor, grants offered through FUSE provided by two other STEM industry partners. The second new actor was the two-day professional development (PD) workshop offered to all new and returning FUSE facilitators and administrators. Jessica, Carol, Natasha and several new implementing teachers and building administrators attended this PD in Chicago. When we asked Jessica whether the PD had been helpful, she said, *‘Oh, absolutely. Well, you know you kind of jump into it and you figure things out as you go, but it did really help validate my feelings as to what I was doing, that I was doing it correctly.’* During PD, Jessica, Carol, and Natasha helped new facilitators understand FUSE and lent credibility to the program. However, during the PD, some new facilitators and administrators expressed some ambivalence about their enrolment in the FUSE network. For example, some did not attend the PD, positioning FUSE as less of a priority than other initiatives. Others pushed back on elements of FUSE, like the lack of formal assessment. However, many attendees reflected on the PD’s importance in shaping their understanding of FUSE and implementation. For example, the Middle School A principal said, “I’m so glad I did that [went to the training], because I think as a principal, you’ll never understand FUSE if you don’t do it, and I think that’s why we have a full class of it, instead of just a couple of sections in a couple of days in science, because I felt it, saw it, loved it.”

Another set of actors that needed to be recruited to facilitate rooting were physical spaces, materials, and technology. Physical spaces were important, because many of the tools and materials needed to run FUSE were relatively immobile (e.g., 3D printers, vinyl cutters). Several new, year two schools delayed the start of FUSE by several months, because they did not have physical spaces set up for the program. Once the physical spaces were complete, however, they contributed to the rooting of FUSE. These spaces, alternately referred to as ‘FUSE Studios’ or ‘STEAM Labs’ were outfitted not only with computers, flexible seating, and STEAM-themed bulletin boards, but also with FUSE-branded banners, carpets, and bulletin boards. They represented both an additional investment in FUSE and a physical home for it at each school. Consequently, they aided FUSE in establishing itself as something of an obligatory passage point for STEAM learning. The need to install multiple software programs on the computers for FUSE also delayed implementation. However, unlike the physical spaces, which ultimately aided rooting, software problems continued to provide obstacles at many schools. Jessica reflected on software installation, saying that even though her building had a technology person right across the hall, she had to get ‘put on a list somewhere’ and the technology person ‘gets very, very busy. So it's hard to get her to come in and do 24 computers.’ She and another facilitator in Marvel County never got the software for the popular Game Designer challenge installed correctly. So, students did not have access to that challenge.

Finally, the physical kit materials for FUSE challenges proved important actors in rooting. While initial delivery of kits to Marvel County wasn’t problematic, once the kits were in use, teachers had to manage the materials to prevent loss, damage, or disorganization. Many teachers described this as burdensome. Consequently, some turned materials management over to students, but others denied students access to certain kits.

Despite these setbacks, the network sustained itself, and teachers’ and administrators’ initial impressions of it were positive. In interviews during Fall 2017 and Winter 2018, they mentioned observing emerging student skills like problem solving, persistence, collaboration, and self-directed learning. For example, Jessica said of her students, ‘They're more willing to take on problems. They're more willing to try and figure it out on their own. They're more willing to fail.’ Teachers also said students demonstrated increased confidence, new interests, and engagement in FUSE. For example, Jessica said, ‘I hear so many of them say it's their favorite activity.’ The Middle School B principal echoed these same sentiments and added, ‘I noticed...it was absolutely student led, not teacher led, which is amazing. Kids that I wouldn't normally see work together are working together. They want to help each other, and they congratulate each other.’ These positive impressions played an important role in rooting, as seeing the value in the program seemed to make stakeholders more willing to work to sustain it.

In Helsinki, as implementations progressed, new actors were also enrolled and created. Teacher training brought in teachers, who in turn, brought new spaces and students, as they set up and started their FUSE studios. FUSE also made its way into schedules, and School 2 created a new elective course. To set up the studios, the IT administration, laptops, software, charging stations, kit materials, and 3D printers were enrolled in the network. To facilitate set up, the IT administration also created an installation package of the various FUSE software.

However, not all the requisite actors had been recruited. Although district leadership had agreed on the implementations, they had not provided all necessary materials to schools. School 1 waited three months for their laptops, in part, because of the digitalization program that had helped FUSE get into Helsinki. The program outlined a plan to both upgrade and increase the use of IT in education. The district’s contracted supplier could not keep up with the demand, and when new computers were distributed, non-FUSE schools, with out-of-date devices or a low computer to student ratio, were prioritized. Additionally, the district decided to break down the standard FUSE materials package and purchase some equipment themselves, to cut costs and help with maintenance. This delayed the delivery of 3D printers and vinyl cutters. Local adaptations to the kit materials were also needed. For example, two challenges required electrical plugs and charge converters to work in the Finnish power grid, and pen lasers had to be swapped out to follow Finnish safety regulations. Managing materials, especially replacing broken materials, locally, also proved troublesome for teachers and meant some challenges were not available for considerable time periods. To address this problem, both schools assigned specific teachers to manage materials. Thus, while partly committed, as an assemblage of actors, the district maintained a degree of ambivalence in its connection to FUSE. Despite these setbacks, the network sustained itself. As in Marvel County, early teacher feedback was positive and helped keep the teachers, students and principals engaged with FUSE. For example, one teacher said, ‘The FUSE elective has been very motivating. The students have been enthusiastic about the challenges, have helped each other and learned to problem solve’.

Comparing across the cases, both human and non-human actors played significant roles in rooting. For example, FUSE PD significantly mediated rooting in both cases. New actors were recruited via the PD, however, recruiting these new actors surfaced ambivalence that needed to be managed. In Marvel County, Jessica, Carol, and Natasha played an intermediary role similar to Liisa’s and helped to enroll ambivalent actors by lending credibility to the program. However, Jessica and Carol also served as mediators, shaping implementation. Physical and technological infrastructure also mediated rooting in both cases, especially in establishing FUSE as an obligatory passage point for STEAM learning in Marvel County. However, to mediate rooting, these actors needed to be recruited into the network. Until recruitment occurred, they impeded rooting. In both cases, teachers’ and administrators’ first-hand experiences of FUSE helped stabilize the extending network. Finally, to further stabilize the network, new actors were created: material managers. However, while in Helsinki, these managers were always teachers, in some Marvel County schools, these were students.

One difference between the cases was that grant funding served as an intermediary in Marvel County but not in Helsinki. Stark Industries, in its capacity as a funder (as opposed to a provider of mentors/expertise), functioned as an intermediary, similar to Liisa in Helsinki, providing support for the program without altering it significantly, although the type of support differed. Another difference was in the needs and processes of setting up the physical and technical infrastructure for FUSE. For example, in Marvel County, obtaining computers was not difficult, once funding was in place. However, physical spaces needed to be created, which took time. In contrast, in Helsinki, physical spaces and funding were already in place, but the logistics of centralized distribution and the priority placed on equitable distribution across the whole Helsinki district led to delays in schools getting technology and highlighted the district's ambivalence toward FUSE, relative to other priorities. Finally, while digitalization served as an interessement for FUSE in Helsinki as STEAM did in Marvel County, FUSE did not establish itself as an obligatory passage point for digitalization in Helsinki as it did for STEAM in Marvel County.

Spread

In year three, the network of FUSE in Marvel County expanded, adding five non-magnet schools, for a total of 12 elementary, middle, and high schools. One actor that supported this was grant funding. However, funding also placed limitations on FUSE's ability to spread, because only schools able to procure grants could run it. The physical FUSE studios also played an important role in spread. Once these studios were set up, they were used as showcase spaces for visitors. For example, Wanda, the FUSE facilitator at Elementary School B, described her school showcasing their new FUSE studio, saying, "[W]hen we had our grand opening we invited a lot of district members. We had the chief of police. We had the mayor, the superintendent. [Carol] was here...Oh my gosh, it was amazing. It was, we had about 25-30 people." These visits and showcases helped increase awareness of and support for FUSE from district officials and local stakeholders, which helped it spread to additional schools. Carol also played a significant role in spreading and sustaining FUSE. She championed the program, applied for grant funding, supported teachers, and created opportunities for teacher collaboration. All teachers reported finding this helpful. Finally, spread was facilitated by the same adaptability that helped FUSE get into Elementary School A. Although FUSE came into the district as a fairly top-down initiative, each school was free to translate it to fit their needs. For example, at High School A, the interessement for FUSE was a need to redesign the ninth-grade career and technology education (CTE) pathways course. FUSE became the core component of that class.

There were also actors that inhibited spread. One, already discussed, was money. Two others were computers and standardized tests. Marvel County had recently switched to computer-based standardized testing. Because the district had limited funds for computers, the computers used for FUSE were also required for testing. Consequently, FUSE was significantly disrupted from March through May each year, while tests were occurring.

In Helsinki, in Fall 2016, building and district leaders and researchers from the University of Helsinki, including Liisa, visited the FUSE team at Northwestern University and toured Chicagoland schools implementing FUSE. The visit significantly impacted how FUSE spread in Helsinki. After the visit, the district's representative called FUSE 'the missing link' between the district's digitalization and STEM goals and the schools' current practices. He suggested to the district leadership that FUSE should be spread to five other Helsinki schools. The leadership agreed, and in a meeting of the district's Innovative Schools network, five new elementary schools expressed interest in implementing FUSE. However, word of FUSE had already found its way to some of the schools before this. In Fall 2016, School 1 showcased FUSE to other teachers in their local area as part of a professional development workshop. The principal of School 3, Eeva, recalled this, saying, 'But way before that [the network meeting], when I had been to [School1] and seen [FUSE] for the first time, I had then thought that how could we get this, like what would be my channels that I could pull so that we could get our own FUSE.'

As enrolment of new actors continued, complexity increased. New teachers, rooms, students, and equipment became part of the network, and the district showcased FUSE as a frontier innovation in educational events in Helsinki. However, again, there were significant delays in mobilizing infrastructure. New, FUSE-dedicated laptops and charging stations arrived three months late. This was due to both the digitalization program and centralization in the district's IT support, spurred by the discovery of embezzlement. This centralization meant that IT support was slow in responding to equipment orders. Furthermore, the FUSE software package created previously by IT support could not be used, because the new system required a different installation method.

This complexity eventually impacted the network's size and composition. Because of the delays, School 5 never started FUSE and School 4 implemented FUSE only as one part of its IT elective. Teachers, who were initially enticed by FUSE, told us, by the time the laptops had arrived, they had needed to plan their year without FUSE, and they had largely forgotten the PD. This ambivalence drove remaining teachers to organize themselves in a new way. To share FUSE experiences and information, they began regular meetings organized by a teacher from School 2, who had been appointed to the district's STEAM coordination team as a FUSE expert teacher.

We see similarities in the actors responsible for spreading FUSE in both cases. For example, technological infrastructure was key mediator that both supported and impeded spread. However, how technology mediated spread and the new actors it enrolled were different. Showcase spaces or events were important actors in both Marvel County and Helsinki, recruiting additional human actors. Specific humans also played important roles in both cases in advocating for the program or connecting other actors. However, these humans occupied different institutionalized roles and supported the network differently. Finally, the adaptability of FUSE to new contexts with particular interessements supported both within and between school spread in both cases.

Discussion

In answer to our question, 'How did FUSE get in, get rooted, and spread in these two contexts?', we found that in both cases, getting in was determined by how well FUSE aligned with local ideas and initiatives. It was also aided by the individual advocacy and support of actors like Liisa and Sanna (in Helsinki) and Carol and Stark Industries mentors (in Marvel County). Getting rooted was facilitated by the recruitment of additional teachers and administrators, through PD and these actors' positive firsthand experiences of FUSE. It was also impacted by the recruitment (or lack thereof) of non-human actors, including physical spaces, computers, challenge materials, and funding. Rooting was also aided by the program's ability to be translated to local needs and constraints. Finally, spread was facilitated by adaptability; non-human actors like physical showcase spaces, money, and technological infrastructure; and human actors serving as advocates, recruiting external actors to the network.

In answer to our second research question, there were important differences between the actors and processes of translation in the two cases. First, the interessement for FUSE was different. In Marvel County, it was a need for equity-oriented STEAM programming aligned with technology standards and the goals of the CTE pathways course. In Helsinki, it was the digitalization initiative and the new national curriculum. Second, in Marvel County, Stark Industries served as both a mediator (providing mentors) and intermediary (providing funding). In Helsinki, Liisa provided external support for implementation but only as an intermediary (advocate for the program). Third, while physical and technological infrastructure played an important role in both cases, they mediated implementation differently. Physical spaces played a more significant role in initially impeding and ultimately supporting implementation in Marvel County than in Helsinki. Conversely, computers and kit materials provided a more significant impediment to implementation in Helsinki. In Helsinki, technology problems were mostly with obtaining the computers and materials, while in Marvel County the problems were with their use and functionality. Finally, while adaptability was important in both contexts, in Marvel County, FUSE was adapted for use across multiple grade levels, and implementations varied widely based on specific local interessements. The Helsinki adaptations were more homogeneous; four of the five schools implemented FUSE as a grade 5-6 elective class, and only one incorporated FUSE into grade 5-6 science.

These differences in the processes and outcomes of translation reflect larger economic and cultural-historical differences between the two contexts. For example, Marvel County schools were reliant on external grant funding, reflective of the capitalist economic system in the U.S. and the inequitable way in which public educational resources are distributed. In contrast, in Helsinki, public funding for programming and materials was assured, but it depended on centralized distribution systems that moved slowly and had to balance multiple demands. The way in which equity was conceptualized and mobilized differently in the two countries was also reflective of cultural differences. In Marvel County, a diverse and majority low-income student population spurred an interest in programming that equitably engaged diverse students. In Helsinki, equity focused more on ensuring equitable distribution of technology across schools. Finally, in Finland, a country with a long and rich tradition of craft education, the interessement for FUSE was integrating digitalization into this craft tradition, whereas, in the U.S., where there has long been a push for technology in schools, the interessement was hands-on STEAM.

Our analysis has implications for understanding the spread of educational innovations broadly and specifically for innovations like FUSE. For example, as a STEAM program, FUSE is heavily dependent on technology, physical materials, and dedicated physical spaces. Therefore, the actors needed to implement it successfully were different from those for a traditional text-based curriculum (and may better reflect the future of educational innovations). FUSE activities also make connections to the work of industry professionals. This bent invited in Stark Industries, and it poses the question of the comparative advantages and disadvantages of external industry partners becoming more prominent actors in the spread of future educational innovations.

Altogether, our results underscore the importance of conceptualizing spread as an active, in vivo process in which enrolled actors—including the innovation itself and the adopting educational system—need to be seen as complex entities nested in and constituted by already existing and changing networks. In line with work on the spread of the Fifth Dimension (Cole et al., 2016), our analysis indicates that the spread of FUSE resulted from active efforts by various actors, both expected and unexpected. However, by following implementation processes as they happened, we demonstrated that some actors' roles changed over time, and some actors worked for and against the spread of FUSE. Ambivalence was created by the spread process and needed to be managed as part of it (cf. Fenwick, 2011). What this highlights for future spread studies is the need to remain open and responsive to changing circumstances. While the specifics of every future spread process will be endemic to and emblematic of the innovation and the adopting system(s) in question, what can be learned from our study is that existing network ties will need attention and maintenance while the innovation spreads. In this sense, our comparative case study offers a prototypical narrative (Nissen, 2015) that embodies the concreteness of lived practices and espoused theoretical perspectives in ways that can help researchers and designers see innovations in a new light.

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Representations of Computational Thinking in Policy Documents in an Educational Context: The Cases of Denmark, Finland, and Norway

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Abstract: Nordic countries have recently introduced computational thinking (CT) into school curricula. In this paper, we address the question: "Which key understandings of computational thinking are presented in Danish, Finnish, and Norwegian policy documents for primary and lower secondary education?" This study analyzes and compares the policy documents by using a combination of social network analysis (SNA) to obtain an overview of the whole dataset, and qualitative analysis to elaborate on some specific elements in the policy documents. Importantly, we find that: (1) all three policy documents focus on interpreting CT as both a problem-solving process and related to programming processes, and (2) how CT is written up in the policy documents reflects the line of thought concerning the extent to which CT is an integrated part of the course subjects in education.

Introduction

In recent years, digital transformation has become an indispensable part of society and is expected to be fostered in schools to better prepare students for their future lives. Along with digital transformation, the concept of computational thinking (CT) has become a frequently mentioned concept (Lenke & Tenberge, 2022). The term CT can be considered a relatively novel concept (Merino-Armero et al., 2022). CT was first introduced by Papert (1980), who claimed that when a child is given a computer, their learning processes and intellectual structures are strengthened. According to Wing (2006), who is often credited with reigniting interest in CT education, CT is defined as solving problems, understanding human behavior, and devising programs with the help of the core concepts of computer science. Since then, CT has been defined differently by various scholars. For example, Barr and Stephenson (2011) understood CT as a problem-solving skill that involves certain training, such as perseverance and confidence while facing a specific problem, whereas Zhang and Nouri (2019) captured CT as a 21st-century skill that future generations should develop.

CT is a concept that is both widely discussed and difficult to define (Psycharis, 2018; Tedre et al., 2021), and there is no one agreed-upon definition of CT (Shute et al., 2017). Therefore, researchers generally focus on the basic components of CT (Juškevičienė, 2020). Many countries include CT in their education policies and curricula (Hsu et al., 2019; Merino-Armero et al., 2022; Swaid, 2015). Scandinavian countries include and apply CT in their curricula in different ways (Bocconi et al., 2018). For example, in 2016, Finland, one of the first European Union countries to do so, integrated programming and CT into the "National Core Curriculum for Basic Education 2014" as a skill that should be taught to students starting from the first year of school (1st grade) (Finnish National Board of Education [FNBE], 2014). Similarly, Norway integrated CT and programming into the curriculum in mathematics, natural sciences, and arts and crafts, effective autumn of 2020. In Denmark, CT is integrated into the curriculum at the primary and secondary levels (K-9) (Bocconi et al., 2018). Furthermore, in Denmark CT was a key part of a three-year pilot program with technology comprehension that took place in 46 schools in the years 2018–2021 (Ministry of Children and Education, 2022). Despite the integration into several curricula, understanding the meaning of CT remains challenging for teachers, teacher educators, and researchers (Lee et al. 2020). Thus, we address the following research question: Which key understandings of computational thinking are presented in Danish, Finnish, and Norwegian policy documents for primary and lower secondary education?

Computational thinking in STEAM education

Science, technology, engineering, and mathematics (STEM) education has become renowned in educational studies, since it is an interdisciplinary approach (Liliawati et al., 2018; Tan et al., 2021) aimed at contributing to the improvement of students' skills such as problem-solving, creative thinking, questioning, and critical thinking (Psycharis, 2018). In STEAM, the art discipline is integrated into STEM disciplines to increase efficiency in STEM education (Tan et al., 2021) and add an aesthetic and authentic dimension to STEM (Bequette & Bequette, 2012). There is a close relationship between STEAM disciplines and CT. STEAM disciplines also aim to provide individuals with skills such as problem-solving, debugging, and sharing their ideas with others (Juškevičienė, 2020). Several researchers have emphasized the need to train students to acquire CT skills and use them (Barr & Stephenson, 2011; Park & Park, 2018). Moreover, researchers argue that CT should be taught by integrating it with an interdisciplinary approach, such as STEAM (Psycharis, 2018). Through STEAM education, students are expected to learn certain concepts in a meaningful way and to use these concepts to solve problems (Park & Park, 2018). Through STEAM education, students are exposed to many problem-solving activities that contribute to the development of students' CT (Charlton & Luckin, 2012). Beyond using technology, CT occurs while solving complex problems (McClelland & Grata, 2018). Thus, CT is an integral part of STEAM (Dolgopolovas & Dagienė, 2021).

Studies related to CT and policy documents

CT has been recognized as an important issue in policy and curriculum documents in various countries and has been recognized as a key competence (Voogt et al., 2015) and included in several transnational policy initiatives (McGarr et al., 2021). Robertson (2005) highlighted the demand for schools to respond to the global knowledge economy. Hsu et al. (2019) examined CT educational policy, concluding that CT involves diverse terminology, and its current status is diversified across the globe. The authors further highlighted four development trends that arise: collaboration and partnerships across sectors and nations, arguments presenting a broad perspective and citing common themes, a redefinition of digital competence, and an accentuation of expanding access and interest. Hsu et al. (2019) found that although a term that refers to "computational thinking" is used in policy documents and curricula, it is not used by others or is used rarely when compared to other terms. For example, in the Nordic context, "algorithmic thinking" is the CT term used in Finland and Norway (Hsu et al., 2019).

Methods and case design

This study adopted social network analysis (SNA) (Scott, 2000) as a research approach. Prior to conducting the data analysis, two steps were taken. First, all three countries participated in the data analysis, which ensured contextual understanding. Thus, we were conscious of the challenges inherent in comparative interpretation (Phillips & Ochs, 2004). Second, to increase the validity of the process, a minimum of two researchers analyzed each policy document from the respective country.

Methods for collecting data

Relevant policy documents from Finland, Denmark, and Norway were accessed through government repositories. In Finland, strategic education aims are described in national-level curriculum materials and government programs. The national-level curriculum is revised, on average, every 10 years. Consequently, two documents from Finland were included in this study. One of these documents is the National Core Curriculum for Basic Education 2014 and the other is the current Government Programme 2015. The Finnish documents were accessed through two archives; National Core Curriculum for Basic Education 2014 was accessed from the "Finnish National Agency for Education" website https://www.oph.fi/en and "Government Programme 2015" website https://vnk.fi/en/government-programme.The Danish documents were obtained through searches in two governmental databases: the Danish Ministry of Higher Education and Science at ufm.dk and the Ministry of Children and Education at buvm.dk. The Norwegian documents were accessed through two repositories: the government.no and the Directorate for Education and Training websites. Only documents related to education were extracted, and the included documents focused on compulsory education and primary and lower secondary education.

Screening policy documents with a set of predefined CT keywords

The relevant policy documents were screened using a set of predefined CT keywords. Shute et al. (2017) defined CT as consisting of the following components: *decomposition*, which is about the process of breaking a complex problem into manageable smaller pieces; *abstraction*, which is about the ability to extract the essentials of a complex problem; designing logical *algorithms* and ordering them to solve the problem; *debugging*, which is about the process of finding and resolving errors; refining the process by performing *iterations* to achieve the ideal result; and *generalization*, which is about the ability to transfer CT skills to other problems and situations.

Taking Shute et al. (2017) as our point of departure as well as the source of country-specific CT terms, we used the following CT terms to screen the policy documents: digitalization, algorithmic, problem-solving, programming, automation, identifying patterns, computational thinking, computer science, modeling, coding, and technological comprehension.

Methods for analyzing the data

SNA was used to analyze the most relevant policy documents in teacher education in Finland, Norway, and Denmark. Scott (2000) defined SNA as a set of techniques and operations that analyze the relational aspects of a network by utilizing algorithms and computational techniques. Since SNA makes it possible to analyze and compare a considerable set of data by evaluating the social relationships in a network by conceptualizing individuals or groups as nodes and their connections as ties and by scrutinizing these connections as mathematical or visual patterns, it was considered a suitable method (Scott, 2000). We applied SNA measurement degree centrality to calculate which policy documents had the highest frequency of CT keywords and, as a result, identified the most central policy documents regarding the use of CT keywords. Degree centrality is defined as the number of ties attached to a node (Scott, 2000). In our case, this means the number of times the CT keywords appear in the policy documents. Gephi, a software program for conducting SNA analysis (Gephi, 2022), was used to create and visualize the sociograms of the different countries (Norway, Denmark, and Finland) (Figures 1, 2, and 3) and their policy documents and the use of CT keywords in them. A sociogram is a visualization of SNA analysis, which consists of nodes representing actors and lines to show ties or relations (Hanneman & Riddle, 2005). SNA provided us with useful information about the most relevant policy documents and CT keywords connected to them; the analysis did not reveal information about the qualitative content in the documents. To address this limitation, we also take on a qualitative perspective by analyzing the qualitative data extracts illustrating the use of CT keywords in the policy documents.

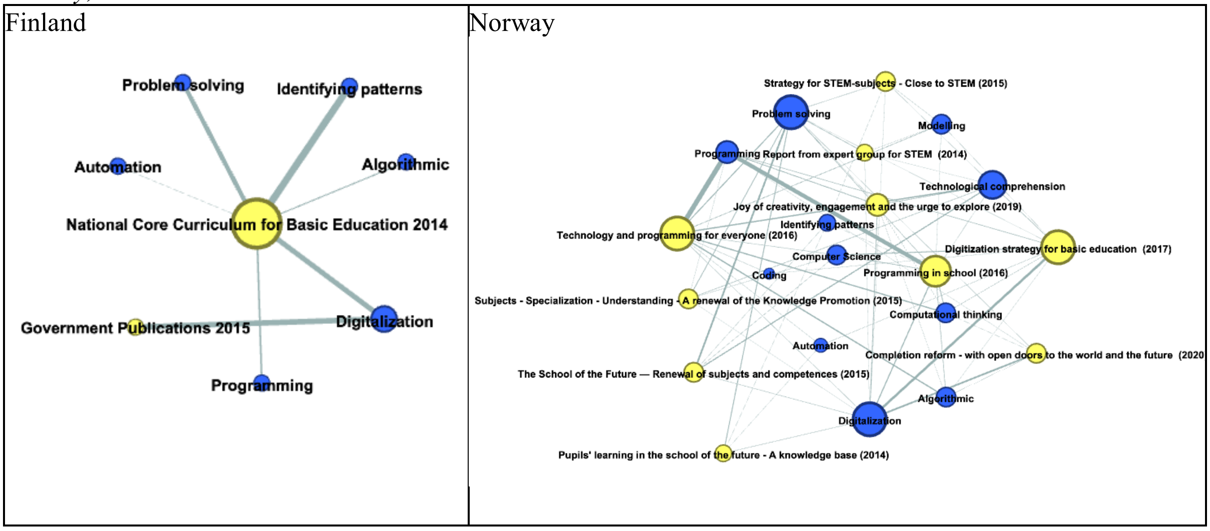
Results

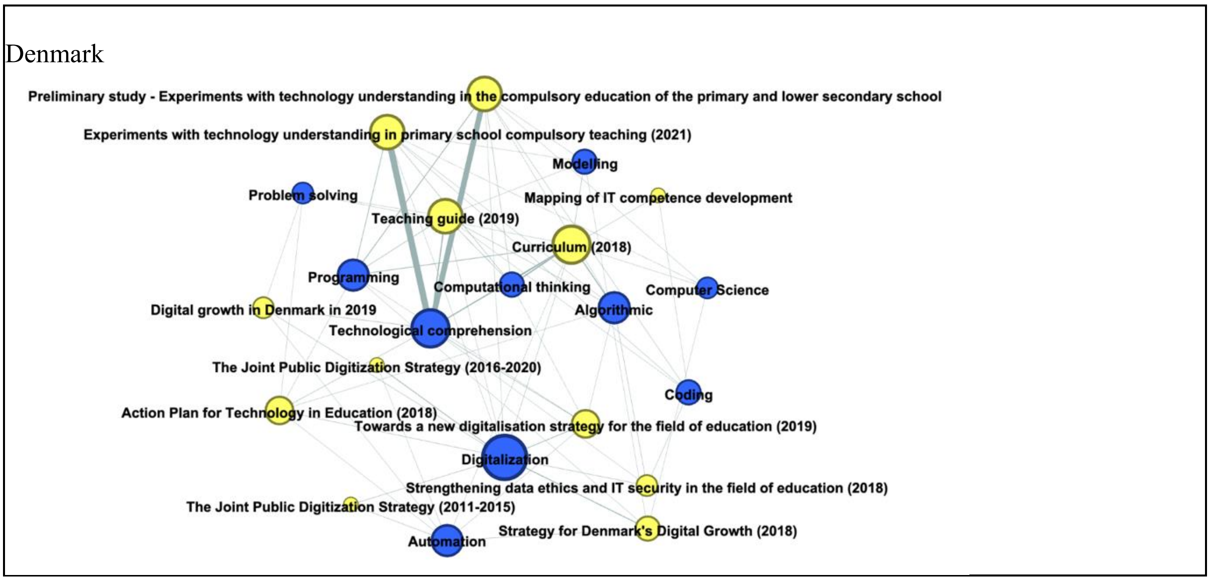
Social network analysis of policy documents in Finland, Norway, and Denmark

Below, in Figure 1, we present three sociograms that visualize the SNA results, reflecting Finland, Norway, and Denmark. The yellow nodes visualize the policy documents, and the blue nodes visualize the CT keywords. The SNA centrality degree measurement was computed for both the policy documents (yellow nodes) and the respective CT keywords (blue nodes). As such, the larger size of a node reflects a larger degree of centrality. A thicker tie indicates a higher frequency of the use of the CT keyword in the policy document, as the size of the ties also provides information on degree centrality. Figure 1 presents a visualization and comparison of the policy documents.

Figure 1

An overview of the policy documents (yellow nodes) and the related CT keywords (blue nodes) in Finland, Norway, and Denmark.





Denmark

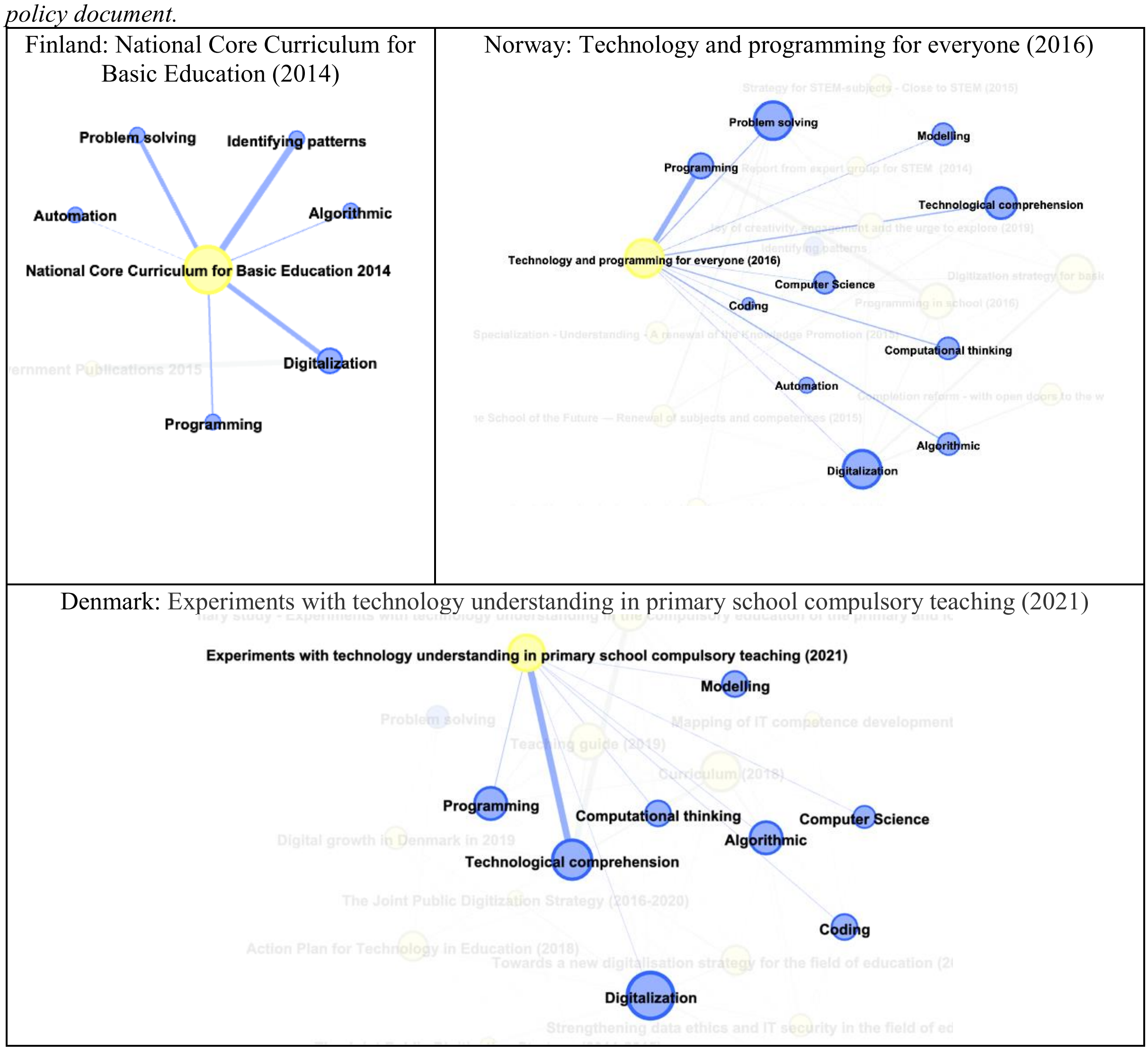
Analyzing the policy documents: In Finland, the sociogram shows that there are mainly two policy documents, with the "National Core Curriculum for Basic Education 2014" being the most relevant document from a CT perspective, as reflected by the size of its yellow node being the largest. The positioning of the node in the center of the sociogram reveals that this document often refers to and uses several CT keywords. However, in Norway and Denmark, the landscape is quite different, where there are multiple policy documents that relate to CT in different ways. In Norwegian policy documents, the most central policy document using CT keywords is "Technology and programming for everyone." However, the policy documents "Digitalization strategy for basic education (2017)," "Programming in school" (2016), and "Joy of creativity and the urge to explore" are central according to the degree of centrality (reflected in the size of the node). The most central policy document in Denmark is "Experiments with technology understanding in primary school compulsory teaching (2021)," since it has the largest degree of centrality (reflected in the largest yellow node). However, as the nodes visualize with their size, "Curriculum (2018)," "Preliminary study – Experiments with technology understanding in the compulsory education of the primary and lower secondary school," and "Teaching guide" are also among the top 5 most relevant policy documents using key CT words.

Analyzing the use of CT keywords in relation to the policy documents: In the Finnish sociogram, we found that the CT keywords *digitalization* and *automation* are the ones with the highest degree of centrality (reflected in the blue nodes with the largest size), which means that these keywords are most used in the policy document in connection to CT. By contrast, it is interesting to observe that *computational thinking* and *algorithmic thinking* as explicit keywords are not present in the policy document at all. In the Norwegian sociogram, the top three most used CT keywords across the policy documents are *problem-solving*, *digitalization*, and *technological comprehension*. The CT keywords *programming* and *computational thinking* are also central. In the Danish sociogram, the two most prominent keywords in the policy documents are *technology comprehension* and *digitalization*, whereas *identifying patterns* does not appear at all. To summarize, most keywords appear in policy documents across all three countries, with *digitalization* standing out as a prominent keyword in all three countries, setting an important context for the integration of CT in education. However, the sociogram also reveals significant differences: For instance, while *problem-solving* is a predominant keyword in the sociogram for Norway, it is far less central for the other two countries. Similarly, *computational thinking* as a keyword is markedly present in the Norwegian and Danish sociograms but does not appear at all in the Finnish case. Thus, the sociograms expose how the different countries apply different CT keywords in their policy documents, entailing different implementations and approaches to CT.

Exploring the understanding of the CT keywords in the policy documents

Based on the SNA analysis visualized in Figure 1, we selected the most central policy document in each country that had the largest degree of centrality. This document was used as a starting point for the qualitative analysis. Figure 2 below present an overview of the selected policy document from each country and the CT keywords that are connected to that policy document, as reflected in the sociograms in Figure 2. Furthermore, the two most relevant CT keywords from each policy document were selected. To contextualize the CT keywords, qualitative data extracts are presented together with their interpretations.

Figure 2
Sociograms reflecting the selected policy document from each country and the CT keywords connected to that policy document.



Finland: National Core Curriculum for Basic Education (2014)

Norway: Technology and programming for everyone (2016)

Denmark: Experiments with technology understanding in primary school compulsory teaching (2021)

A comparison of the sociograms in Figure 2 revealed a common denominator in the policy documents: CT keyword *programming* is among the top 3 most used CT keywords in the documents, which is reflected in the size of the nodes. The CT keyword *problem-solving* is also the most central node in the selected policy document in Finland and Norway, whereas it is not apparent at all in the Danish policy document. Although *digitalization* is a prevalent keyword in all the policy documents, it does not reveal much about how CT is understood and will therefore not be further discussed. However, a notable difference in the sociograms is in Denmark's policy document, in which *technological comprehension* stands out as a central node, which we further explored.

In the Finnish policy document, National Core Curriculum for Basic Education (2014), programming is mentioned as being integrated into the subjects: "As part of the studies of various subjects, programming is practiced." The document further expands this notion: "Students develop an understanding of in how the decisions taken by people have an effect on the path technology progress while working on programming." Programming is considered the way that "ordinary relationships are defined and objects are placed, classified and compared by the learners. By taking different perspectives, they practice analyzing mathematical situations. The learners become acquainted with the core features of programming by formulating and testing step-by-step instructions." We can also conclude that the policy document defines the reason for the relevance by stating that "the learners get the chance to have and share their practices with digital media and programming activities fitting their ages and the rationale being to inspire the learner to come up with as computer programs in graphic programming medium." In the policy document, problem-solving is described as "the guidance for the learners to develop their algorithmic thinking and skills in applying mathematics and programming in problem-solving," and it is explained as a process of "guidance for the learners to develop their reasoning and problem-solving skills." It is further expanded as the way "the learners are mentored to use information on their own and in interaction with others in terms of problem-solving, argumentation, reasoning, drawing of conclusions and invention." Together, these statements underscore the relationship between problem-solving and programming.

In the Norwegian document "Technology and programming for everyone" (2016), *programming* is defined as "breaking a given problem into a set of commands and then having a computer execute those commands." The document underlines that the rationale behind programming is for students to take control of technology and "gain insight into and experience with basic technological principles and digital technology - including programming." Programming can be viewed as both a problem-solving process and a technical process when using a computer to perform tasks. Problem-solving is highlighted as part of a key competence in digital technology, and an integral part of computational thinking: "Solving a problem by specifying a precise sequence of commands is called computational thinking or algorithmic problem-solving, and such a precise sequence of commands is called an algorithm." The notion of problem-solving as an integral part of CT is further elaborated as "transforming a general problem into a form that can be solved using programming." Programming in the Norwegian policy document is understood as the technical programming process when using a computer to perform tasks, whereas problem-solving is understood in relation to CT and programming.

The Danish policy document "Experiments with technology understanding in primary school compulsory teaching" (2021) is an assessment of the three-year pilot program in the years 2018–2021. Technological comprehension is mentioned as "an educative and creative subject in the school consisting of four competence areas: (1) digital empowerment, (2) digital design and design processes, (3) computational thinking, and (4) technological knowledge and skills." Thus, in Denmark, CT occurs in the context of this subject. The subject is displayed in two general approaches: one that is "creative and constructive (focus on design and skills), and the other that is critical and analytical (focus on empowerment and thinking). The overarching purpose of the subject is described in the document as enabling students to become "active, critical and democratic citizens in a digitalized society," again displaying the two general approaches. CT is explicitly employed as a key concept in the document. It is characterized as being about "analysis, modeling, and the structuring of data and data processes." Thus, CT is understood as a predominantly *analytical* competence, and not a creative and constructive one. Accordingly, CT does not include programming, coding, debugging, etc. in the Danish case. Although it is not part of CT, programming is nonetheless included in the subject of technological comprehension as part of "technological knowledge and skills." Here, it is linked to the creative approach, as programming "makes it possible for students to influence what they want to create" and "means the freedom to determine in which direction the students want to work."

Discussion

Our comparison of the policy documents from the three Nordic countries and their relations to CT keywords (Figures 1 and 2) revealed two main findings: (1) All three policy documents have a focus on interpreting CT as both a problem-solving process and related to programming processes. (2) How CT is written up in the policy documents reflects the line of thought concerning the extent to which CT is an integrated part of the course subjects in education.

CT as both problem-solving and a programming process. One common denominator from the analysis of the sociograms in Figures 1 and 2 is that CT is portrayed in all three policy documents as both a problem-solving process and a programming process. However, by focusing on the qualitative data extracts from the policy document in Denmark, we observed that the picture is more nuanced. Programming is not part of CT in the Danish context, as CT and programming are viewed as two separate competences, both elements of the overarching subject of *technological comprehension*. Lee et al. (2020) stressed that although programming and coding may be considered part of CT, it would be incorrect to restrict CT to computer science, since it is present in a broad range of professional fields. Thus, the separation of CT and programming in Danish policy documents seems to take one step further, emphasizing the difference between the general, predominantly analytical thinking processes of CT and the creative and constructive skills of programming. Similarly, although there are no instances of *problem-solving* in the Danish policy documents, this CT keyword is part of the overarching subject *technological comprehension* and thus related to, but nevertheless separated from, CT. In Norway and Finland, the policy documents reveal that problem-solving and programming can be considered related.

CT as an integrated part of learning subjects. How CT is presented in the policy documents reflects the reasoning of the policy documents concerning the extent to which CT is an integrated part of the course subjects in education. In Norway, CT is viewed as fully integrated in the subjects of math, science, music, and arts and crafts. In Denmark, CT is part of the wider subject of "Technology comprehension", which in the pilot program was taught both as a separate subject and as an integrated part of the subjects Danish, math, visual arts, natural sciences/technology, craft and design, physics/chemistry and social studies. In Finland, CT is fully integrated into subjects. The analysis of the qualitative text extracts from the policy documents in Norway and Finland showed that they both mentioned CT as a keyword. In the Norwegian policy document (Figure 2), CT is mentioned in connection with programming as part of specific course subjects, which is similar in Finland. However, Denmark differs, as it has an explicit focus on CT (supported by the visible node in Figure 2). Denmark has its own subject, *technological comprehension*, which focuses on CT. This supports the finding that CT in the Nordic countries is an integrated part of learning subjects: (a) In Norway, CT is viewed as fully integrated into the subjects of math, science, music, and arts and crafts; (b) Finland has fully integrated CT into subjects; and (c) Denmark considers CT as part of the wider subject "Technology comprehension".

Conclusion and implications

In this study, we explored key understandings of CT as presented in Finnish, Norwegian, and Danish policy documents for primary and secondary education. By conducting an SNA analysis of selected policy documents retrieved using CT keywords, we found that the understanding of CT is two-fold in these countries: 1) CT as both a problem-solving and programming process, and 2) CT as an integrated part of learning subjects. Integrating CT and programming as part of learning subjects enforces new demands on teachers in classrooms, as many of them have only some or no experience with CT and, especially, programming from their own schooling or teacher education. Some of the skills needed have previously been associated with computer science, and often these skills have been left to teachers of computer science to teach. However, the new changes imply a new focus on teachers' competencies, and we urge teacher educators to strengthen continuing professional development programs, enhance the focus on CT in teacher education, and facilitate support for communities of CT practice involving teachers, teacher educators, and researchers.

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Preparing Collaborative Future Learning with Representational-Competency Supports

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Abstract: Collaboration in many STEM domains centers around the collaborative construction and interpretation of visuals. Thus, to become effective practitioners in the STEM disciplines, students need representational competencies: the ability to appropriately use and understand visuals that depict scientific concepts. Although visuals are often used in collaborative contexts, prior research on representational-competency supports has mostly focused on individual learning. To address this limitation, we conducted an experiment with 134 undergraduates who worked collaboratively in 56 small student groups as part of an engineering class. Students were randomly assigned to work with different types of representational-competency supports. The main outcome measure of interest were students' learning gains from a subsequent, novel collaborative learning activity. We found that representational-competency supports can prepare student groups to efficiently learn from novel instructional materials.

Introduction

Many professional practices in STEM domains are collaborative in nature. Indeed, STEM instruction is moving toward active learning, where students are encouraged to collaborate during learning (Freeman et al., 2014). Such collaborative practices often center around joint interpretation and construction of visual representations (Johri et al., 2013) because visual representations can help establish a common ground and make divergent views apparent (Nathan et al., 2013). Hence, collaborative STEM instruction often uses visual representations.

However, research on learning with visual representations shows that students may have difficulties interpreting visual representations (Ainsworth, 2006; Rau, 2017). Students need *representational competencies:* the ability to understand how visual representations depict relevant scientific concepts and use those visuals appropriately (diSessa, 2004; Kozma & Russell, 2005). Indeed, previous research on representational-competency supports found that supporting students' competencies enhanced students' content knowledge both in individual and collaborative learning settings (Berthold et al., 2009; Kellman & Massey, 2013).

However, prior research on the effectiveness of representational-competency supports has two limitations. First, prior research has examined only short-term effects of representational-competency supports. For example, Rau et al. (2017) tested whether adding support for representational competencies to instructional activities enhances students' learning from those activities. It is unclear whether representational-competency supports also enhance students' learning from future instructional activities where students encounter novel visuals they have not seen before. A second limitation is that prior research has mostly focused on individual learning settings even though, as mentioned, visuals are commonly used collaboratively (Rho et al., 2022). To our knowledge, only one study systematically tested the effects of representational-competency supports in a collaborative setting, but focusing on short-term effects on chemistry learning (Rau et al., 2017). In sum, it is unclear whether representational-competency supports enhance *future collaborative learning*. The goal of this paper is to address these limitations by investigating whether representational-competency supports enhance students' collaborative learning from future instructional activities.

Additionally, previous research suggests that spatial skills may affect students' learning with visual representations (Stieff et al., 2020). Visual representations typically depict visuospatial concepts. Students draw on spatial skills when mentally generating, retaining, and manipulating information depicted in visual representations. Students with low spatial skills have fewer cognitive resources to store and process such visuospatial information (Hegarty & Waller, 2005), making them more likely to struggle when learning with visual representations (Kozhevnikov et al., 2007). Hence, a further goal of this paper is to investigate whether representational-competency supports differentially affect students with different levels of spatial skills.

Literature review

Representation competencies

Instruction in STEM domains commonly uses visuals because they can help students understand content knowledge by making abstract concepts accessible (Ainsworth, 2006). However, previous research also showed that such visuals can impede students' learning if students lack representational competencies. Specifically, students need two types of competencies; sense-making competencies and perceptual fluency (Rau, 2017).

First, sense-making competencies refer to explicit, analytical knowledge that allows students to explain how representational features map to concepts (Bodemer & Faust, 2006) and to connect multiple representations depicting the same concepts (Chang et al., 2021). Since students acquire sense-making competencies by verbally explaining how representational features map to concepts, instructional supports for these competencies ask students to explain relationships between representational features and concepts (Joo et al., 2021). Students should receive support to focus on explaining structurally relevant relationships between the representations instead of surface similarities (Ainsworth, 2006). Second, perceptual fluency refers to implicit, automatic knowledge that allows students to efficiently extract meaning from representations and to quickly translate across representations (Kellman & Massey, 2013). Students acquire perceptual fluency via nonverbal and inductive processes (Koedinger et al., 2012). Consequently, instructional supports for these competencies expose students to a variety of representations while asking them to quickly identify relevant information (Kellman & Massey, 2013).

So far, research has established that these representational-competency supports enhance students' acquisition of content knowledge in individual learning settings (e.g., Rau et al., 2017). However, previous research has focused less on the effectiveness of representational-competency supports in *collaborative* learning settings. Thus, this study investigates whether representational-competency supports help students' acquisition of content knowledge in a collaborative learning setting.

Role of representation competencies in collaborative learning

Collaborative instruction in STEM often uses visual representations because they can provide common ground for students' discussions (Nathan et al., 2011). Effective collaboration builds on representational competencies. First, collaboration involves sense making of visual representations. When students collaborate, they often verbally share their thoughts about visuals and critically discuss different interpretations of the visual (Kozma & Russell, 2005). Sense-making competencies enable students to verbally explain how visuals show information about problems (Johri et al., 2013). Therefore, sense-making competencies may enhance collaborative learning. Indeed, previous research on sense-making competencies found that providing adaptive collaboration scripts as a supportive tool for sense-making competencies improved students' benefit from a collaborative learning session (Rau et al., 2017). Second, collaboration involves perceptual fluency. When collaborating, students often refer to visual representations (Singer, 2017). This requires students to be perceptually fluent at extracting information from the visuals while also following along with the conversation. Indeed, previous research found that supporting perceptual fluency can enhance collaborative learning (Rau & Patel, 2018).

Thus far, the few studies that examined effects of representational-competency supports on collaborative learning have focused on students' immediate learning outcomes from instruction that contained the supports. However, students may not always have access to representational-competency supports. It remains unknown whether representational-competency supports enhance students' future learning from later instruction when students no longer have access to representational-competency supports. To address this question, this paper investigates whether representational-competency supports prepare students for *future* collaborative learning.

Preparation for future learning (PFL)

Students build on prior knowledge when learning novel concepts (Singley & Anderson, 1985). Building on this finding, research on preparation for future learning (PFL) examines how instruction can support students to adapt prior knowledge or skills in ways that support their learning of novel concepts (Schwartz et al., 2005). While some research has used the PFL framework to guide specific types of instructional designs, we adopt it as a research framework for investigating whether a given type of instructional design is beneficial beyond its duration (as suggested, for instance, by Schwartz et al., 2005). Although prior research shows that representational-competency supports can enhance students' ability to solve problems they have not encountered before (e.g., using a traditional transfer paradigm; Cromley et al., 2013), little research has investigated whether representational-competency supports prepare students' future learning from novel instructional materials they have not encountered before. To our knowledge, only one study showed that support for sense-making competencies and perceptual fluency enhanced students' future learning from novel instructional materials (Rho et al., 2022). However, this study focused on learning in an individual context, even though, as argued above, students often learn with visual representations in collaborate contexts. Thus, it is unknown whether representational-competency supports prepare students for future collaborative learning.

Collaborative learning may naturally promote discussion among students, which helps students to understand novel visuals in instructional materials (Strickland et al., 2010). Consequently, students may not need extra support for representational competencies in future collaborative learning. However, when students work with novel instructional materials they have never encountered before, students may have difficulties because they may not know which visual features they should focus on. Representational-competency supports might alleviate these difficulties, as documented in the context of individual learning (Rau et al., 2017). Furthermore, as argued above, representational-competency supports enhance students' ability to engage in productive collaborative practices with visual representations. Such enhanced collaborative practices may, in turn, result in higher learning outcomes. Therefore, in this study, we investigated the effect of representational-competency supports on future *collaborative* learning.

Spatial skills

Because many concepts in STEM domains are visuospatial, instruction frequently uses visual representations to illustrate concepts (Ainsworth, 2006). To understand concepts depicted in visual representations, students draw on spatial skills that allow students to mentally retain, retrieve, and transform the given visuals (Kozhevnikov et al., 2007; Uttal et al., 2013). Cognitive research on spatial skills explains individual differences in spatial skills in terms of differences in the amount of working memory consumed to store and manipulate visuospatial information (Hegarty & Waller, 2005; Stieff et al., 2020). By definition, low-spatial-skill students require more working memory resources to store and manipulate visuospatial information compared to high-spatial-skill students. Thus, low-spatial-skill students may lose such spatial information while mentally manipulating the given visuals, requiring them to revisit the visuals to find and extract visuospatial information again (Hegarty & Waller, 2005). As a result, low-spatial-skill students are more likely to experience cognitive overload, which can impede their learning (Höffler, 2010). By equipping students with the skills to extract information from visual representations, representational-competency supports might be especially effective for students with low spatial skills.

However, our prior research found that the effectiveness of representational-competency supports depended on students' spatial skills (Rho et al., 2022). While all students benefited from support for perceptual fluency, support for sense-making competencies was effective only for students with high spatial skills. In contrast, support for sense-making competencies was ineffective for students with low spatial skills did not. Our findings suggest that low-spatial-skill students were overwhelmed when working with supports for sense-making competencies. This is, of course, an undesirable finding because it disadvantages students who are known to experience difficulties in STEM domains. However, considering that collaborative learning might give low-spatial-skill students opportunities to discuss their difficulties and receive help from peers, it is possible that the impact of spatial skills on students' benefit from representational-competency supports differs in a collaborative learning setting. Therefore, we tested whether students' level of spatial skills moderates the effect of supports.

Research questions

Our review of prior research reveals a gap in our understanding of how representational-competency supports affect students' learning from future instructional activities, especially in collaborative learning contexts. Therefore, we investigate the following research questions (RQ):

RQ1. Do representational-competency supports prepare students for future collaborative learning with a novel visual representation?

Further, given that spatial skills may affect students' learning with visual representations, we investigate:

RQ2. Do spatial skills moderate the effect of representational-competency supports on future learning?

Lastly, because little research explored representational-competency supports in a collaborative learning setting, we investigate:

RQ3. How do students experience collaboratively working on representational-competency supports?

Methods

Participants

We conducted the experiment as part of an active learning electrical engineering course at a university in the Midwestern U.S. All 184 students who were enrolled in the course participated in the experiment. The course involved twice 75-minute course meetings per week. Our experiment took place in the first three weeks of the course. Students worked collaboratively in groups of two or three. Student groups were formed prior to the intervention and remained intact for the duration of the experiment.

Representational-competency supports

Representational-competency supports were implemented in an educational technology for electrical engineering undergraduates: Signals Tutor. Signals Tutor offers activities where students learn about sinusoids by manipulating interactive time-domain and phasor graphs. Signals Tutor provides three types of activities, which differ in terms of whether and which types of representational competencies they support.

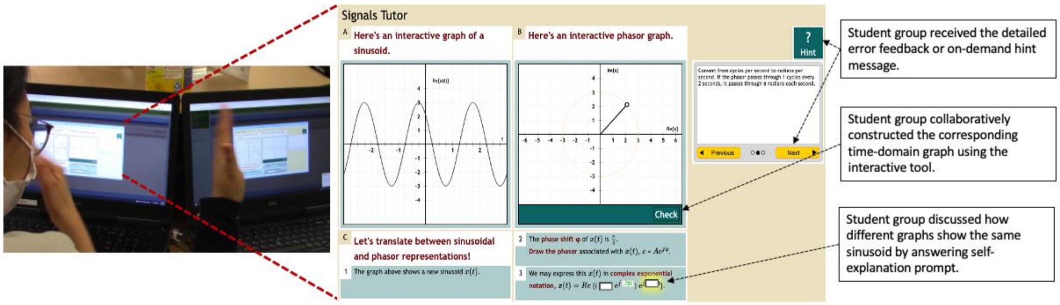
Regular activities

Regular activities do not support specific representational competencies. Following the design of regular instructional activities, they ask students to use time-domain or phasor graphs to answer questions about sinusoids. Regular activities provide detailed feedback and on-demand hints related to the concepts covered in the activities.

Sense activities

Sense activities support sense-making competencies. Prior to working on sense activities, student groups see a brief video instructing them to actively participate in a discussion and come to an agreement before submitting their answers. As shown in Figure 1, students receive step-by-step guidance to build a phasor graph that represents the sinusoid given in a time-domain graph (or vice versa). Then, sense activities ask student groups to verbally explain how specific features of a phasor graph can be translated into a time-domain graph. For example, in Figure 1, the student group is prompted to reflect on how the phase shift shown in the given time-domain graph can be translated to the vector's rotation in the phasor graph. Similar to regular activities, sense activities provide detailed feedback and on-demand hints to guide students.

Figure 1
Example of student group collaboratively working on a sense activity



Here's an interactive graph of a sinusoid.

Here's an interactive phasor graph.

Convert from cycles per second to radians per second. If the phasor passes through 1 cycles every 2 seconds, it passes through π radians each second.

Let's translate between sinusoidal and phasor representations!

1 The graph above shows a new sinusoid $x(t)$.

2 The phase shift φ of $x(t)$ is $\frac{\pi}{4}$. Draw the phasor associated with $x(t)$, $c = Ae^{j\varphi}$.

3 We may express this $x(t)$ in complex exponential notation, $x(t) = Re\{(\square e^{j\,.785})\, e^{j\square}\}$.

Student group received the detailed error feedback or on-demand hint message.

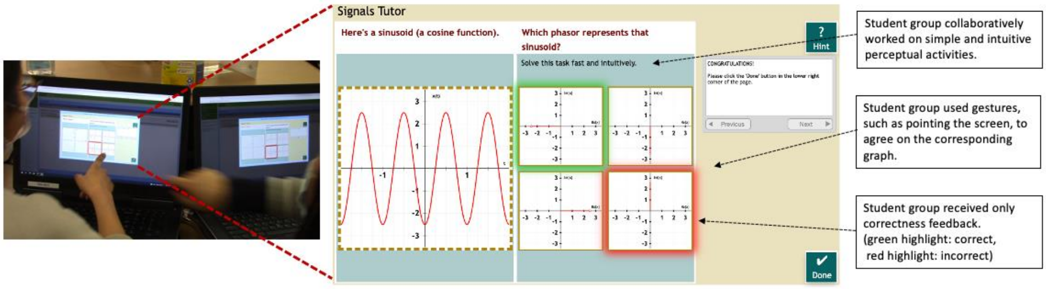
Student group collaboratively constructed the corresponding time-domain graph using the interactive tool.

Student group discussed how different graphs show the same sinusoid by answering self-explanation prompt.

Perceptual activities

Perceptual activities support perceptual fluency. Prior to working on these activities, student groups see a brief video instructing them on perceptual learning. They are instructed to solve the activities quickly and intuitively. Further, the video asks students to collaborate using nonverbal communication, such as pointing gestures, because verbal communication interferes with perceptual learning processes (Schooler et al., 1997). As shown in Figure 2, perceptual activities ask student groups to find one out of four time-domain graphs which represent the same sinusoid depicted in the given phasor graph (or vice versa). The four choice options are designed to direct students' attention to important visual features. Perceptual activities only provide correctness feedback so that students focus on perceptual processing (Kellman & Massey, 2013).

Figure 2
Student group collaboratively working on a perceptual activity



Here's a sinusoid (a cosine function).

Which phasor represents that sinusoid?

Solve this task fast and intuitively.

CONGRATULATIONS!

Please click the 'Done' button in the lower right corner of the page.

Student group collaboratively worked on simple and intuitive perceptual activities.

Student group used gestures, such as pointing the screen, to agree on the corresponding graph.

Student group received only correctness feedback.
(green highlight: correct,
red highlight: incorrect)

Experimental design

Student groups were randomly assigned to one of four conditions resulting from a 2 (sense activities: yes/no) x 2 (perceptual activities: yes/no) experimental design. To control for time on task across conditions, we ensured that all conditions solved the same number of problem-solving steps.

The sequence of instructional activities was organized as follows across five Signals Tutor units. Unit 1 was identical across conditions because it introduced to time-domain and phasor graphs. Unit 2 covered time-domain graphs and their corresponding equations. Because time-domain graphs were the only type of visual used in this unit, Unit 2 did not provide sense activities. However, Unit 2 provided perceptual activities where students practiced quick translation between equations and visuals. Units 3 and 4 involved both time-domain and phasor graphs. Thus, each group received representational-competency supports according to the assigned condition.

Finally, Unit 5 provided regular activities on a novel concept, phasor addition, which is depicted in a novel visual, a vector addition graph. Working on activities about phasor addition required student groups to apply concepts and representational competencies they practiced in previous Units 2-4.

Measures and analyses

To investigate the effect of representational-competency supports on students' future collaborative learning (RQ1), we assessed learning gains with pretests and posttests for each unit (except for the introductory Unit 1). The tests for Units 2-4 served as an implementation check. Our main outcome of interest were the tests for Unit 5, which assessed students' learning from future instruction that did not offer representational-competency supports. Students solved all tests individually. We computed learning gains through accuracy and efficiency scores. Accuracy scores were computed as the percentage of correct answers. Efficiency scores were computed to take account how long it took students to achieve correct answer, following as: efficiency = (z-score of accuracy – z-score of duration) / $\sqrt{2}$, (Van Gog & Paas, 2008). We used statistical analyses to compare students' learning gains scores (i.e., efficiency and accuracy scores) across four conditions. To investigate the moderation effect of spatial skills (RQ2), we assessed spatial skills with the Vandenberg & Kuse mental rotation test (Peters et al., 1995), which is prevalent measure of spatial skills in engineering education. We used statistical analyses to see students' level of spatial skills moderate the effect of representations-competency supports across conditions. To investigate how students experience collaborative work on representational-competency support activities (RQ3), we qualitatively examined interview responses for themes that emerged across dyads.

Procedure

On the first course meeting day, students were briefly informed about the study and instructed to collaborate on problems in Signals Tutor. In the following course meeting days, students completed the instructional activities according to their experimental condition, with Unit 2 being assigned in class in the second course meeting day, Unit 3 in the third meeting day, Unit 4 as homework, and Unit 5 in the fourth meeting day. Students worked collaboratively on Units 2, 3, and 5. We also conducted a semi-structured interview asking students to reflect on their collaboration experiences with peers in Unit 2, 3, and 5. We randomly chose one student from each condition. The interviewers asked questions about what was difficult and what was helpful and, how a group collaborated.

Results

Student groups were excluded from analysis if one of the group members absent from any test, failed to complete the instructional activities, or dropped the course. As a result, a total of N = 134 students and 56 small groups were included in the data set (control: n = 37;15 groups, sense: n = 39; 16 groups, perceptual: n = 30; 12 groups, and sense-perceptual: n = 28; 13 groups). We report p. η2 as a measure of effect size, p. $\eta^2 \geq 01$ being a small effect, p. $\eta^2 \geq .06$ being a medium effect, and p. $\eta^2 \geq .14$ being a large effect (Cohen, 1992). Table 1 shows the mean and standard deviation of efficiency scores for Units 2, 3 and 5, on which students collaboratively.

Table 1
Means and standard deviations (in parentheses) of efficiency scores for each unit

Unit	Test	Control	Sense	Perceptual	Sense-Perceptual
2	Pre	-0.197 (0.874)	0.106 (0.807)	-0.093 (0.761)	-0.559 (0.938)
	Post	0.231 (1.097)	0.426 (0.989)	0.514 (0.692)	0.320 (0.802)
3	Pre	-0.460 (0.866)	-0.225 (1.040)	-0.435 (1.048)	-0.276 (1.058)
	Post	0.419 (0.989)	0.178 (0.870)	0.957 (0.978)	0.506 (0.891)
5	Pre	-0.480 (0.720)	-0.238 (0.820)	-0.402 (0.993)	-0.088 (0.854)
	Post	0.086 (1.056)	0.727 (0.938)	0.620 (1.072)	0.928(0.914)

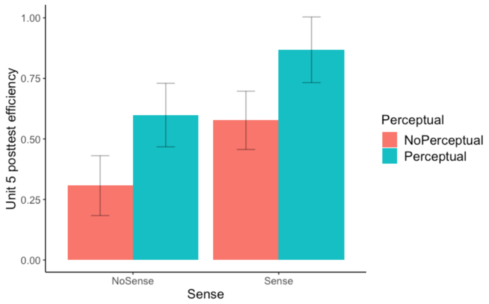
Effects on future collaborative learning

Following Cress (2008), we tested if adjustments were necessary for that fact that students were grouped together during learning with Signals Tutor. We calculated intraclass correlations (ICCs), which provided an estimate of how much clustering occurred due to factors such as group, TA, professors or sections. The ICCs score for our primary outcome variable, Unit 5 posttest scores, were very low (ICCs < .10). Therefore, adjustments for non-independence were not required. We investigated whether representational-competency supports prepare students future collaborative learning (RQ1) by conducting an ANCOVA with Unit 5 posttest as dependent measure, sense and perceptual factors as independent variables, and Unit 5 pretest and spatial skill as covariates. For the accuracy measure, we found no significant effects. For the efficiency measure, as shown in Figure 4a, we found that student groups working on perceptual activities showed significantly more efficient performance on the posttest than groups which did not work on perceptual activities, $F(1, 133) = 3.941$, $p = .049$, p. $\eta^2 = .030$. Similarly, student groups working on sense activities showed marginally more efficient performance on posttest than groups which did not, $F(1, 133) = 3.239$, $p = .074$, p. $\eta^2 = .024$.

To test whether students' level of spatial skills moderate the effect of representational-competency supports (RQ2), we tested for aptitude-treatment interactions of spatial skills with the sense and perceptual factors by adding these effects to the ANCOVA model described above. To be consistent with previous research on aptitude-treatment interaction, we did not categorize spatial skills into separate group, but instead modeled how sense and perceptual factors interacted with continuous variable of spatial skills. In Unit 5, we found no significant interaction between sense or perceptual factors and spatial skills ($p > .10$).

Figure 3

Student groups that worked on both sense and perceptual activities showed the higher efficiency on posttest.



Collaboration experiences

To understand how students experience collaboratively working on representational-competency supports activities in Signals Tutor, we examined students' collaborative experiences. We found that three themes emerged: confidence, comfort, and helpfulness.

First, with respect to *helpfulness*, students commented that they were able to cement their understanding through verbally explaining the concepts to her partner during collaboration. Similarly, another student commented that collaboration was helpful because they were able to explain each other about the confusing points during Unit 2: "we spoke out our thoughts and it was helpful because the parts I missed or got confused was the part he knew how to solve."

Second, regarding *confidence*, all students reported that collaborative working increase their confidence: "Collaboration gives me confidence, because when you think you know how to do the problem and you get the same answer as your partner, it shows that two brains are better than one." Collaborative working also released self-doubt: "Sometimes there's self-doubt, especially when answering a complicated question and having someone else agree with you makes you feel more confidence and feel like you understand the material better."

Lastly, regarding *comfort*, students reported that they become comfortable about working with their partners in Unit 5: "Yes, we got more comfortable with each other now, like, we are not strangers anymore so that helped." Students were able to find each one's strengths based on previous collaboration experiences in Units 2 and 3: "From the past experiences, we got to know each other.", which leads to more comfortable collaborative work on Unit 5: "We now kind of know who's explaining what, so I think that it got easier [in Unit 5]."

Discussion

This study investigated whether representational-competency supports enhance students' future collaborative learning (RQ1). Specifically, we provided sense and perceptual activities to student groups and tested whether these activities have an effect on students' learning of a novel concept with a novel visual in Unit 5. We found that student groups who worked on sense or perceptual activities showed higher learning efficiency in Unit 5 than student groups who did not receive these activities. These results extend previous findings about the effectiveness of representational-competency supports to collaborative learning. Further, our findings expand prior research by showing that representational-competency supports are an effective intervention to prepare students for their future learning.

Our finding that perceptual activities alone were effective stands in contrast to the prior research on representational-competency supports in individual learning contexts, which showed that students benefit from perceptual activities when they were combined with sense activities (Rho et al., 2022). While prior research found perceptual activities to be effective only when they were preceded by sense activities first, student groups in the present study benefited from perceptual activities even if they had not previously received sense activities. A possible explanation for these divergent findings is that student groups in the present study learned in an active learning format, which encourages students to engage in co-construction of explanations and inferences (Freeman et al., 2014). The active learning format may have supported students in making sense of visual representations so that additional sense activities were no longer necessary to enable students' learning from the perceptual activities. Indeed, our interviews revealed that students who worked on perceptual activities had an active discussion, which supports our interpretation.

Further, we investigated whether spatial skills moderate the effect of representational-competency supports (RQ2). We found no evidence that spatial skills affected students' benefit from sense activities or perceptual activities; in other words, all students benefitted equally. This finding differs from our unfortunate previous finding (Rho et al., 2022), where sense activities were effective for high-spatial-skill students in preparing for future learning. It is possible that collaboration alleviated the moderation effects of spatial skills. As mentioned, the active learning setting of our encouraged students to help one another, which might have particularly benefitted students with low spatial skills. Our findings related to students' experiences of collaborative learning with representational-competency supports activities (RQ3) supports this interpretation. We found that students received *help* from each other while having an active discussion. Through such discussion, students felt *confidence* and *comfort* about collaboratively working on activities. As a result, students created a supportive environment where low-spatial-skill students can ask for and receive timely help from their peers. Further, high-spatial-skill students were able to enhance their understanding by providing an elaborated explanation to their peers.

Our findings should be interpreted considering the following limitations. First, we conducted our experiment as part of an electrical engineering course. While the naturalistic context of a real classroom enhances the external validity of the experiment, it might have reduced its internal validity. For instance, students might have received help other than our intervention in an unknown way, for example from teaching assistants. Thus, future research should replicate our findings in a more controlled environment. Second, we did not test whether collaborative work on representational-competency activities is more effective than individual work on activities for preparing for future learning. Future research could address this limitation by comparing individual to collaborative learning from representational-competency supports.

To conclude, our research is, to the best of our knowledge, the first to demonstrate that representational-competency supports in collaborative learning are effective for preparing future learning with novel visuals. This finding provides new evidence that fills the existing research gap between representational-competency supports and preparation for future learning. Our findings also provide practical contributions to instructional design in collaborative learning. Considering many STEM instruction activities moving toward collaborative learning, our study demonstrated that collaborative work occurring in a supportive environment has potential to evenly distribute the effect of representational-competency support, especially for preparing future learning.

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Middle School Students Modeling Viral Transmission

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Abstract: This study explores how middle school students build and share knowledge about viral transmission through scientific modeling. We built a framework for modeling based on the literature with a focus on the epistemic dimensions of the practice. In the framework, we identified five epistemic considerations related to modeling: 1) representation, 2) mechanism, 3) communication, 4) justification, and 5) limitation. We use these considerations to inform our analysis of how middle school students discuss and participate in knowledge construction around viral transmission through modeling. Our results indicate (a) students use several modeling considerations from the Framework for Modeling Principles and Performances to build and share knowledge about viral transmission, and (b) through the modeling experience, students came to appreciate the multi-dimensional nature of viral transmission and pandemics. The findings indicate that middle school students can engage with modeling as part of socio-scientific issues, such as pandemics, in sophisticated ways.

Introduction

The COVID-19 pandemic has highlighted a long-standing call for classrooms to be spaces where learners develop knowledge and practices for informed decision-making. Specifically, science educators saw the need for students to engage in learning experiences around public health issues, including the transmission of disease and methods for preventing epidemics. Unfortunately, the science education community was not well prepared to support student learning concerning viral outbreaks because of the complex, multidimensional nature of pandemics. As the pandemic spread across the globe and impacted the lives of students and their communities, there were limited curricular materials from which educators could draw and many teachers felt ill-prepared to design learning experiences that could address students' emerging questions (Trygstad, Smith & Craven, 2021). Pandemics, such as COVID-19, fit into a broader class of issues referred to as socio-scientific issues (SSI). SSI are complex social issues conceptually connected to science, such as climate change, antibiotic resistance, and pandemics (Friedrichsen et al., 2020). SSI positions learners to explore these complex issues through disciplinary practices such as modeling as a means of developing more sophisticated understandings of complex phenomena (Zangori et al., 2017).

Modeling as a pedagogical tool has long been included in classroom instruction (for a review, see Louca & Zacharia, 2012); however, since the dissemination and implementation of *Next Generation Science Standards* (NRC, 2012), modeling has gained much attention as a science and engineering practice. With this renewed popularity as a target for learning and an instructional approach, some research warns that the practice can be reduced to procedural routines, such as copying pictures, that do little to encourage productive disciplinary engagement and therefore does not leverage the epistemic potential of modeling (Ke & Schwarz, 2020). This essentialized method of modeling comes from an implicit trust that simply *doing* science practices will render scientific understanding. Unquestioned routines that mechanically focus on student attainment of pre-determined components or ideas are a pitfall of science teaching and learning that can be most evident in some modeling activities (e.g., making a cell model from candy with a list of required organelles). Berland and colleagues (2016) suggest that one way to mitigate this pitfall is to highlight the epistemic considerations of the practice and create learning environments where students actively construct and evaluate ideas. In response to this recommendation along with the broader modeling literature, we developed a Framework for Modeling Principles and Performances with the purpose of highlighting the epistemic considerations of modeling.

When used meaningfully, modeling is a powerful practice that can help learners visualize and make sense of their ideas and externalize them in a way that makes visible how their ideas fit into a broader context (Berland et al., 2016; Ke et al., 2021; Schwarz et al., 2009; Schwarz et al., 2022). Because of its value as a learning tool, many researchers have investigated how a modeling experience can be made meaningful to learners. For example, several researchers have explored the importance of providing a model as a physical representation of an abstract phenomenon (Winsberg, 2001), a tool to facilitate scientific discourse (Penner, 2000), and provide insight into systems' mechanisms (Zangori et al., 2017). We build on our prior research that models are made more meaningful when learners are active epistemic agents and engaged with phenomena that are relevant to their lives, such as the climate crisis (Zangori et al., 2017). Given the significance of the COVID pandemic for students and society more generally and the relatively limited knowledge base that we as a research community have about learner understandings of viral disease processes particularly in the context of use of this knowledge in disciplinary practice (Ke et al., 2021), we focus on student modeling practices associated with the transmission and spread of respiratory viruses like COVID. This proceedings paper describes our development of a Framework for Modeling Principles and Performances which informed our analysis of how middle school students discussed and participated in knowledge construction around viral transmission through modeling. The following research question guided our analysis: How do middle school students use modeling to build and share knowledge about viral transmission?

Framework

We built a framework based on the modeling literature (Berland et al., 2016; Forbes et al., 2015; Pluta et al., 2011; Schwarz & White, 2005; Schwarz et al., 2009) with a focus on the epistemic dimensions of the practice. In the framework, we identified five epistemic considerations related to modeling: 1) representation, 2) mechanism, 3) communication, 4) justification, and 5) limitation. For each consideration, we highlighted two dimensions: principles and performances. By principle, we refer to epistemic ideas about the nature of scientific models that students can use to guide their modeling work. For example, in the case of representation as a modeling consideration, principles that learners should understand include that models should represent key features of a phenomenon or system; models are not intended to replicate reality; model can take multiple representational forms; and the degree of detail included in a model will depend on the model type and the nature of the detail itself. By performance, we refer to modeling tasks students should be able to accomplish when they model for certain epistemic goals. For example, again using the case of representation as a consideration, a performance that learners should be able to engage with is the construction of models that represent key features of a phenomenon or system. The framework also suggests that students should be able to move flexibly between different representational forms as they use models. We further describe what each dimension entails in Table 1.

While this framework was influenced by prior work on modeling, it differs from other modeling frameworks or rubrics and contributes to the field in two major ways. First, the framework focuses on both epistemic knowledge (i.e., modeling principles) and practice (i.e., modeling performance) with the assumption that they are both important for students' learning and experiences with modeling. We contend that meaningful modeling practices involves students using modeling principles as epistemic criteria to guide their modeling performances. In turn, engaging in modeling performances gives students opportunities to reflect on the experience and revise their understanding about modeling principles accordingly. Second, existing frameworks for modeling account for ideas consistent with the first four considerations included in our work (representation, mechanism, communication, and justification)—we offer limitation as a new consideration for modeling practice. The limitation consideration addresses a critical research gap in the modeling literature, that is, how students evaluate not only individual models, but multiple models as well. We argue that it is essential for students to recognize the merits and limitations of different models, and how a combination of different models may better represent, explain, and predict the underlying phenomena or system.

Table 1
A Framework for Modeling Practice

Modeling Consideration	Modeling Principle	Modeling Performance
Representation	• Models represent key features (e.g., conditions, components, processes) of system/phenomenon/issue • Models don't replicate reality • There are multiple representational forms of models • The particular details necessary for a model depend on its purpose	• Construct and use models to identify/represent/simplify key features of system/phenomenon/issue in their models • Move flexibly between different representational forms of models
Mechanism (about how/why)	• Models are used to explain system/phenomenon/issue	• Construct and use models to explain system/phenomena/issue

	- Models can be used to make predictions (based on the mechanism)	- Construct and use models to predict system behaviors/scientific phenomena/issue dynamics
Communication	- Models are communication tools for conveying understanding/knowledge - Models are communication tools for supporting arguments.	- Construct and use models to communicate understanding
Justification	- Models should align with relevant evidence - Models are revised based on new evidence obtained.	- Construct/Revise/Evaluate models based on evidence - Select among models based on their evidentiary support
Limitation	- Different models have different merits and limitations - Multiple models combined could better represent/explain/predict system/phenomena/issue	- Recognize the merits and limitations of single models - Compare and evaluate the merits and limitations of multiple models

Method

Context and participants

This study was conducted as part of an afternoon outreach program for middle school (grades 6-8) students in the summer of 2022. During a three-hour session, researchers facilitated a series of curricular events designed to activate and investigate students' prior knowledge of COVID-19 and promote engagement with modeling viral transmission. These learning activities are the first iteration of a multi-year project in which researchers will investigate how middle school learners coordinate different types of models to make sense of multidimensional and profoundly complex phenomena, such as pandemics.

The afternoon began with a modified version of a susceptible-infectious-recovered (SIR) model to encourage students to think about viral transmission at the level of a population (modified from Gaff et al., 2011). The SIR model was presented as a game which is essentially a simulation. The goal for students working with the simulation was to track how numbers of infected individuals within a population change over time. The simulation featured two processes: transmission, the process through which susceptible individuals become infectious ones, and recovery, the process through which infectious individuals become immune. Following engagement with the SIR model, we facilitated a conversation about respiratory droplets and their role in the transmission of viral infections between individuals. Students then completed four different stations where they participated in activities to inform their thinking about social distancing, how germs spread via objects, how masks are designed, and how particle size relates to the spread of viruses through different types of masks. In the social distancing and the particle size station, students completed an investigation answering driving questions: a) How does distance affect transmission, and b) are all materials effective barriers against transmission. The other two stations were a demonstration and an observation lab using microscopes to investigate the differences between the materials masks are made of. Following the activity stations, students worked in groups to construct a model, on whiteboards, based on the following prompt: *draw a model to explain how and why you may (or may not) get infected by a COVID-19 positive person in an indoor space, such as in a classroom, on a school bus, or in a restaurant.* The intent of the model creation exercise was to encourage students think about and share their knowledge of the mechanism through which respiratory viruses spread. As a final step, students were asked to reflect on the SIR model as it was given to them and the transmission model that they created and to critique both models.

The outreach served 14 students in 6th – 8th grades (ages 11 – 13 year old). Six of the 14 students identified as people of color. All names in used in this paper are pseudonyms. The students were divided into five learning groups designated by a color (i.e., yellow, purple, green, red, and blue groups). Students completed the SIR model, the activity stations, and the transmission model in their learning groups.

Data collection and analysis

The data for this study included videotaped recordings of the learning groups as they completed the modeling activities. A researcher facilitated activities within each group and employed a group interview protocol after the

SIR model, each station, constructing the transmission model, and discussing the critiques of the models. The researchers facilitated the interviews to allow learners to build on their group members' responses in order to capture a more authentic experience. Students were asked a series of questions that encouraged them to explain their models, what evidence they used to construct them, how they knew their models were correct, and to identify the limitations of their models. For the purpose of this paper, we focus primarily on the groups' creation and critique of their transmission models.

Through constant comparison (Glaser, 1965), the transcripts from the videotaped recordings were categorized based on modeling considerations from the Framework for Modeling Principles and Performances (see Table 1). These considerations were then further divided into themes that captured the nature of the students' modeling experience. For example, in the modeling consideration representation, students negotiated representation in terms of details, relationship to reality, and accuracy. These were each used as themes to inform how the learners built and shared knowledge about viral transmission.

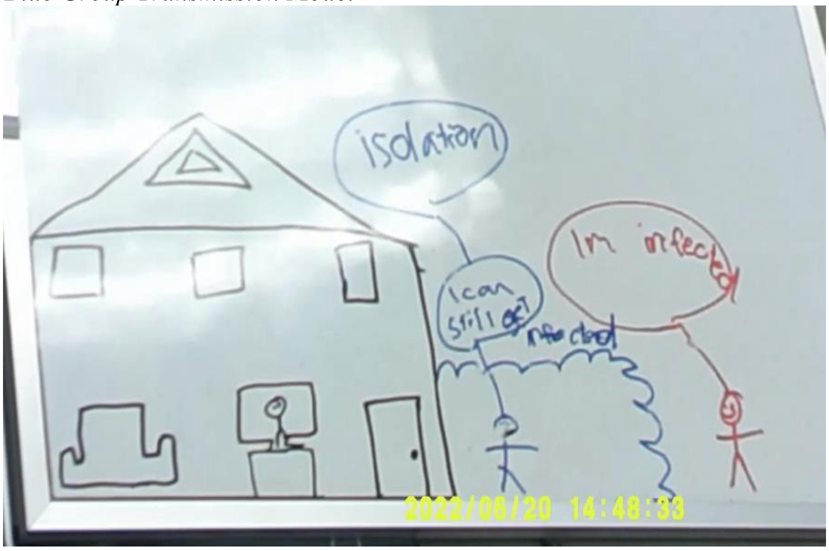
Results

Our results indicate two main findings: (a) students use several modeling considerations from the Framework for Modeling Principles and Performances to build and share knowledge about viral transmission, and (b) through the total learning experience, students came to appreciate the multi-dimensional nature of viral transmission and pandemics. Of the modeling considerations, representation was the most frequently discussed or demonstrated followed by limitation and justification. The other considerations (mechanism and communication) were reflected in some of the students modeling work. For example, Georgia, a student from the green group declared that "the messages will be different" when considering different models. However, this focus on communication was not as prominent as other considerations. Therefore, for the purpose of this presentation, we focus our analysis on how the groups worked with representation, limitation, and justification in their modeling experiences.

Modeling consideration: Representation

All of the modeling principles within the consideration representation (presented in Table 1) were evident in the video that captured group participation and/or the models they created, and the most common theme observed related to the first principle: how students represented key features of viral transmission in their models. Although students varied in how they approached representing the key features of their transmission model, they each generated a strategy (not provided to them) to distinguish the key features of the system. In all but one of the models, the students identified COVID-19 positive person using a different color, usually red. In most models, the susceptible person was represented in blue, while the background context was typically black or a neutral color; see Figure 1 as an example.

Figure 1
Blue Group Transmission Model



The need to provide a context to show viral transmission presented a challenge for the learning groups. Here we are classifying contextual details as background information that was not necessary for representing the key features of viral transmission. For some of the groups, the context of their model was as important as what might be considered the key features of transmission. In these cases, groups devoted a lot of time to negotiating contextual details like where transmission might be taking place and specifics associated with these places. For example, the yellow group immediately decided on a COVID-19 positive person sneezing as a means of infecting a susceptible person; however, there was extended discussion about what context they would represent in their model. The below excerpt captures a brief part of their conversation.

Yandy: Somebody sneezes, and it goes through the mask.
Gabriel-Yosuf: No, the kid's not wearing a mask.
Yasir: No, the kid's not wearing a mask, and he has huge snot particles.
Yandy: You can see it through a microscope.
Yolanda: It's on a school bus.
Gabriel-Yosuf: It's the chef. Okay, whoa, whoa, whoa, whoa, he's sneezing all over the food. Then they eat the food, and the people get COVID. Let's do that.
Yolanda: Yeah, okay. Let's just draw two pictures.

Ultimately, the yellow group drew two representations of the transmission of COVID-19 from one person to another through a sneeze in two different contexts, a restaurant and on a school bus.

While constructing these two representations, the group members further debated which illustrations to include to capture the key features and contextual details in their model. For instance, Yolanda critiqued the restaurant representation and suggested a simplified version; "make the chef delivering your food and sneezing because it's easier to understand," indicating a desire for models to be simplified representations. This is further supported by an interaction between the yellow group and their facilitator about their decisions representing COVID-19 in their models.

Yolanda: Maybe it shows that that’s not what COVID looks like at all. It looks like it is extremely small, and it doesn’t have color.
Yasir: You can’t see it.
Facilitator: Okay. It’s extremely small. It doesn’t have color. Probably can’t see it.
Gabriel-Yosuf: It probably does have a color
Yolanda: It's grey.
Gabriel-Yosuf: Right, but grey is a color.
Facilitator: So, can I ask you all about a decision? You said you can’t see COVID. Why did you draw all of the dots?
Yasir: As a representation to show
Yolanda: To show where it is going

This interaction highlights the yellow group’s understanding that representation is separate from reality but serves a visual purpose.

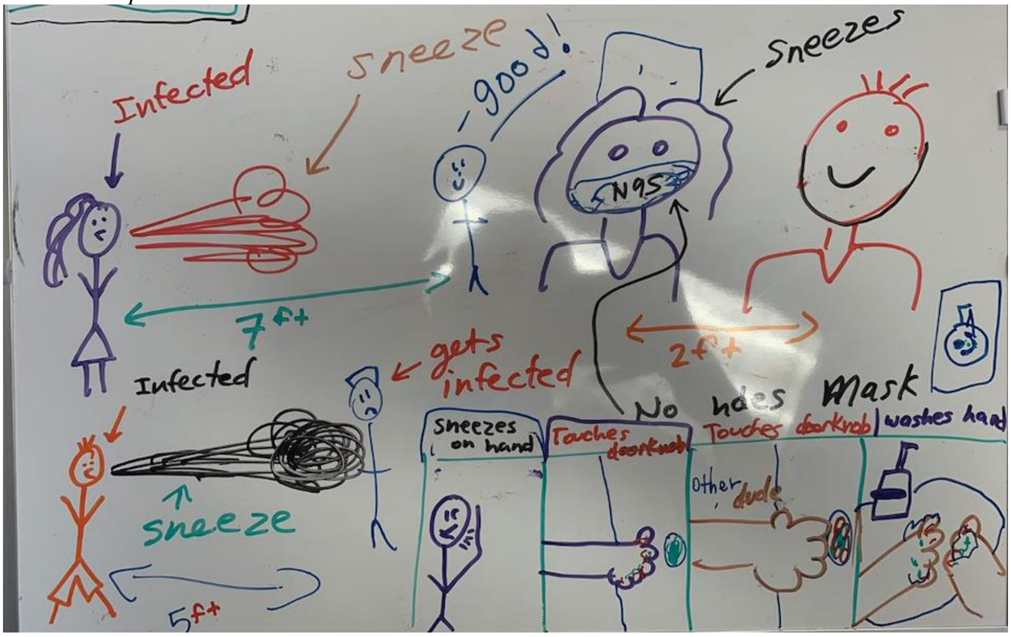
Additionally, upon reflection, the yellow group pointed out that their model was good because it fulfilled their representational goals. Yandy said, "They [models] do their purpose by showing the spreading of germs." He placed the value of their model on its ability to show the spread of COVID-19. So even though they spent time negotiating contextual details which were not essential for the representation (like the fact that the infected individual was a chef) of their models, when pressed to reflect on the purpose of their model they were able to recognize and discuss mechanistic aspects of the model. Along with the attention to distinguishing key features, this implies that the learners value the context of the model; but they see the purpose of the model is to represent a simplified version of COVID-19 transmission, not to deliver a broader narrative for which contextual details may have been more significant.

Modeling consideration: Limitation

Students mentioned the limitations of their transmission models throughout the entire experience. At times, they expressed dissatisfaction with their model's inability to fully explain all aspects of viral transmission. Groups tended to initiate model creation with a single figure or representation, but as they considered dimensions of transmission not accounted for in this initial representation, they would start adding scenes to account for additional aspects transmission. In some cases, the additional representation did not necessarily expand a model's account of transmission mechanisms. For example, the yellow group started their model by drawing a possible transmission scenario in the context of a restaurant (with an infected chef spreading respiratory droplets to customers). Some group members were dissatisfied that this initial attempt only showed transmission in one context so they added a new scenario showing how a virus might spread to multiple individuals in a school bus.

In contrast, the green group added to their representation as a way of expanding the mechanistic explanations accounted for in their model. Figure 2 presents the final model from the green group. The group started with scenes on the left with the intention of showing how respiratory droplets spread through sneezes and highlighted the significance of distance as a factor influencing transmission. They were concerned that this initial representation did not show enough so they next added the figures to show the importance of mask wearing (Figure 2, top right). Next, the conversation shifted to the potential for viruses to spread on objects, and in response, the group added a final scene (Figure 2, bottom right) that showed how viruses might spread on objects and the importance of hand washing. When asked by the facilitator what the model did not show, Georgia responded, "it's hard to tell why some masks are good, and others aren't." If space on the white board remained, it seems likely that the group would have added another scene to account for variation in mask quality. This pattern, which was observed in other groups as well, reveals that the students could recognize model limitations and sought strategies for expanding what their models could explain. In some cases (e.g., the yellow group), the changes to the models added contexts but did not necessarily expand the ability of the models to account for transmission mechanisms. In other cases (e.g., the green group), the changes broadened the explanatory power of the models. In all cases, the learners remained focused on specific examples (spreading viruses in a restaurant, on a bus, at different distances, with/without a mask, etc.) and responded to perceived model limitations by adding new examples. An alternative strategy could have been to consider aspects of transmission in more abstracted ways that could apply across specific examples, but the students did not appear able to take that step, at least not with the scaffolds provided.

Figure 2
Green Group Transmission Model



Modeling consideration: Justification

Students discussed the justifications that supported their models primarily by pulling evidence directly from that day's activities. When asked how they knew what they were modeling was true, they responded with particular reference to the station activities. They reflected on the fact that the stations showed the complex nature of viral transmission, such as not all masks offering adequate protection from the virus. When asked why the green group labeled the mask as "N95," Grace responded, "because, in the microscope, it had no holes." She later described how the "gaiter masks" are ineffective because she saw large holes under the microscope, which would not offer protection to a susceptible person. In the microscope station, students looked at an N95 mask, a surgical mask, a homemade double layered cotton mask, and a neck gaiter. Grace was referring to the porous, loose weave of the neck gaiter she observed under the microscope. Additionally, in the blue group, Bill said he used what he learned from the "6 feet apart" station which showcased the inverse relationship between spread of respiratory droplets and distance, to build his model showing isolation (Figure 1).

Evidence emerged that the students also justified their models based on personal experience. For example, Grace from the Green Group referenced her own experiences wearing a mask to protect herself and the people around her as a justification for including masks in her group's model. The attention to protecting others through wearing a mask, which was not discussed in the stations, indicates that Grace is bringing personal experience to her understanding of viral transmission. In a separate conversation, Yolonda similarly responded that the yellow group's model was good because it showed possible scenarios from real life, "Yes, people can sneeze on your food, and people can get sick from riding the bus." At another point in the modeling experiences, Yolanda expressed dissatisfaction with the SIR model by saying, "if there's a pandemic, you're most likely not just going to be walking around without anything on"—a reference to her own experience wearing masks in public places throughout the COVID pandemic. In the case of the SIR model, the students used a fixed simulation, and the fact that this simulation did not account for evidence from Yolonda's experience was a source of her critique for the model.

Conclusion

This research shows that, with a limited, short intervention, middle school students can effectively use models to better understand viral transmission. Moreover, both their transmission models and their discussions of the models include a variety of critical components that support the development of scientific literacy. In each group, we saw evidence that students engaged in informed decision-making through collaboratively creating, reflecting on, and critiquing the models.

The learning activities and interview questions prompted students' engagement with the representation, limitation, and justification dimensions of modeling. At the same time, these designed experiences were less effective at eliciting communication and mechanism dimensions of modeling. The activities that students participated in around the modeling exercises provided students with opportunities to gather evidence of (a) the best types of materials to use as a mask, (b) why social distancing is an important strategy for limiting transmission, and (c) how germs spread through objects. The limited attention on the part of student groups to other modeling considerations, namely mechanisms and communication, may have resulted from the design decisions our team made in creating the overall set of learning activities.

Notably, the findings suggest that middle school students can engage with modeling as part of socio-scientific issues, such as pandemics, in sophisticated ways, which is consistent with explorations of young learners modeling competencies in the context of strictly scientific phenomena (Duschl, Schweingruber, & Shouse, 2007; Louca & Zacharia, 2012; Zangori & Forbes, 2016). These young learners articulated scientifically appropriate criteria for modeling as the practice is ambitiously outlined in the *Next Generation Science Standards* (NRC, 2012). Students authentically engaged in building their transmission models and, as a result, navigated between complex decisions of what to include and for what purpose (i.e., superficial details, context, and simplified illustrations, as seen in the representation section). For example, although the yellow group included multiple contexts representing the same type of transmission, they ultimately decided that their model was appropriate because it showed the spread of germs. Additionally, all the groups identified limitations of their transmission and SIR models to conclude that COVID-19 is too complex to be singularly represented. Their dissatisfaction with what one model could accomplish shows an understanding of the pandemic that can be useful for supporting scientific literacy, most importantly in this case, informed decision-making for a healthy lifestyle.

Understanding how middle school students engage in modeling viral transmission may guide future researchers in clarifying how young learners use modeling to make sense of other complex SSI. Educators may also leverage the modeling considerations to encourage the types of learning environments that allow for all five considerations to flourish for meaningful epistemic engagement.

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Cultivating Generative Emotion in Science Classrooms

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Abstract: This paper addresses two shifts in science education: (1) a move away from a focus on content and toward a focus on practice to engage students in inquiry and (2) calls for learning to be justice-oriented and dignity-affirming. We propose that attending to generative *feeling* can cultivate *emotional configurations* (interrelationships between feeling, sensemaking, and practice; Vea, 2020) that help students make progress on investigations that are personally meaningful to them. Using data from a 6th grade STEM classroom, we illustrate how attending to generative feeling opens up the questions students can ask and answer, the stances they can take, and the interpretations of data that are recognized as legitimate in their classroom. Thus, attending to feeling enables investigations that respect the dignity of students and the dignity of the more-than-human participants in their investigations.

Objectives and significance

This paper addresses two shifts in science education. First, science education has moved away from a focus on content alone and toward a focus on *practice* in order to engage students in inquiry (Duschl et al., 2007; National Research Council, 2012). Second, science education researchers have called for learning to be *justice-oriented* and *dignity-affirming* (e.g., Espinoza et al., 2020; Warren et al., 2020)—a shift that could empower students to ask and answer personally meaningful questions. We argue that, when integrated, these two shifts could support genuine and generative inquiry through the development of classroom knowledge and practices related to students' concerns and interests. With such goals, it can be challenging for teachers to recognize students' potential contributions and amplify them. First, a shift toward forms of practice modeled on disciplinary science (e.g., NGSS practices; NGSS Lead States, 2013) has, in some cases, led to students' rote participation rather than empowering them to generate their own knowledge and practices as a community (Berland et al., 2016; Manz & Suárez, 2018). Second, teachers have traditionally been encouraged to amplify student contributions with explicit connections to specific disciplinary ideas and phenomena (e.g., in "storylines;" Reiser et al., 2021). This approach filters students' contributions in a way that could feel manageable for teachers, but oppressive for students. On the other hand, a perspective that centers students' contributions could be overwhelming for teachers (and also students), because attempting to incorporate any and all student contributions could threaten the coherence of students' investigations. This paper asks: How can teachers invite and cultivate students' ideas, practices, and connections in order to support classroom investigations? How can students shift this discourse?

We propose that one solution is attending to generative *feeling* (embodied intensities) in order to cultivate *emotional configurations* (interrelationships between feeling, sensemaking, and practice; Vea, 2020) that help students make progress on investigations that are personally meaningful to them. Using data from a 6th grade STEM classroom, we illustrate how attending to generative feeling opens up the questions students can ask and answer, the stances they can take, and the interpretations of data that are recognized as legitimate in their classroom. In this setting, we argue that attending to feeling enables investigations that respect the dignity of students as well as the dignity of the more-than-human participants in their investigations (in our case, guppies).

Our findings offer theoretical and pedagogical contributions. First, while *emotional configurations* has previously been used as a descriptive framework, we demonstrate how this tool could be used to design for justice-oriented and dignity-affirming classroom science learning. Second, while emotional configurations have previously been used to analyze emotions within small groups in science classrooms (Lanouette, 2022; Pierson et al., in revision), we use this framework to analyze emotion within a classroom as an emergent *social* field. Third, by focusing on generative feeling as a lens, we suggest an approach that teachers could use as a means for determining when and how to amplify their students' expressed emotion to support classroom investigations.

Conceptual framework

We argue that attending to feeling can be responsive to calls for justice and dignity (Boler, 1999; Shalaby, 2017), as well as calls for authentic science practice (Jaber & Hammer, 2016; Zembylas & Papmichael, 2017). To understand emotion in 6th grade STEM classrooms, we draw on Vea's (2020) emotional configurations framework. Rather than separating emotion from practice, Vea argues that emotion is an inextricable dimension of learning as a sociocultural activity. This perspective shifts the analytic focus from *affect* (a heuristic used to describe "ambiguous felt intensity as a mode or moment in the process of emotion;" Vea, 2020, p. 326) to *emotion* (the coordination of feeling with social meaning and practice). To understand the nature of emotion in learning, Vea offers the analytic construct of *emotional configurations*: the situated and reciprocal interrelationships between feeling (embodied intensities), sensemaking, and practice. This framework was developed in the context of activism; in our application to classroom science learning, we draw on science education literature to understand sensemaking (recognizing and resolving inconsistencies or gaps in knowledge; Odden & Russ, 2018) and practice (developing procedures and measures to build knowledge; Lehrer & Schauble, 2015).

We conceptualize dignity-affirming and justice-oriented science learning as valuing participants' "intrinsic worth" (Espinoza & Vossoughi, 2014, p. 290), enabling students to feel that their "whole person" is invited into learning (Calabrese Barton et al., 2021, p. 1231). In addition, in our data, a sense of justice and dignity includes more-than-human participants (Tzou et al., 2021)—in this case, the guppies that the students studied to understand ecosystems. As Calabrese Barton and colleagues (2021) explain, justice-oriented and dignity-affirming science learning requires making space for students to be "disruptive." Rather than framing students as "troublemakers" in moments of disruption, instructors can instead frame disruptive moments as opportunities for transformation (Shalaby, 2017). Our data include examples of such generative disruption—for instance, one student critiqued classroom practices that put guppies at risk based on her commitment to caring for the guppies.

Method

This study was conducted in a public middle school in a suburban school district in the southeastern US in Ms. S's classroom. Ms. S is a STEM teacher who was in her 26th year of teaching at the start of the study. We analyze data from two of Ms. S's 9-week sixth grade classes (13-25 students per class). Q1 refers to the first implementation of the unit (August-October); Q2 is the second (October-December). According to the state report card, 18% of the school's students qualify for free or reduced lunch. The students in the school are culturally and linguistically diverse: 55% of students identify as White, 34% as Hispanic or Latino, 7% as Black or African American, and 4% as Asian. 8% are classified as English Learners. Students participated in a unit that foregrounded modeling that was co-designed and co-taught by Ms. S (teacher, author 4) and Ms. P (researcher, author 1). The unit was framed by two design challenges: students designed a biosphere, a closed-system physical model that included plants, snails, and guppies; and they programmed a computational model that represented a larger ecosystem of plants, snails, guppies, and guppies' competitors and predators. Throughout the unit, the students gathered information and re-represented the guppies' environment with increasing complexity.

We analyzed whole-class data during two implementations of the 9-week unit. Two cameras positioned on opposite sides of the classroom captured classroom discourse. We began by creating content logs and rough transcripts of classroom videos (Erickson & Schultz, 1997). In our analysis, we focused on identifying feelings that shaped the trajectory of classroom investigations. We used Discourse Analysis (Gee, 2014; Norris & Jones, 2005) to closely analyze the multimodal expression and interplay of feeling, sensemaking, and practice. We conceptualized emotional configurations as sustained and shared sensitivities to phenomena during the class's investigations, where (a) students expressed embodied intensities (feelings), (b) students worked collaboratively to build knowledge (sensemaking), and (c) students developed shared ways of participating in the investigation (practice). We then traced these emotional configurations back to their roots in classroom interactions, as well as forward to their ending points (when students' goals for their investigations were achieved, frustrated, altered, or otherwise exhausted). For evidence of feeling, we attended to the following forms of expressed emotion (Boler, 1999): (a) physiological, for example, a gasp or laughter; (b) cognitive/conceptual, for example, describing a feeling of connection with the guppy, including hope or concern; and (c) moral/evaluative, for example, making decisions about guppies or models based on feelings of connection. For evidence of sensemaking, we attended to moments where students iteratively noticed inconsistencies or gaps in their knowledge and generated explanations to reconcile these issues (Odden & Russ, 2018). For evidence of practice, we attended to the ways that students used procedures, measures, and materials in service of the shared investigation (Lehrer & Schauble, 2015). Then, after identifying these components of emotional configurations, we traced their interplay. Specifically, we analyzed transcripts to determine whether and how feeling influenced sensemaking (new questions or understandings) and practices (new ways of seeing and interpreting the biosphere jars), as well as whether and how sensemaking and practice sustained or evoked feeling within small groups or across the classroom (for instance, observing the jar evoking feelings of care or concern for the guppies).

Findings

Below, we illustrate how Ms. S attended to feeling in order to cultivate generative emotional configurations that supported justice-oriented and dignity-affirming science learning. This analysis shows how one student, Dolores, shifted the classroom's discourse about the biosphere jars through her persistent representation of feeling to critique classroom practice on a day when guppies were discovered to have died—a shift that influenced the design of the unit and Ms. S's teaching in subsequent implementations of the unit.

Dolores's critique of classroom practice:

Although no guppies had died in the pilot implementation of the unit (during the previous school year), in Q1 several of the guppies did die, soon after being placed in the biosphere jars. The classroom discussion illustrates tensions that arose between students' feelings and the pursuit of the classroom investigation. In the end, Ms. S's classroom culture did enable the group to navigate these tensions, but the episode also pointed to the need to adjust the framing of the unit in ways that would tap more deeply into students' feelings as epistemic guides.

Ms. S began the class session with a focal question, "What is happening in our [biosphere] jars?" Dolores's group was one of the groups whose fish had died, and one of her group mates, Reid, normally a quiet student, spoke first, saying "Nothing, because ours are all dead." Dolores's subsequent participation in the class discussion carried this theme forward. She was habitually a more vocal contributor to class discussions than Reid, and she was quite active in this session as well. During our focal episode, she accounted for 35 of the 73 student turns of talk. Much of the classroom interactions on this day followed the Initiation-Response-Evaluation ("IRE") pattern (Mehan, 1979; 1980); and several additional exchanges involved a slightly more open "IRX" form, in which Ms. S replaced the Evaluation turn with a request for additional responses to the Initiation prompt. Dolores participated in 13 of the 15 IRE sequences in this episode and 3 of the 5 IRX sequences.

The IRE format is effective in eliciting expected answers to teacher questions (Mehan, 1980), and many of Ms. S's questions aimed to confirm students' memories of key facts in the Carbon Cycle and in plant and animal respiration. This agenda appeared to bother Dolores, who seemed increasingly impatient with a discussion of general knowledge that neglected the specific events of the fish's deaths. Dolores responded by participating in ways that increasingly subverted the IRE interaction pattern. The first came in an exchange about plant respiration:

Ms. S: They take in something. What do they take in?
Dolores: Carbon Dioxide
Reid: Oxygen?
Ms. S: They take in which one?
Reid: [Oxygen]
Dolores: [Carbon Di]oxide ((pause. raises hand)) Carbon Dioxide
Ms. S: Mm- Carbon Dioxide (.) What do they release? ((Hand gesture))
Dolores: Oxygen
Reid: Ohh! ((realizing his prior error))
Dolores: ((softly)) But then we just stressed out the fish; that's why they're all dead.
Ms. S: Right.

In her second-to-last turn, Dolores responded rapidly with the correct answer (Oxygen). Then, before Ms. S could close the IRE sequence with her ratifying "Right," Dolores quickly interjected a novel idea ("But then we just stressed out the fish; that's why they're all dead"). This turn introduced a conjecture about the *cause* of the fish's deaths (stress), and, in using the pronoun "we," it implicated the classroom group as *culpable* for their deaths. Further, caught by Dolores's quick interjection, Ms. S's "Right" (unintentionally) endorsed Dolores's statement. Ms. S then moved on to ask about animal respiration:

Ms. S: What do WE, what do WE take in?
Dolores: Oxygen
Ms. S: Oxygen, ok
Dolores: ((gesture over shoulder at fish tank)) but [inaudible] in there.
Ms. S: What do the fish take in?
Dolores: Nothing, because they're dead.

As before, Dolores worked within the form of the IRE pattern to introduce ideas that interrupted Ms. S's press for general knowledge with a focus on the fish. In saying "Nothing, because they're dead" Dolores also returned to Reid's first comment. Dolores's answer further reframed Ms. S's "the fish" (in general) to refer to the particular fish who had died in the jars. Ms. S attempted to move on, resetting and asking the question again:

Ms. S: What do the fish take in?
STUDENT: Oxygen
Dolores: Stress

Ms. S: Oxygen
Dolores: And stress

At one level, Dolores's responses here returned to the theme of "stress" that she initiated in the first exchange. At another, participating in the IRE pattern also led her to develop her argument. Whereas she earlier introduced the idea of stress as a cause of death, here the parallel with "oxygen" positioned stress as a material factor that the fish "take in" from a hostile environment.

Next, Ms. S steered the conversation to the reasons that some fish had survived while others had died. Dolores raised her hand, and Ms. S called on her:

> Um. Maybe they weren't as stressed out. Or they like – they got used to the hot tank quicker. Or the other ones, they still were confused and weren't um. Because you had them in that big tank and you put them into a smaller ecosystem, so they weren't sure and they didn't know what to do.

Dolores advanced further sensemaking about the fish, connecting the concept that the classroom group was culpable for their death with the idea that their environment was hostile. To this, she added the concept that the *size* of the jars was a problem, and that fish in an environment with very limited space wouldn't "know what to do." This raised a theme that she had been concerned about on Day 12 of the unit. (On first seeing the jars they would be using for biospheres on that day, Dolores had asked, "Isn't it kind of bad for a fish to live in a jar since it's not much space?")

Then, Ms. S described how she had introduced the guppies to the classroom tank, acknowledging that she didn't take the usual step of giving them some time floating in their bags before releasing them. The discussion then returned to the question of why some fish died.

Dolores: I think it was because maybe they got STRESSED OUT - like the ecosystem was too small. Or the fish let out these things, and it caused them to like [dysfunction] with sand [inaudible] got in whenever they breathe — the gills
Ms. S: There are lots… there are lots of things for us … to consider, lots of things for us to consider.
Dolores: Because I feel like whenever you imagine like a project, you imagine fish would be in a big tank. And not in like little jars, because fish can get stressed out really easily if they don't know what to do, or they don't ... not sure what to eat, so they don't eat, they don't know they can't really… function right. So then everything just goes off and they just die because of the stress.
Ms. S: Okay.
Dolores: Everything just starts to shut down within them…
Ms. S: Um, stress can be a factor.

In this exchange, Dolores linked the fish's experience of stress to the emerging theme of environmental factors that could be harmful to the fish. Stress now served as a bridge connecting the interior states of the fish (e.g., "they don't know what to do"), the external conditions (e.g., "the ecosystem was too small" and "sand…going wherever they breathe"), and the fish's health (e.g., "they can't really function right" and "everything just goes off") leading them to die "because of the stress." Dolores generated a conjecture in the form of a causal web of factors and symptoms, which could in fact serve as a guide for monitoring the health of the remaining fish. Moreover, Dolores's passionate articulation of her conjecture showed how empathy and connection with the fish's plight animated her reasoning. For her part, Ms. S made a large amount of space in the classroom discussion for Dolores to develop her thinking, first by responding in a tolerant way to Dolores's disruptions of IRE sequences, and then by inviting her to voice her thinking in a more extended way in these final contributions. She acknowledged that Dolores's evocative explanation has been compelling in her last line: "stress can be a factor."

The significance of this episode was twofold. On one hand, it showed how one student, Dolores, experienced emotions and ethical concerns that made her feel out of sync with the classroom and the way that the investigation was being conducted. On another, it demonstrated how, by insisting upon the relevance and importance of her emotional response, Dolores was able to articulate her sense-making grounded in that emotion and bring this to light within the constraints of the classroom's existing discourse practices.

While Dolores's contributions did not shape the direction of the class's investigations immediately, Ms. S did make room for her to articulate her perspective. Thus, the tension between her emotional response and the classroom's perspective was resolved in a way that validated and re-integrated her and her ideas. Moreover, this episode had an impact on the design and facilitation strategies for the unit in future quarters, guiding refinements that invited emotion and tapped into the epistemic potential of connecting feeling, sensemaking, and practices.

Adapting teaching based on dolores's critique: Inviting and incorporating feelings

In response to the episode above, in subsequent quarters, Ms. S adjusted her stance toward inviting and incorporating students' feelings as important resources for class investigations. Below, we show how she built upon her existing practices for fostering supportive relations among the humans in the room to make additional space for students to develop connections with the non-human living beings in the investigation as well as to express and act on feelings of care and concern for their survival, health, and well-being.

In Q2, Ms. S did several new things that invited students to engage with the ideas of the unit in ways that foregrounded feeling. After showing a video about the Biosphere 2 project, she gave students time and specific prompts that asked them to make connections between human needs and the situation of being sealed up in a closed system as part of a scientific investigation. For instance, Ms. S asked the class whether they would be willing to be a member of the team sealed into Biosphere 2. Students' responses showed that they were beginning to visualize what this would mean. They expressed hesitation for a variety of reasons, including a desire to be paid, to bring particular belongings (a blanket, their bed), or to bring their family as a whole. Later discussion opened up questions about whether they could bring a change of clothes, and how one might wash clothes within a closed ecosystem. This question in particular appeared to create visceral reactions—disgust about not being able to expel waste water, concerns about its being too hot inside, and claustrophobia about being shut in. Here, students were practicing perspective-taking for other humans; the following conversations invited students to take the perspective of more-than-human beings.

Ms. S then introduced a recurring theme of "planning well" for the biosphere jars:

Ms. S: Why do you want to plan well?
Ana: Because you want your guppies to live.
Ms. S: Ye-es!
Abby: And your snails!
Ms. S: And our snails, and whatever else we put in there!

Even in this first contact with the idea, the importance of planning well was framed in slightly different ways than it had been in Q1. In Q1, this was the opening exchange:

Ms. S: Someone tell me about planning well. Why is that important? (.5 sec) David?
David: You don't want everything in your ecosystem to die on the first week ((smiling))
Ms. S: No-ho we don't, we don't. Because it IS a contest, it's a contest.

The framing of the class's parallel biosphere jar investigations as a *contest* (to see which group's jar would do best) was not a persistent one, even in Q1, but it was a framing that foregrounded feelings of pride and competition in the students, as opposed to feelings of connection to the fish and other living organisms, which were more consistently highlighted beginning in Q2.

In Q2, after discussing "planning well," Ms. S moved to another key question that she asked multiple times in the days before the class created and closed off their biosphere jars.

Ms. S: Now, I want you to be honest with me, ok? Closing that lid, does it make anyone go "ooh" ((gasping)) –
Hillary: No. No.
Ms. S: -- those fish are going to die? Or whatever's in there.
Abby: They won't get oxygen, because there's no holes in the lid!
Ana: [inaudible] ((gesturing))
Ms. S: That's what, that's what's scary, ok?
Student: They'll jump out
Hillary: They'll be fine.
Ms. S: But why will they be fine?
Hillary: Because there- (.) Because fish need water, and water is in there.
Abby: But they also need (inaudible)
Ms. S: What? ((pointing to Abby))
Abby: They need plants.

Hillary: Well ((gesturing)) then well, we'll PUT plants in there!

Above, a range of levels of concern was revealed, from Abby's experience that fish can die even when cared for to Hillary's confidence that the class could provide for the guppies' needs.

Later in the unit, on Day 7, after the Plant Investigation, Ms. S returned to the question of whether students were concerned:

Ms. S: And you're going to be ready to design your...
Student: Yay!
Ms. S: ...little ecosystems? ...that we're going to ((screwtop gesture)) CLOSE OFF? Is that scary to [anyone? That]
Students: [Yes]
Abby: [Yes!]
Ms. S: we're going to close that jar?
Ana: I feel like the guppies are going to DIE because ((inaudible))
Abby: ...they're all going to die, and it's going to be our FAULT.

Here, the group expressed not only greater concern ("the guppies are going to die"), but also accountability ("it's going to be our fault"). The discussion continued, as students imagined possible problems that could arise. Andrea asked "How are we going to clean it?" which launched a discussion of algae, the possibility of an "algae explosion," and Ana's personal experience with her turtle's tank if it was not cleaned for a few days. Finally, Lucy asked:

Lucy: Will the guppies try and eat the plants?
Ms. S: M-m! That's a good question
Abby: We need to KNOW this stuff!

Along with others in the class, Lucy has shifted to imagine the dynamic behavior and emergent needs of the living beings in the jars. This line of thought emphasized the responsibility of students, as scientists, to imagine what *could* occur (e.g., the guppies might "try and eat the plants" that sustain them), to do research to prepare for such contingencies ("we need to know this stuff"), and to be on the watch for what was actually happening in the jars.

Again, there was a subtle difference between how Ms. S responded to and encouraged these "what if" reflections about the ecosystems processes in the biosphere jars in Q2, compared with how she responded to similar ideas in Q1. In Q1, after the class began to process the idea that the fish and plants might each make important contributions to the other's survival, Madison had asked a question:

Madison: The ideal thought is that the water will be turned into ... what [the fish] needs. But what if the system that usually like makes it do that…the plant…dies? So, then what if our fish dies?
Ms. S: Ah-h. Well that, would answer some questions for us, right? Now we would probably have to test many times before we could say, ok this is definitely what is going on.

Ms. S's response here was consistent with a line of thought that she had pursued earlier that day, positioning the students as scientists and researchers who should think about designing experiments to control variables of interest and offer opportunities for repeated measures to verify findings (which anticipated the upcoming Plant Investigation).

Yet, in light of the experience of guppy deaths later in that quarter, Ms. S made a shift in how she positioned the biosphere investigation as connecting with scientific practices in her future facilitation. Specifically, in Q2 and following, Ms. S framed the investigation of the ecosystem as a whole (including the fish) as an engineering design challenge. The notion of a controlled experiment *did* persist as the focus of the unit's Plant Investigation, but Ms. P and Ms. S were careful to distinguish this kind of controlled-variable testing to identify what the plant needed for survival from the Biosphere Jar inquiry into ecosystem dynamics that depended on the survival and well-being of the fish. On Day 7 of Q2, they made this contrast explicit:

Ms. P: So, with the plants, we were totally cool with saying, "Let's give some plants some water, and let's give some plants no water." Why would we feel not so good about saying, "Let's have a guppy that we feed and a guppy that has no food?" Why would we feel worse about that?

Student: Because guppies actually [move around?]
Lucy: We think that guppies are like... (1 sec). Even though plants are living, too, we don't think of plants with personality. We think of guppies as things that live, and eat, and stuff. So they need [inaudible]. We have this instinct that makes us want them to live.
Ms. P: We do, and so how does that make testing what guppies need different for us? Like, how does that make our GOALS different when we test plants versus when we test for animals? Yeah?
Lucy: We want to make sure that like the guppies have enough dirt, and enough, like everything, and that like [inaudible] they have enough air, and....
Ms. P: Yeah, so with our plants we were kinda trying to see what works, but also what DOESN'T work. And we wanted to be sure about what DOESN'T work, right? With guppies, we don't really want to roll the dice in that way, right?

Ms. P reframed the Biosphere Jar investigation as having a different kind of goal from the Plant Investigation. In Q2 and following, Ms. S and Ms. P cast this investigation as an *engineering design challenge*, whose scientific focus was on the ecosystem level. Such investigations depend on establishing and maintaining a thriving biological system whose network of behaviors and interactions can then be studied. This enterprise opens up an avenue by which students' feelings of connection to the organisms involved and their sense of justice and dignity for these more-than-human beings can be intertwined with their sensemaking and practice.

Discussion and implications

In the analysis above, we illustrate how Ms. S heard and responded to Dolores's generative feeling as a critique of classroom practice, shifting her teaching in the subsequent quarter to invite and acknowledge students' feelings as part of classroom practice. We argue that attending to feeling in this way contributed to justice-oriented and dignity-affirming science learning and respected the feelings of both the students and the more-than-human participants in their investigations (the guppies).

In Q1, the research and teaching team experienced two forms of "disruption" to the intended unit plan. First, the death of guppies was a new experience in this unit—guppies did not die during the pilot implementation of the unit. In this way, tragedy occurring to the more-than-human participants created an opportunity for the classroom to reconsider and critique classroom sensemaking and practice. When Ms. P and Ms. S responded to this disruption by drawing on existing classroom resources grounded in disciplinary sensemaking and practice (asking questions, for example, about the variables that changed from quarter to quarter), Dolores instead took up the opportunity to critique this approach, building from her feelings of care and concern for the guppies. Disciplinary sensemaking and practice had failed to protect the guppies from harm, and Dolores's commitment to caring for the guppies offered a new resource for moving forward with the investigation in a way that honored the guppies' lives and respected their wellbeing. The way that Dolores shared her care and concern was disruptive to the intended lesson. However, rather than framing this disruption as a problem, Ms. S made space for Dolores to share her feelings and engaged with Dolores's concerns. Ms. S and Ms. P continued to listen to this critique as they redesigned the unit to more carefully establish a foundation of connection and care with the guppies in Q2, which served as a starting point for generative sensemaking throughout the unit.

These episodes offer an example of how teachers might attend to and amplify generative feeling in science classrooms. Creating space for students to share their feelings, even if their contributions may be disruptive to the planned lesson, can open new trajectories for sensemaking and practice while also recognizing emotional resources that are not always welcomed in science classrooms. Yet, encouraging students to express all feelings could be overwhelming to students and teachers; we offer *generative feeling* as a lens to help teachers consider when and how to encourage and amplify student feelings in class discussions. In our case, Dolores's feelings of connection and concern were generative, because they led to the classroom exploring new questions and practices for studying guppies that impacted Author 4's teaching not only in Q1, but also in subsequent quarters. The foundation of care that was established in later quarters led students to new questions about the guppies and their ecosystems (see Authors, in revision, for more detail about these later cases).

This approach is a theoretical contribution because it applies the emotional configurations framework in a new way. Rather than using the framework retrospectively to recognize the interplay of feeling, sensemaking, and practice, we argue that considering how feeling could shape sensemaking and practice could help teachers make pedagogical decisions about how to facilitate classroom discussions. Moreover, this application of the framework demonstrates how emotional configurations can operate at a classroom scale, taking up one student's concern to influence how content and practice is discussed in her classroom and with future students, and at the same time, affirming the dignity of students and of the more-than-human participants in their investigations.

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Braiding Feeling, Sensemaking, and Practice in Science Investigations

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Abstract: Attending to emotion can expand the range of resources valued for science learning and offer insights about how students develop investigations and science practices. However, research that characterizes emotion as an integral part of science learning is relatively nascent (Jaber & Hammer, 2016; Lanoutte, 2022). In response, we explore dynamic relationships between feeling, sensemaking, and practice in a 6th grade STEM classroom, guided by Vea's (2020) framework of *emotional configurations*. Following from critical perspectives on western science that emphasize connectedness rather than objectivity (e.g., Fox Keller, 1985; Kimmerer, 2013), we illustrate how students' feelings, their sensemaking about biology and ecology concepts, and their practices of observation were intertwined in generative and mutually-reinforcing ways.

Objectives and significance

Attending to emotion in science classrooms can be a means to critique and expand typical images of science, which position science as culturally-neutral, objective, and value-free (Bang et al., 2012). Attending to emotion in this way takes students' feelings and their role in investigations seriously. Yet, education research that attends to emotion as a part of science, rather than as ancillary to disciplinary engagement, is relatively nascent (e.g., Lanouette, 2022; Jaber & Hammer, 2016). As a result, the role of emotion in learning is undertheorized (Boler, 1999). This is particularly problematic for our understanding of science learning, because, as critical scholars have noted, feeling is intertwined with sensemaking and practice (Vea, 2020), and feeling can generatively drive and even shape scientific investigations (Barad, 2007; Fox Keller, 1985; Haraway, 2016; Kimmerer, 2013).

We draw on Vea's (2020) emotional configurations framework to illustrate the dynamic interplay of feeling, sensemaking, and practice in 6th grade STEM investigations, focusing on classrooms' participation in a 9-week unit about biology and ecology. From our analysis, we argue that feeling is a critical part of learning in these classrooms. We illustrate that feeling is not only important to individuals and the classroom community inherently (Boler, 1999), but also that it plays key roles in constituting classroom investigations. Feeling shapes students' stances toward the organisms and systems they study, and it shapes the direction of their collective investigations. Reciprocally, novel sensemaking and practices provoke new feelings and depth of feeling.

In this paper, we focus on aspects of feeling and practice that have not yet been explored in research about emotion in science classrooms: feelings of *connectedness* and the practice of *observation*—both of which have been the focus of critiques of western images of science (e.g., Fox Keller, 1985; Kimmerer, 2013). In addition, whereas previous research has explored emotional configurations within student dyads (Lanouette, 2022), we trace emotional configurations across student groups to illustrate how feeling, sensemaking, and practice interact to shape multiple groups' investigations.

Theoretical framework and literature review

From physiological, psychological, and philosophical perspectives, emotion has historically been seen as an individual and interior affair. Classically, perspectives that view emotion as individual and interior have also positioned emotion as separable from scientific practice, which has been portrayed as objective and value-free (Bang et al., 2012). In response, in critiques of western science, scholars have argued that emotion is embodied, situated, and collaboratively constructed (e.g., Boler, 1999; Greene, 1988; Jagger, 1989) and have illustrated the fundamental roles of emotion in shaping disciplinary work (e.g., Barad, 2007; Fox Keller, 1983; 1985; Kimmerer, 2013). Applying such critiques to education, Boler (1999) argues that our educational systems and institutions have restricted expression of feeling as a form of social control (for example, through gendered ideas about who is allowed to express feelings in classrooms or by promoting skills such as "emotional intelligence").

While recent research has begun to attend to the role of emotion in learning, most studies characterize emotion as a "psychological construct distinct from the substance of learning" (Vea, 2020, p. 313; see also Pintrich, 2003; Ryan & Deci, 2000). In science education specifically, emotion, while intrinsic to scientific work, has been framed as a distinct instructional goal in its own right—for example, helping students "feel like a scientist" (Jaber & Hammer, 2016; see also Davidson et al., 2020; Jaber, 2021; Jaber et al., 2021; Radoff et al., 2019; Watkins et al., 2018). Rather than separating emotion from practice, Vea (2020) argues that emotion is an inextricable dimension of learning as a sociocultural activity. This social perspective shifts the analytic focus from *affect* (a heuristic used to describe "ambiguous felt intensity as a mode or moment in the process of emotion;" Vea, 2020, p. 326) to *emotion* (the coordination of feeling with social meaning and practices). To understand the nature of emotion in learning, Vea (2020) offers the analytic construct of *emotional configurations*: the situated and reciprocal interrelationships between feeling (embodied intensities; Vea, 2020, p. 315), sensemaking, and practice. In the context of science classrooms, we define sensemaking as recognizing and resolving inconsistencies or gaps in knowledge (Odden & Russ, 2018) and practice as developing procedures and measures to build knowledge (Lehrer & Schauble, 2015). We also build on Lanouette's (2022) application of the emotional configurations framework in her analysis of two pairs of elementary students engaging in ecology. Drawing on indigenous epistemologies that emphasize the importance of place in learning, Lanouette focused on how students' sampling practices were shaped by feelings related to specific places in the schoolyard. Following from this work, we look to critiques of western science to identify additional emotional resources that may often be overlooked in science classrooms. Inspired by these critiques, we focus on feelings of *connectedness* that were intertwined with sensemaking and with *observation* practices. However, we do not anticipate students' values or practices would reproduce these professional values or practices; such an assumption would be a disservice to both professional and classroom contexts, which each address different goals.

In professional science, scholars from multiple backgrounds and perspectives have emphasized *connectedness* to critique western practices, which are often positioned as unemotional and objective (Bang et al., 2012). For instance, reflecting on her own practice as a scientist, Kimmerer (2013) offers a critique of the ideology of mainstream western science—a critique that motivates her own approach as a biologist, which she conceptualizes as "braiding" traditional disciplinary practices and perspectives with indigenous ways of knowing. One of the many transformative effects of this braiding is a radical reconfiguration of the relationality between scientists and nature. In particular, Kimmerer critiques the dualistic stance of objectivity, in which separations between knower and known, observer and observed, and scientist and nature underwrite the extractive perspective of traditional science (e.g., industrial forestry practices that maximize short term yield of lumber but damage complex ecosystems). In contrast, Kimmerer advocates a transformed relation that integrates science and scientists with the world being understood. From this perspective, science becomes a "conversation" with phenomena that involves "listening and translating the knowledge of other beings" (p. 158). Such conversations offer insights that were not initially apparent from the perspective of western science (e.g., how harvesting sweetgrass promotes its growth; how pecan trees communicate). While Kimmerer draws on her own experience bringing indigenous epistemologies into her disciplinary science practice, others have described ways that scientists have implicitly or explicitly challenged western science by drawing on practices or epistemologies that have historically been considered external to science. For instance, scientists and critics drawing on feminist perspectives (among other critical stances, e.g., post-humanism, eco-feminism, and materialism) have traced standard notions of objectivity and dualism in observation and other scientific practices as a grounding for objectification and power relations (Fox Keller, 1985) that endorse overly limited epistemologies as natural to STEM disciplines (Turkle & Papert, 1992); encourage essentialism (Haraway, 1988); undermine relations of kinship with the more-than-human (Haraway, 2016); and neglect the entanglement of ethical, epistemological, and ontological dimensions of science (Barad, 2007). In classroom settings, we argue that feelings like connectedness can be generative drivers of investigations as well, including in practices such as observation.

Historically, *observation* has been described as "neutral" and "passive" (in contrast with an "active" experiment; Daston, 2011). Pushing back against more recent characterizations of the practice of observation as objective, Goodwin (1994) explained that observation is socially structured, using the term "professional vision" to describe a socially organized way of seeing and understanding phenomena, which influences what is worth observing and what actions should occur in response. Moreover, Hall and colleagues (e.g., Hall & Jurow, 2015) showed that what is "seen" by a professional community is driven by that group's values (a component of feeling or emotion; Boler, 1999). Yet, in classrooms, students are often encouraged to use disciplinary scaffolding (Barth-Cohen & Braden, 2021; Eberbach & Crowley, 2009; Smith & Reiser, 2005), which can them from drawing on their resources to develop their own observational practices (Manz et al., 2020; p. 1159). We argue that encouraging students to draw on resources considered external to science (such as feelings of care and connectedness) could support students' engagement with the full spectrum of practices involved in observation (e.g., asking questions, hypothesizing, developing explanations; Marin & Bang, 2018).

In our findings below, we illustrate that connectedness was a generative force in students' investigations that shaped (and was shaped by) students' sensemaking and practice (specifically, feelings of connection-with-others, including the teacher, peers, and the "object of study;" Jaber & Hammer, p. 193—in this case, guppies). Extending previous research, we consider the reciprocal and generative relationship between feeling, sensemaking, and practice not only for individual students or dyads, but also across student groups, and we illustrate how these strands are *braided* together in classroom investigations. “Braiding,” as a metaphor, builds on Kimmerer’s (2013) personal account of constructing an approach to draw on both indigenous epistemologies and disciplinary science to explore and understand natural phenomena. While students in our data do not draw on indigenous epistemologies, they do critique and are supported to transform their classroom’s understanding of science by bringing their feelings (of care, concern and connectedness) into the realm of scientific investigations as driving factors that organize their observational work.

Method

This study was conducted in a public middle school in a suburban school district in the southeastern US in collaboration with a STEM teacher, Ms. S, in her 26th year of teaching at the start of the study. We analyze data from one of Ms. S’s 9-week sixth grade classes (25 students, August-October 2019). According to the state report card, 18% of the school’s students qualify for free or reduced lunch. The students in the school are culturally and linguistically diverse: 55% of students identify as White, 34% as Hispanic or Latino, 7% as Black or African American, and 4% as Asian. 8% are classified as English Learners. Students participated in a unit that foregrounded modeling that was co-designed and co-taught by Ms. S and the first author, Ashlyn. The unit was framed by two design challenges: students designed a biosphere, a closed-system physical model that included plants, snails, and guppies; and they programmed a computational model that represented a larger ecosystem of plants, snails, guppies, and guppies’ competitors and predators. Throughout the unit, the students gathered information and re-represented the guppies’ environment with increasing complexity.

We analyzed whole-class data during the 9-week unit. Two cameras positioned on opposite sides of the classroom captured classroom discourse. We began by creating content logs and rough transcripts of classroom videos (Erickson & Schultz, 1997). In our analysis, we focused on identifying feelings that shaped the trajectory of classroom investigations. We used Discourse Analysis (Gee, 2014; Norris & Jones, 2005) to closely analyze the multimodal expression and interplay of feeling, sensemaking, and practice. We conceptualized emotional configurations as sustained and shared sensitivities to phenomena during the class’s investigations, where (a) students expressed embodied intensities (feelings), (b) students worked collaboratively to build knowledge (sensemaking), and (c) students developed shared ways of participating in the investigation (practice). We then traced these emotional configurations back to their roots in classroom interactions, as well as forward to their ending points (when students’ goals for their investigations were achieved, frustrated, altered, or otherwise exhausted). For evidence of feeling, we attended to the following forms of expressed emotion (Boler, 1999): (a) physiological, for example, a gasp or laughter; (b) cognitive/conceptual, for example, describing a feeling of connection with the guppy, including hope or concern; and (c) moral/evaluative, for example, making decisions about guppies or models based on feelings of connection. For evidence of sensemaking, we attended to moments where students iteratively noticed inconsistencies or gaps in their knowledge and generated explanations to reconcile these issues (Odden & Russ, 2018). For evidence of practice, we attended to the ways that students used procedures, measures, and materials in service of the shared investigation (Lehrer & Schauble, 2015). Then, after identifying these components of emotional configurations, we traced their interplay. Specifically, we analyzed transcripts to determine whether and how feeling influenced sensemaking (new questions or understandings) and practices (new ways of seeing and interpreting the biosphere jars), as well as whether and how sensemaking and practice sustained or evoked feeling within small groups or across the classroom (for instance, observing the jar evoking feelings of care or concern for the guppies).

Findings

Below, we illustrate how the classroom approach of braiding feeling, sensemaking, and practice emerged and persisted, generating emotional configurations that helped to shape the students’ investigations. First, we describe the appearance of baby guppies in one of the jars. Then, we describe a 26-minute episode focusing on students in one group, Genesis, Hannah, Amy, and Pepper, whose feeling (hope, excitement) about the baby guppies shaped observations and interpretations of their own jar. This event led the focal group to ask new questions, fostering the development of a “professional vision” (Goodwin, 1994) about what was happening with their guppy and to broader scientific and social conversations about reproduction across species relevant to these 6th grade students.

When students arrived in class on Day 15, they were surprised and excited to find baby guppies in Bob, Denise, Princess, and Margaret’s jar. Students crowded around the jar with the babies, gasping, squealing, and expressing excitement about this change. After this interaction, Genesis ran back to his own jar to look for babies. As he leaned in to look at his own jar, he asked Hannah, “wait, did ours have babies?” While they did not find babies, Hannah reminded Genesis that the group thought their female guppy was pregnant, saying “did you not know that? That’s the only reason why we chose it.” These baby guppies indicated to students that birth was a real *possibility* in the jars and attuned students to potential indicators of baby guppies in observations of other jars.

Genesis began to observe and interpret his jar in terms of guppy reproduction. He suggested that their guppy had laid eggs in the jar, though Hannah disagreed:

Genesis: Ours laid eggs, we see little red eggs in there
Hannah: Those aren't eggs
Genesis: No they are eggs
Hannah: ((exasperated)) No they're not.

More than five minutes later, Genesis was still focused on the question of whether babies could appear in his jar. He listened as Ms. S talked to the group with baby guppies in their jar:

Ms. S: Okay, make some observations, that's really interesting, so what about, um, what do they look like, you can keep that observation but what do those babies look like? Do you think that they were an egg first and then a baby or do you think they just came out as a baby?
Genesis: Wait they can come out as a baby? She said do they lay eggs or just come out as a baby.

After hearing Ms. S's question, Genesis considered that the fish might "come out as a baby" rather than as eggs, shifting what was important to look for and notice in his jar. Throughout the class session, Genesis's hope and excitement about the possibility of baby guppies drove how he observed his jar.

On Day 21, Bob, Denise, Princess, and Margaret showed connection to the baby guppies, checking on them at the beginning of each class period and framing the guppies as part of their family (Denise: "I'm a grandma!). Genesis, Hannah, Amy, and Pepper hoped to similarly see baby guppies appear in their own jar. While walking into class on Day 21, Pepper asked her group from across the room, "are our guppies dead? Do we have babies?" When they leaned in to look at their jar, hope for baby guppies shaped how they saw the jar. Amy and Genesis initially focused on "eggs," which led to a discussion of guppy reproduction in the context of observations of their jar:

Genesis: What's happened?
Amy: Where's the - where's the clear eggs?
Genesis: Oh wait! Are those brown things kinds of eggs? Look at all those eggs down in the sand.
Hannah: Eggs don't um - fish don't lay eggs
Hannah: So those are either poop or
Genesis: No wait- no fish lay eggs, but guppies don't. Guppies are like- wait, what if guppies are genetically modified fish?
Amy: Guppies - guppies have live birth
Pepper: Wait I have a question. So, supposedly, they're not pregnant, they have a baby like instantly?

Above, the students looked for eggs in the jar, which required them to decide what might be an "egg" versus "poop." How they saw the "brown things" in the jar was shaped by the reminder that guppies don't lay eggs; thus, their vision of the jar was shaped by their concern, excitement, and specific interest (feeling) as well as their developing understanding of guppies' life cycles (sensemaking). As Pepper wondered if this meant the guppies "have a baby like instantly," Genesis raised a new concern about the jar:

Genesis: What is that thing like sticking out of the female. There's something like sticking out of the female.
Pepper: It's poop
Genesis: No, that's not poop.
Genesis: It doesn't come from the same place.
Pepper: ((whispers to Amy)) Oh, she's on her period. Wait, can fish have periods?
Amy: I don't know
Pepper: ((whispers to Hannah)) Can fish have like, you know, periods?
Amy: Yeah they do
Hannah: They can?
Pepper: I did not know that, I did not know that, I actually, I did, but I didn't like know until like a month ago, like I s—((twirling hair)) Me and my mom were talking about it

and I was like, "I want a girl dog" and she was like "no, it's too much to take care of" and she told me and I was like "really?" And she's like "yeah"
Genesis: There's something pooping out and it's not poop, I can tell. I think, I think - it looks like blood, or it might be part of the fish

Genesis noticed something "sticking out of the female" that was "not poop" – "it doesn't come from the same place." This observation led Pepper to a new question about guppy reproduction – "can fish have periods?" She raised the question with Amy and Hannah, considering evidence from a conversation with her mom about how other animals (dogs) might have periods. This conversation occurred in whispers, and the girls did not include Genesis. Yet, Genesis's continued close observation fit with their theory ("it looks like blood").

This line of investigation reciprocally impacted feeling in the group—it bonded the girls, who had an "inside joke," yet made Genesis feel excluded. He asked Ms. S:

Genesis: Why are they all laughing?
Ms. S: ((wave away gesture)) It's cause they're girls. Alright
Amy: Chill, Pepper, it's not even that funny
…
Genesis: I don't understand. Is there like some inside joke?
Amy: No
Hannah: Yes, it's an inside joke
Pepper: It's a girl joke

Later, Genesis guessed why the girls were laughing:

Genesis: I just remembered something my mom told me
Hannah: No
Pepper: It's an inside joke - I think Genesis knows
Genesis: Why are you laughing at that, that's so gross
Pepper: It's not gross
Pepper: I don't get how that's gross.

After Genesis figured out the "inside joke," he asked, "why are you laughing at that? That's so gross." Pepper pushed back on this characterization of periods as "gross," saying "it's not gross, I don't get how that's gross," braiding students' lived experiences and social issues with their observations of the guppies.

When Ms. S came over to check on the group, Pepper asked Ms. S whether the guppy was pregnant. Ms. S guided the students to look for indicators (a black spot at the back of a female guppy's abdomen could indicate pregnancy). She also raised a new concern for the students – that the male guppy could try to eat the baby guppies:

Pepper: Guys isn't our - isn't our guppy pregnant?
…
Ms. S: Does it have a black sort of spot toward the back of its abdomen? ((pointing at jar))
Pepper: Yes
Ms. S: Usually they have a black spot
Amy: Yeah, right there ((pointing at guppy in jar))
Ms. S: Okay. Now this one may be trying to eat the babies
Amy, Pepper: ((Lean back, surprised/scared faces))
Ms. S: He seems pretty aggressive
Pepper: ((glancing back and forth between Ms. S and the jar)) ohh
Amy: ((laughs))
Ms. S: They do that sometimes
Pepper: What if he already ate a couple?
Ms. S: Could have been
Ms. S: It's happened before. You notice how
Pepper: He's like following her
Ms. S: It's happened
Pepper: ((to the male guppy)) I'm gonna kick you if you do

Ms. S helped Amy and Pepper "see" pregnancy in the jar by looking closely at the female guppy's abdomen, pointing at the jar – a gesture that Amy repeated when she also saw the black spot on the female guppy. Then, she described a new indicator – that the aggressive male guppy could be a sign about babies, as well as a threat to the babies' safety. That is, on one hand, the male guppy's attention could indicate a birth was imminent, but it also could indicate a threat to the newborns, because male guppies, in the past, had tried to eat babies. For the students, this raised another concern for the safety of both the female guppy and the babies, which served as a press for closer observation and once again raised the stakes for the students – making sense of events in their jar could be critical to the guppies' wellbeing. They responded by speaking directly to the male guppy as they watched him for signs of aggression ("I'm gonna kick you").

The question about the blood on the female fish was still unresolved, and it was raised again by Pepper:

Pepper: (to Amy) Wait, how is that possible?
Amy: I don't know
Pepper: (to group) Wait, if she's on her… then how is she pregnant?
Amy: Oh
Genesis: I'm not going to ask question about the blood in the water
Amy: It happens to some girls still
Pepper: I know - it depends like when you start

Pepper and Amy decided it was possible for the fish to be "on her [period]" and still be pregnant – resolving a question that emerged in the process of sensemaking about the groups' observations – but also resurfacing the Genesis's earlier characterization of periods as "gross" that was still unresolved:

Genesis: I have older teenage sisters
Amy: So you know what it is?
Genesis: Yes, I know what it is
Pepper: You find it nasty?
Genesis: ((nods))
Pepper: In my opinion it's not nasty
Genesis: In my opinion it's …
Pepper: You know, probably your mom instead of having her period she had you. That's all what I'm gonna say.
Genesis: ((hides head in shirt))
Pepper: ((covers mouth and laughs))
Genesis: I don't like that
Pepper: No but it's true. Instead of having that she had you, and she probably didn't like that, instead. You should think about that.

Pepper again challenged Genesis's earlier implication that periods are "gross," arguing that periods are "not nasty" because they are a normal part of (human) reproduction and life cycles – connecting Genesis himself to periods ("your mom instead of having her period she had you"). In this way, feeling (in terms of the biosphere jar and in terms of students' social dynamics) continued to be interwoven with students' sensemaking about their jar and their observation of their jar.

Throughout the rest of the class session, the students closely watched their jar – both out of concern for the female guppy and in hope that they might "see her have babies." They raised new questions in an attempt to make sense of their conflicting interpretations of their observations (potential pregnancy, or potential period):

Hannah: Maybe she lost -
Pepper: ((gasps))
Amy: ((hands out, palms up))
Ms. S: Maybe
Genesis: No cause there's a guppy like- it's like that big inside of her. So I think it's too big.
Pepper: They can have miscarriages?

Above, students' observations (e.g., the male guppy following the female), questions (e.g., can a guppy have a period and be pregnant?) and feelings (e.g., concern, hope) guided their observations of the jar. Until the end of class, the students continued to ask questions as they closely watched the female guppy. While the female guppy did not give birth during this class session, attending to the biosphere jar through the lens of the *possibility* of this event led students to engage in in-depth explorations of guppies' life cycles and comparisons to other species (primarily humans) and to events and experiences that were meaningful and familiar to them.

Discussion and conclusions

Our findings demonstrate that attending to emotional configurations in science classrooms can support new understandings of science learning and new forms of participation in these spaces. Existing research in science education shows that emotion is intrinsic to epistemic activity (e.g., Jaber & Hammer, 2016) and can guide students' investigations (e.g., Lanouette, 2022). Our findings build on this work by illustrating the reciprocal relationships between feeling, sensemaking, and practice.

In the episode above, students' feelings, sensemaking, and practice shaped their relationship to their peers and the biosphere jar project, as well as to the trajectory of the classroom's investigation. Bob, Denise, Princess, and Margaret's jar alerted the other students to the *possibility* of reproduction in their own biosphere jars. This possibility fostered an emotional configuration that led students, like Genesis, Hannah, Amy, and Pepper, to more closely examine and actively observe their own jars, looking for new evidence or indicators that could help them make sense of their questions and observations. They exerted effort to make sense of indicators in their jars (sensemaking, practice) because of their own concerns for their guppies' lives and wellbeing (feeling). For this group, questions about guppies' reproduction were intertwined with sensemaking about experiences related to human reproduction (periods, miscarriages) that led to uncomfortable, yet meaningful, conversations in which Pepper pushed back against stigmatizing periods as "gross" or "nasty." In the interactions through which the group regulated and negotiated Genesis's response, at issue was not only his relationship to and participation in the social group of the table, but also his ability to effectively participate in and contribute to the observational work that the group was doing. These conversations unfolded in the context of close observation of their jar, motivated by hope and excitement, but also by concern, for their guppy and its potential babies, in relation to the observations and experiences of other groups with newborn guppies. In this way, feeling and sensemaking were intertwined and shaped students' observations and investigations across the classroom community.

This study adds to the growing body of literature that demonstrates the importance of attending to feeling in order to understand learning (e.g., Jaber & Hammer, 2016; Lanouette, 2022). Specifically, we show that if researchers overlook feeling, they could be missing a driver of students' investigations, especially in classrooms in which students have significant epistemic authority to shape the questions they ask and explore and the practices they develop in response. Just as critical perspectives of images of professional science emphasize the importance of feeling in disciplinary work (e.g., Fox Keller, 1985; Kimmerer, 2013), we propose that feelings like connectedness can play an important role in supporting students' sensemaking by guiding the content they focus on and their practices and by guiding the methods they develop to explore this content. Moreover, we argue that connectedness is important at multiple levels; for the classrooms we have studied, learning was consequential because of connections to guppies, peers, their teacher and to social issues.

Furthermore, we echo the arguments of scholars who propose that attending to feeling is essential for equitable teaching and learning (e.g., Boler, 1999; Shalaby, 2017). While this work has normatively characterized feeling as a separate from learning (through equally important), we follow Vea (2020) and critical scholars of professional science (e.g., Fox Keller, 1985; Kimmerer, 2013) in characterizing feeling as inextricably intertwined, or braided, with the disciplinary work of sensemaking and practice. Acknowledging the epistemic role of feeling can help both researchers and educators transform what it means to participate in science learning, re-interpret students' feelings as essential to inquiry, and thus invite students to bring a wider range of resources to classroom science learning. Moreover, this frame explicitly welcomes non-dominant images of science that have traditionally been excluded from western science learning (Bang et al., 2012; Warren et al., 2020). For instance, this lens enables us to attend to mediating factors for the practice of observation beyond disciplinary knowledge (e.g., social, imaginative, and motivational factors). There is still much to learn about attending to feeling in science classrooms. Even so, these findings demonstrate the transformative potential of emotional configurations as a lens for designing curriculum and for analyzing science learning.

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Influences on Current Motivation in Digitally Supported Learning: An Analysis Using Regression and Necessary Condition Analyses

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Abstract: Learners' current motivation according to the conceptualization of Rheinberg and colleagues is crucial for taking up and pursuing learning activities. Yet, there is still little research regarding the necessary level of factors affecting current motivation itself. This study was designed to start filling this research gap by examining the relative contributions of person-related factors on students' current motivation to learn with a digitally-supported learning environment, focusing on experiments in chemistry education. The study's sample consisted of 155 second graders. Multiple linear regression and necessary condition analysis (NCA) were used to investigate possible factors that predict students' current motivation to learn (i.e., interest and challenge). Results indicate that students' self-perceived experimentation competence and self-determination positively influence interest, while self-determination alone predicts challenge. However, NCA results reveal all variables as necessary conditions, that set restrictions for the maximum level of interest and challenge. Practical and research related implications are discussed.

Introduction

At the beginning of a learning phase, learners' current motivation plays a major role in taking up and pursuing learning activities (Keller, 2008; Thoman et al., 2017; Vollmeyer & Rheinberg, 2013). Current motivation to learn results from an interplay between characteristics of learners (e.g., topic-related interest or motive to achieve) and characteristics of a specific learning situation (e.g., the difficulty of the task at hand). A large body of research has already proven, that especially during self-directed learning situations, the current or initial motivation to learn has a high impact on learning behavior and is closely linked to task performance and learning success (e.g., Barron & Hulleman, 2015; Rheinberg et al., 2001; Scholer et al., 2018; Schwinger et al., 2009; Thoman et al., 2017; Vollmeyer & Rheinberg, 2006). However, there is less research on the factors that in turn influence current motivation itself, in particular on their necessary extent (Liebendörfer & Schukaljow, 2020; Paulino et al., 2016; Scholer et al., 2018). Thus, the purpose of the present study is to investigate potential influences on the level of second graders' current motivation during learning (interest and challenge) when working through a self-directed, digitally-enriched learning environment within chemistry education, the so called EXBOX-Digital. The EXBOX-Digital consists of three main components: 1) a web-based training (WBT) presented on a tablet PC, 2) three small-scale hands-on experiments, and 3) sequential digital support during experimentation. Three person-related aspects were included as possible factors of influence on current motivation: First, students' level of self-determination (i.e., the overall level of intrinsic motivation) to learn in chemistry classes is investigated as a basic and rather time-stable personality variable that is assumed to influence current motivation (Thomas & Müller, 2015). Second, the students' self-perceived experimentation competence is included, because similar to effects of self-efficacy expectations, students' feelings of competence represent an important component for describing interest-driven action (Krapp, 2002). Finally, students' perceived usefulness of tablets for learning is included as an indicator of their attitude towards a characteristic of the learning situation, i.e., the tablet as digital learning medium used in this study (Davis, 1989; Vogelsang et al., 2017). The first aim of this study is to investigate via regression analysis, to what extent those three factors predict students' current motivation to learn with a digitally-enriched learning environment within chemistry education. In addition, the present study uses a relatively new statistical approach called necessary condition analysis (NCA), to investigate the extent to which the above-mentioned factors prove to be necessary (but not sufficient) conditions for current learning motivation (Dul, 2016).

Theoretical background

In the following, the concept of current motivation to learn is introduced as well as the three potential influences: students' level of self-determination to learn in chemistry classes, self-perceived experimentation competence, as well as students' attitude towards the learning medium, i.e., perceived usefulness of a tablet for learning purposes.

Current motivation to learn

Motivation of learners is proven to be essential for learning processes and academic success. However, the nature of motivation is multifactorial and rather complex. The concept of motivation in general describes the intention to actively engage in a learning activity, but it can vary in amount and kind of motivation. Pintrich and Schunk (2002) argue that motivation is a "(…) process whereby goal-directed activity is instigated and sustained" (p. 5). The concept of current motivation as it is described by Rheinberg, Vollmeyer and colleagues (e.g., Rheinberg et al., 2000; Vollmeyer & Rheinberg, 2013) includes different aspects of activity-related (or intrinsic) motivation in the sense of self-determined behavior, interest or the will to achieve anticipated goals (Rheinberg et al., 2000; Rheinberg & Engeser, 2018) and is of high relevance for task processing in learning situations. It captures a current motivational state that is a product of the learners' rather enduring personality traits (trait variables) and the specifics of the learning situation at hand (state variables; Scheffer & Heckhausen, 2018; Vollmeyer & Rheinberg, 2013). Person characteristics include rather stable motives, interests and self-efficacy beliefs, while situational characteristics are defined by the specific circumstances of the learning situation, like task difficulty, its structure or subject matter. Rheinberg and Vollmeyer (2013; see also Freund et al., 2011) describe four components of current motivation: 1) situational interest in the specific task content (how much learners are interested in the content at hand), 2) anticipated challenge (learners' perception of to what extent the task at hand requires competence; competence-related opportunity to test one's proficiency), 3) anxiety (how anxious are learners to fail the task), and 4) probability of success (extent of probability to succeed in the task). Current motivation influences, for example, learning performance, learning success and persistence during learning (Barron & Hulleman, 2015; Rheinberg et al., 2001; Scholer et al., 2018; Schwinger et al., 2009; Thoman et al., 2017; Vollmeyer & Rheinberg, 2006). In particular situational interest and anticipated challenge are related to learning performance in understanding-oriented and self-directed learning environments that require a certain amount of effort beyond routine, e.g., the use of (meta-)cognitive strategies (Freund et al., 2011, Rheinberg, et al., 2001).

Possible factors influencing students' current motivation to learn

While it is empirically confirmed that the various aspects of current motivation have a high impact on learning, there is less empirical research on the level of possible factors of influence on current motivation itself. In the following, three factors are described in more detail, that might affect current motivation when learning with the EXBOX-Digital and, thus, are part of the following empirical investigation: students' level of self-determination during chemistry learning in school, self-perceived experimentation competence, and perceived usefulness of the tablet as digital learning device.

Level of self-determination during chemistry learning (SDI)

Self-determination theory (Deci & Ryan, 2002; Ryan & Deci, 2000, 2018) has differentiated between two main facets of motivation: intrinsic motivation (or activity-related motivation; Rheinberg & Engeser, 2018) and extrinsic motivation. According to Deci and Ryan (2002; Ryan & Deci, 2000, 2018) intrinsic motivation refers to self-determined interest- or joy-based engagement in an activity, while extrinsic motivation refers to rather outcome-oriented motivation. Intrinsic motivation in particular is of relevance for instruction, as it fosters sustainable learning. However, within the framework of self-determination theory, motivation is not considered as a dichotomous variable, but extrinsic motivation is divided into four subdomains according to the increase in self-determination (Ryan & Deci, 2018). All types of motivation can be located on a continuum, from extrinsic to intrinsic motivation with a gradually increasing proportion of self-determination (Müller & Palekčić 2005; Thomas & Müller, 2015).

Based on these assumptions, a possible influence on current motivation in learning with the EXBOX-Digital might be the students' level of self-determination in school-related chemistry learning, which expresses the degree of the students' intrinsic motivation. It can be considered as an overarching trait variable and is assessed in this study via students' self-determination index (SDI; Levesque et al., 2004; Müller & Palekčić, 2005; Thomas & Müller, 2015). The SDI is calculated using a formula composed of individual components of motivational profiles and based on self-determination theory (Ryan & Deci, 2000, 2018; Deci & Ryan, 2002).

Self-perceived experimentation competence

Self-perceived competence is a major factor of influence of intrinsic motivation and according to self-determination theory one of the motivation-related basic needs of learners (Deci & Ryan, 2002; Ryan & Deci, 2000, 2018). It can be seen as closely related to self-efficacy expectancy, which is an important component in promoting overall motivation and interest-driven actions (Barron & Hulleman, 2015) and can be seen as a necessary but not sufficient condition of interest development (Krapp, 2002). Self-efficacy describes the beliefs of persons in their own ability to perform a specific task and has a positive influence on learning performance and motivation (Bandura, 1997).

Since the EXBOX-Digital includes a practical part with real hands-on experiments after the web-based training, self-perceived experimentation competence can be considered important for the successful completion of the EXBOX-Digital intervention. Preparing, conducting and observing experiments can be seen as essential components of experimentation competence (Busker et al., 2010; Meinhardt et al., 2018). Although all of the EXBOX-Digital experiments are designed to be easy to understand and can be performed by all students using the digital sequential learning aids, it is still important to examine the influence of how the students perceive their own experimentation competence.

Attitude towards the learning medium: Perceived usefulness of a tablet

The tablet plays a major role in learning with the EXBOX-Digital, both in the WBT and for accessing the digital sequential learning aids during experimentation. The third factor investigated is therefore the students' attitude towards the learning medium, i.e. the perceived usefulness of a tablet for learning purposes. This factor is derived from the attitude variable "perceived usefulness" of the Technology Acceptance Model (TAM; Davis, 1989; Venkatesh et al., 2003) that is often used to classify possible factors for a person's intention to use digital technology.

The extent to which a tablet is perceived as helpful for learning is relevant to students' current motivation to learn with the EXBOX-Digital, given its prominence in the lesson. Ngai and colleagues (2007) found that perceived usefulness is a dominant factor affecting the use of a web-based learning program. Therefore, it is interesting to investigate how strong the influence of the perceived usefulness of a tablet for learning purposes might be on current motivation.

Research questions

Taken all the above described issues into account, this study seeks to explore the following research questions: (1) *To what extent do self-perceived experimentation competence, self-determination in chemistry learning, and perceived usefulness of the tablet for learning purposes influence current motivation (interest and challenge) when learning with a digitally-supported learning environment, focusing on experiments in chemistry education?* (2) *To what extent are self-perceived experimentation competence, self-determination in chemistry learning, and perceived usefulness of the tablet for learning purposes necessary conditions for current motivation (interest and challenge) when learning with a digitally-supported learning environment, focusing on experiments in chemistry education?*

Method

In the following, sample, learning material and instruments will be described. Finally, data analysis methods are explained in more detail.

Sample

158 Austrian students with a mean age of 13.38 years (*SD* = 0.73), attending lower secondary school, participated in the study. The participants consisted of 82 males, 74 females and one non-binary person (plus one missing value). Three students were excluded from the calculations as outliers, leaving a sample size of *n* = 155 participants.

Learning material

STEM education aims to provide with an understanding of scientific concepts, scientific thinking, and problem solving (Brown et al. 2016), and experiments are an essential component of STEM education. In this study, students learned about redox reaction in two chemistry lessons using the EXBOX-Digital. The three components of the EXBOX-Digital adapt to the individual learning pace and provide support when needed: 1) An adaptive web-based training (WBT) was designed for the respective lesson, which teaches basic subject knowledge via tablet PC. The students' comprehension is checked by some quizzes and, if necessary, supplementary learning modules are presented to bring all students up to the same level of knowledge. 2) When the WBT is successfully completed, three real hands-on experiments follow. These are designed as small-scale experiments, and students individually work on them. 3) While working on these experiments, students can independently receive scaffolded digital assistance in the form of images, videos, or augmented reality (AR), which can be accessed via tablet PC through QR codes provided on a separate document for individual use. This concept allows learners to work according to their individual competences and at their own pace.

Instruments

Data collection took place within the winter semester 2019/20 and in the summer term 2020 at Austrian secondary schools. The following measurement means were used:

Current motivation to learn: As dependent variable, we assessed students' current motivation to learn, i.e. current *interest* and anticipated *challenge*, based on Rheinberg et al. (2001). Since the students already had experience with another version of the EXBOX-Digital, the learners already knew what to expect. Five items assessed interest (example item: "The tasks seem very interesting to me."; α = .85), and four items assessed challenge (example item: "These tasks are a real challenge for me.", α = .77). Each item could be answered on a seven-point Likert-scale ("agree" to "disagree").

Level of self-determination in learning chemistry (SDI): Furthermore, the level of self-determination in learning chemistry was added to the analysis. This was calculated using the SDI questionnaire, that includes 13 items related to intrinsic motivation, identified regulation, introjected regulation and external regulation (e.g., "Mostly I learn chemistry because I enjoy it", Levesque et al., 2004; Thomas & Müller, 2015) with the following formula: SDI = (2 x intrinsic motivation) + identified regulation – introjected regulation – (2 x external regulation). Values between -12 and 12 can be assumed: If the SDI is negative, the person is more externally determined; if the SDI is positive, the person is rather self-determined (cf. Levesque et al., 2004; Müller & Palekčić, 2005; Thomas & Müller, 2015). A four-point Likert-scale was used, with answers ranging from "not true" to "completely true".

Self-perceived experimentation competence (SEC): As first independent variable, the self-perceived experimentation competence of the students in chemistry was surveyed. For this purpose, a scale with 15 items was developed based on Busker et al. (2010) and Meinhardt et al. (2018), assessing students' self-perceived competence in setup, execution, and observation of experiments (e.g., "I have manual skills to set up experiments independently,"). All items could be answered on a five-point Likert-scale ("strongly disagree" to "strongly agree"). A mean value was calculated across all domains (α = .88).

Perceived usefulness of a tablet for learning purposes (PU): Finally, the perceived usefulness of a tablet PC for learning was assessed. Two items measured students' perceived usefulness of the tablet for school-related learning purposes (α = 0.69; e.g., "The tablet allows me to complete tasks faster."). The items were created based on the paper of Vogelsang et al. (2017) and could be answered on a five-point Likert-scale from "strongly disagree" to "strongly agree".

Data analysis

For answering RQ1, SPSS version 27 was used to analyze descriptive data and to conduct regression analysis in order to find determinants that (on average) contribute to current motivation, to predict current motivation based on the independent variables. It is of further interest (RQ2) to analyze to what extent the independent variables are actually necessary for a certain amount of current motivation (even if the presence of the variable cannot guarantee the occurrence of motivation, i.e., it is not sufficient). A relatively new approach to the educational sciences is used to address this issue and to complement regression analysis: necessary condition analysis (NCA; cf. Dul, 2016; see also Garg, 2020; Garg & Sarkar, 2020; Lee & Borgonovi, 2022; Tynan, 2020). To compute NCA, we used the statistical software R version 4.2.1 with a package entitled NCA. The logic behind NCA is explained by Dul (2016) as follows: A necessary condition is a critical factor of an outcome (like a constraint or bottleneck). If a necessary condition is missing, there will be no outcome, and this cannot be compensated by other determinants. To prevent failure of a specific outcome, each single necessary condition must be in place. However, when the necessary condition is in place success is not guaranteed: the condition is necessary but not sufficient. Three statistical values are of importance in NCA: accuracy of the ceiling line (must be above 95%; NCA reveals areas that indicate the presence of a necessary condition by determining a ceiling line on top of the data in a XY-scatter plot. This boundary separates the zone with observations from the empty zone without observations in the left upper corner by drawing a straight ceiling line. Its accuracy is described by the number of observations that are on or below the ceiling line divided by the total number of observations, multiplied by 100%), effect size (common d-value standards to detect the impact of the necessary condition) and statistical significance (common p-value standards, calculated by permutation test). Further, a bottleneck table reveals which level of each condition is necessary for which level of interest and challenge.

Results

Within the next section, descriptive data and results of regression analysis and NCA are presented.

Descriptive data

Table 1 shows mean values and standard deviations for each scale.

Table 1
Means and standard deviations of each scale

	M	*SD*
Interest^{+}	4.60	1.38
Challenge^{+}	4.85	1.46
Self-determination index (SDI)$^{++}$	2.19	2.93
Self-perceived experimentation competence (SEC)$^{+++}$	3.71	0.63
Perceived usefulness of tablet (PU)$^{+++}$	4.05	0.85

Notes: $^{+}$Likert-scale 1 to 7; $^{++}$Scale -12 to 12; $^{+++}$Likert-scale 1 to 5

On research question 1

According to regression analyses, the predictors explained a significant amount of the variance in interest ($R^2_{corr} = .30$; $p = .000$) and challenge ($R^2_{corr} = .09$; $p = .002$). SDI ($\beta = .39$) and SEC ($\beta = .25$) significantly predict interest (see also Table 2). For challenge, SDI ($\beta = .24$) is a significant positive predictor (see also Table 3).

Table 2
Beta-values, t-values and p-values of possible predictors of interest

	β	*t*	*p*
Self-determination index (SDI)	.39	5.20	.000***
Self-perceived experimentation competence (SEC)	.25	3.18	.002**
Perceived usefulness of tablet (PU)	.14	1.89	.062

Table 3
Beta-values, t-values and p-values of possible predictors of challenge

	β	*t*	*p*
Self-determination index (SDI)	.24	2.80	.006*
Self-perceived experimentation competence (SEC)	.12	1.33	.184
Perceived usefulness of tablet (PU)	.10	1.16	.247

On research question 2

For both interest and challenge, all three variables turn out to be significant necessary conditions according to NCA. All variables show medium effect sizes for interest (PU: $d = 0.24$; $p < .01$; SEC: $d = 0.21$, $p < .00$ and SDI: $d = 0.17$, $p < 0.01$) and challenge (PU: $d = 0.21$, $p = .02$; SEC: $d = 0.14$, $p = .03$; SDI: $d = 0.13$, $p = .04$). CR-FDH ceiling line accuracy for all scales is above the critical value of 95%.

The bottleneck table indicates the required level of the necessary conditions for specific levels of interest (Table 4) and challenge (Table 5). Guideline is the range of conditions and outcome: 0% is the smallest observed value and 100% is the largest observed value. Table 4 reveals, that from the value of 50 % of interest level (3.50 points on interest scale) and up, all variables can be identified as necessary conditions (SEC: 17.5 % / 2.30 points on SEC scale; SDI: 8.6 % / -6.29 points; PU: 13.2 % / 1.53 points). Table 5 reveals that all three variables are indicated as necessary conditions for a 40% challenge level (2.80 points on challenge scale) and up (SEC: 8.0% / 2.0 points on SEC scale; SDI: 9.3% / -6.18 points; PU: 2.5% / 1.1 points).

Table 4

Bottleneck analysis for interest (in %)

Level of interest	SEC***	SDI**	PU**
0	nn	nn	nn
10	nn	nn	nn
20	nn	nn	nn
30	0.6	nn	nn
40	9.1	nn	nn
50	**17.5**	**8.6**	**13.2**
60	26.0	18.2	26.8
70	34.5	27.9	40.3
80	42.9	37.5	53.8
90	51.4	47.2	67.4
100	59.8	56.8	80.9

Notes: ** significant on .01 level; *** significant on .001 level; nn = not necessary;

Table 5

Bottleneck analysis for challenge (in %)

Level of interest	SEC***	SDI**	PU**
0	nn	nn	nn
10	nn	nn	nn
20	nn	1.8	nn
30	3.0	5.6	nn
40	**8.0**	**9.3**	**2.5**
50	13.0	13.0	13.1
60	18.0	16.7	23.8
70	23.0	20.4	34.4
80	28.0	24.1	45.0
90	33.0	27.8	55.6
100	38.0	31.5	66.2

Notes: ** significant on .01 level; *** significant on .001 level; nn = not necessary;

Discussion

This paper contributes to existing knowledge about what factors influence learners' current motivation, namely interest and challenge. It is one of the first studies to examine in detail the levels of possible influences (i.e. self-determination during chemistry learning, self-perceived experimentation competence, and perceived usefulness of tablets for learning) necessary for students' motivation to learn with a digitally-supported learning environment in chemistry education.

Results from regression analysis indicate that level of self-determination and self-perceived experimentation competence have an average positive influence on learners' current interest at the beginning of the learning process. With regard to current challenge, regression analysis reveals an average positive influence of self-determination. In addition, necessary condition analysis contributes to these findings by revealing all predictors as individual necessary conditions for current interest and challenge, with different effect sizes. NCA further reveals restrictions for the maximum level in interest and challenge based on the extent of the necessary conditions: The absence of self-perceived experimentation competence, self-determination and perceived usefulness of the tablet constrains high levels of current motivation, while their presence enables motivation. Thus, all three variables are required for currently motivated students; however, they might still be insufficient on their own because other variables also need to be present when learning with a digitally-supported learning environment in chemistry education (e.g., prior knowledge or self-regulation competences; Song et al., 2016). These results provide further evidence to the assumption that person-related factors are of high relevance for current motivation (Freund et al., 2011; Scheffer & Heckhausen, 2018; Vollmeyer & Rheinberg, 2013).

Limitations of our study include the fact that our data is limited to a specific domain (chemistry) and specific task type (experiments and digital learning). Investigation within another subject or other tasks would be of advantage. Further research could also include other possible influencing variables, (e.g. the influence of prior knowledge; social and emotional aspects; qualitative approaches and situational factors such as task-difficulty).

It would also be of interest, to analyze what level of interest and challenge is conducive to learning in this learning environment, e.g. using post-test scores. Finally, the NCA values are point estimates, so no confidence intervals, can be calculated so far, for example.

In conclusion, taking measures to promote the self-determined motivation of the students in learning chemistry could enhance students' current motivation to learn in the digitally-supported learning environment. However, bottleneck analyses reveal that even students with a relatively low level of self-determined motivation (represented by low negative scores on the SDI) can show a relatively high current learning motivation. Thus, it is not only a purely intrinsic level of motivation that is necessary to be currently motivated to learn with the EXBOX-Digital (in line with the assumptions about rather autonomous forms of extrinsic motivation that are relevant for learning in school; Ryan & Deci, 2000). Furthermore, it can be motivating to provide students with manageable experimentation tasks to foster their self-perceived experimentation competence (preparatory exercises or competence-based feedback can be helpful here; Nguyen et al., 2019; Wollenschläger et al., 2011). Finally, demonstrating the usefulness and handling of the tablet PC for learning purposes could help to avoid unfavorable attitudes and increase current motivation (whereby the values in the present sample are already quite high on average). The effect sizes show that these implications can be seen as more relevant to interest (emphasizing the voluntary nature of the activity) than to challenge (challenging one's ability).

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The Creation of an Epistemically Authentic Learning Environment: Making Space for Epistemic Practices in High School Science Classrooms

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Abstract: With the rise in post-truth discourse, there is growing urgency to develop an informed understanding of the evolving nature of scientific knowledge through the teaching of epistemic practices (EPs) (i.e., practices scientists use to establish knowledge). Researchers recommend creating *epistemically authentic* environments to help meet this objective. However, creating such an environment requires teachers to make fundamental shifts in the way science is taught. Specifically, it requires highlighting the ambiguity inherent within the application of EPs and creating evaluation measures that communicate the socially negotiated nature of science. We have limited models examining how this goal can be accomplished inside formal classrooms. In this study, we examine how a teacher created an *epistemically authentic* environment using a curriculum designed to promote EPs. Our results show that the teacher was successful in creating this environment by distributing instructional authority, crowdsourcing parameters to evaluate EPs, and normalizing making wrong predictions.

Introduction

Increase in post-truth discourse has resulted in citizens questioning the validity of science and scientific methods (Hobbs, 2017; Peters, 2017). Citizens' skepticism about the nature of scientific knowledge is particularly relevant among topics such as climate change, evolution, and vaccination, where the information evolves based on emerging evidence (Chinn et al., 2021; Hobbs, 2017). Researchers recommend the integration of epistemic practices (EPs) into K-12 science classrooms to help with this reasoning gap among the public (Barzilai & Chinn, 2020; Muis et al., 2016). EPs are domain-specific processes that scientists use–such as peer review, systematic experimental design, and collecting ample evidence–to negotiate, debate, and establish knowledge across fields such as science and mathematics (Barzilai & Chinn, 2020; Sandoval et al., 2016). A deeper understanding of EPs is likely to help students understand the nature of scientific knowledge, as a construct that changes over time and one which is socially negotiated among scientists instead of as an absolute and static construct (Sandoval, 2016; Ford, 2008). However, current high school instructional structures lack an explicit focus on EPs as a primary goal of instruction (Chinn et al., 2021). Additionally, most instructional models inside schools lack the messiness of scientific information found in the real world where multiple claims are made with evidence that appears convincing (Sandoval, 2016; Ford, 2008).

Researchers recommend creating *epistemically authentic* environments inside classrooms to teach EPs (Chinn et al., 2021; Muis et al., 2016). These are classrooms designed to intentionally narrow the gap between environments found inside and outside classrooms - by engaging students with information that vary in claims, authorship, quality, and reliability of methods used. The premise is that engaging students in the ambiguity involved in the processes of *how to know* instead of processes of *what to know* - through these environments - will promote students' understanding of the nature of scientific knowledge. However, creating such environments requires a significant shift in how disciplines such as science are taught in schools. For example, from a content perspective, it requires selecting portions of science curricula that can communicate the epistemological underpinnings of scientific knowledge as fluid and changing rather than binary and static (Muis et al., 2016). With respect to pedagogy, this requires teachers to create an inquiry environment where students negotiate EPs as being good or bad, mirroring the real-world practice of peer review and the socially negotiated nature of knowledge (Chinn et al., 2021). Additionally, this environment also requires assessments that evaluate the EPs students use and additional supports that help students through negative emotional experiences that may be triggered by navigating ambiguity inside classrooms that usually direct them toward the right answer (Muis et al., 2016). In sum, this requires creating a classroom climate where ambiguity inherent in using EPs is emphasized and evaluated as opposed to a climate that focuses on content-driven instruction (Muis et al, 2016). However, important components of *epistemically authentic* environments, such as pedagogical choice, evaluation structures, and instructional supports, continue to be under-examined (Chinn et al., 2021; Muis et al., 2016). This limits our scope to understand the nuances teachers navigate to create such environments and consequently, limits the field in providing teachers with the support they need to teach EPs effectively.

Over the last couple of years, our work based on design-based research has focused on promoting EPs in science classrooms to address post-truth issues. In our previous analysis, we found that the teaching of EPs is difficult for science teachers to integrate into their existing curriculum (Cottone et al., 2022). So, in our third year of this research, we designed a curriculum unit on epidemics where the primary objective was for students to engage with EPs to understand the nature of scientific knowledge, using an agent-based simulation. In this paper, we investigate the ways in which one teacher created an *epistemically authentic* environment using this curriculum. We ask the following research questions: (1) In what ways did the teacher create an *epistemically authentic* environment? and (2) What strategies did the teacher use to promote an understanding of EPs?

Theoretical framework

There are different conceptual recommendations for creating *epistemically authentic* environments (Chinn et al., 2021; Muis et al., 2016). In this paper, we use the **PACES** framework (Muis et al., 2016) to conceptualize *epistemically authentic* environments. This framework provides a way to analyze multiple salient elements of a learning environment required to create a climate focused on EPs inside classrooms. The framework details five facets of a learning environment that should be intentionally designed to teach EPs. We use these facets to analyze the classroom environment created by the teacher. They are: 1) **P**edagogy: studies show that the use of social constructivist pedagogies, where the nature of inquiry is emergent and there are opportunities for students to engage in the knowledge building process actively - is more likely to engage students with EPs (Stroupe, 2014). Here the focus of the inquiry is on engaging students with epistemological underpinnings of scientific knowledge. Additionally, honing in on opportunities that highlight the ambiguity or paradox inherent within the use of EPs is likely to promote an informed understanding of scientific knowledge (Chinn et al., 2021), 2) **A**uthority: this examines the degree to which the instructional authority is distributed inside a classroom. In an optimally designed *epistemically authentic* environment, the source and justification of knowledge from an expert (e.g., teacher) are decentralized. Teachers will create opportunities for students to actively engage and lead the knowledge building processes by legitimizing the criteria and negotiations students engage in to establish knowledge inside the classroom (Miller et al., 2018). Some emerging literature references this as epistemic agency (Miller et al., 2018; Stroupe, 2014), for clarity we choose to reference this as authority, 3) **C**urriculum: refers to any instructional content, and resources used to achieve the educational objective of promoting students' understanding of EPs. Refutational texts, content that explicitly focuses on scientific methods (e.g., the iterative process of experimentation, systematic planning of experiments, socially negotiating consensus), and prompts that elicit conversations about the tentative nature of knowledge are recommended as more conducive to creating an *epistemically authentic* environment (Muis et al., 2016), 4) **E**valuation: refers to ways in which students understanding of EPs is measured. Complex, less structured, or more challenging tasks that elicit mental processes (e.g., knowledge elaboration, integration of new knowledge into prior knowledge, and critical thinking) are more aligned with the goals of promoting EPs. As opposed to tasks that are simple, overly structured, and require content recall and match processes, and 5) **S**upport is any scaffolding that teachers provide to facilitate the change process in students, such as explicit modeling of critical thinking or resolution strategies opportunities for students to discuss their beliefs or acknowledgment of the negative emotional experiences that students may face during epistemic change (Muis et al., 2016).

A well-designed *epistemically authentic* environment will result in the explicit talk about EPs that lends itself to establishing an informed understanding of scientific knowledge. In such an environment, students are most likely to engage in the EPs scientists use to establish reliable and valid knowledge. This will include, designing controlled experiments, running multiple trials, testing for multiple hypotheses, and socially negotiating the criteria to evaluate EPs. We use this framework to code for interactions that occurred inside the classroom to make inferences about the degree to which the epi*stemically authentic* environment the teacher created was successful in promoting an informed understanding of scientific knowledge.

Methodology

Context

This study is part of a larger NSF-funded project that aims at designing professional development (PD) supports to promote EPs in high school science classrooms (Cottone et al., 2020). This study explores the implementation of an epidemic curriculum designed to teach EPs. Students use an agent-based simulation to design and run experiments to propose the most ideal mitigation factor to control the pandemic. This issue was chosen because it allowed teachers to draw from their recent experiences of navigating COVID-19 and the publicly contested nature of facts about the pandemic. This is a curriculum that consists of eight lessons designed for 45 minutes each. Students engaged with *"The Epidemic Unit"* while working in groups of 2-5 as they played the role of scientists trying to control an outbreak by running experiments and gathering data to find which mitigation strategies (e.g., masking, vaccination, lockdown, and surface cleaning) they would recommend as the most effective for controlling the spread of the disease. Students start by coming up with class criteria for evaluating scientific evidence and experimental designs. In the following lessons, they collect data and engage in productive disagreements about the validity of methods used across groups to come up with recommendations. In this paper, we examine the last two out of the eight lessons. These two lessons were selected because of the rich discussion we observed unfolding regarding EPs during the implementation. In the first lesson, students were asked to provide feedback on the experimental designs proposed by their peers to investigate the mitigation strategies and revise their respective designs based on the critique received. In the second lesson, students executed their experimental designs and presented their findings. The lessons were implemented in a public school in the Northeast U.S.

Participants

We used a case study methodology which requires researchers to purposefully select information-rich cases, to gain an in-depth understanding of relevant and critical issues under investigation (Yin, 2017). Therefore, we investigated one of the teachers who participated in the PD, Nafisa, and her class implementation of the curriculum. She identified herself as African American and was in her 22nd year of teaching, with previous experience teaching biology, and environmental science, all at the high school level. She taught the unit across two weeks with a section that had 25 students in her environmental class. Students in this class identified as 54% Latino/a, 24% Black, 12% Asian, 7% White, and 4% other.

Data source and analysis

We analyzed three data sources: Videos of the two classroom implementations which included whole-class instruction and small group discussion among students (90 mins), teachers' post-implementation interviews (90 mins), and classroom observation notes. The observation notes included descriptions of the classroom conditions, teachers' instructional practices, and the activities and interactions among students taking place. The semi-structured post-implementation interview was conducted to probe the teacher's specific practices, beliefs, and understanding of implementing the new curricula, as well as the teacher's experience of preparing the class and participating in the project. These two data sources were primarily used to answer the first research question on the nature of the *epistemically authentic* environment the teacher created in the classroom.

Data analysis was qualitative in nature, informed by constant comparative method (Glaser, 2008). There were three interacting phases of data analysis: a) applied open coding to classroom implementation videos, b) used a priori codes informed by **PACES** framework to code for interactions that spoke to **P**edagogy, **A**uthority, **E**valuation, and **S**upport constructs during whole class interaction. The **C**urriculum was conceptualized as the two lessons from the larger *"The Epidemic Unit"*. This included the agent-based simulation students used to design and run their experiments and teacher and student-facing worksheets. The other constructs (**P**edagogy, **A**uthority, **E**valuation, and **S**upport) were coded from teachers' implementation of this lesson (refer to Table 1) and c) thematic analysis and triangulating data. The first phases of data analysis focused on developing a coding scheme. The coding scheme was initially informed by the **PACES**, and later by emergent themes from the data. The coding scheme was debated and iteratively revised until a consensus was reached between the two authors. We each coded a sample of data using the final coding scheme and identified areas of disagreement and refined the coding process over time. Refer to Table 1 for the coding manual used and the excerpt of instructional episodes coded.

Table 1
Coding scheme and examples of instructional episodes that were coded for the lesson where students were asked to provide feedback to the experimental designs proposed by their peers

Codes	Description of Codes	Examples of Instructional Episodes
Pedagogy	Opportunities where the teacher explicitly highlights the ambiguity in *ways of knowing*, presents varying interpretations, and highlights the importance of the justification process through valid evidence, and/or highlights the iterative	The teacher highlighted the ambiguity that the public felt on the dissemination of COVID-19 vaccine information when explaining the iterative nature of scientific knowledge, "So how many people remember that conversation initially? Like if you got COVID-19 and you took the vaccine, you won't get COVID-19 […]. Then there were some people

	process of how knowledge is established in science.	like me like, I'm not taking that, how sure are you of the data?"
Authority	Moments where the teacher reinforces the legitimacy of students' role as active decision-makers by positioning them as scientists capable of driving the decision-making process in class, and by encouraging students to set their own aims for investigation.	The teacher encouraged students to select the critique they want to work on just as scientists do when engaging with feedback received from peers, "I mean you are two brilliant scientists who received feedback from fellow scientists, you don't have to ask me which to pay attention to, decide which feedback is most useful in strengthening your experiment."
Evaluation	Instances when students are exposed to the assessment criteria, and the teachers explicitly link those criteria to facets of knowledge and knowing.	The teacher highlighted that the way to evaluate students' work is to refer to the list of scientific practices students negotiated as good EPs at the beginning of the unit. "Be explicit about the evidence in terms of the data, this is what you set as a class as good way to do science. [...] We need some facts. We need to know that you're just not saying this mitigation factor works because this is what you want. Instead, show some proof that this might work. Okay?"
Support	Teachers help students through negative emotional experiences of being wrong by normalizing those experiences.	The teacher signaled it is okay to get data that negate their initial predictions, positioning this as a practice scientists do in the real world by saying, "All scientists have a plan, okay? And sometimes their plan changes. So, I want you to take that into consideration.? So, you don't have to prove your hypothesis is right, focus on the evidence you see."

Result

In this section, we present the analysis of PACES categories and our coding of how an *epistemically authentic* learning environment was created in Nafisa's classroom. We aim to provide illustrations of the main themes that emerged and how these themes connected to the teacher's attempt to provide an informed understanding of the nature of scientific knowledge.

Pedagogy: Navigating ambiguity with EPs and historical narratives

In implementing the curriculum, Nafisa honed in on opportunities to highlight the ambiguity and uncertainty inherent within the EPs used by scientists to investigate emerging processes and establish scientific knowledge. She used students' lived experiences with COVID-19 to explicitly focus on the ambiguity that resulted among the public, from not understanding the iterative nature of scientific knowledge. For example, she mentioned in her post-implementation interview, "So, I asked the students about the vaccine and how scientists, you know, came up with a vaccine and they first said it won't give you COVID but then people who got the vaccine started getting sick, so were the scientists lying?"

Nafisa navigated these ambiguities by asking students to reflect on the nature of evidence (e.g., did they have a control group? how many times did they run the experiment? Did they test multiple hypotheses?) when confronted with conflicting results or claims when running their respective experiments. For example, the observation notes highlighted that when two groups designed their investigation on a common mitigation strategy (e.g., masking) but found that their experiments resulted in opposing claims of the effectiveness of the strategy. Nafisa asked the two groups to examine their EPs, she noted,

> You need to make sure that your process in which you're carrying out your plan is one that will not be biased toward what you think is right, as you carry out the processes you'll be able to get enough evidence to either prove your hypothesis correct or find something that needs to change [..] Did both of you use the same control design - I see that you (Group A) tested masking with a vaccine and (Group B) tested with social distancing. Now, look closer did you both run the same number of trials [..] "

In the above example, Nafisa draws students' attention to the iterative nature of scientific knowledge by mentioning that the goal of EPs is to improve our understanding of a concept or product as new or opposing evidence emerges. She references EPs as 'processes' and points out that these are in place to ensure scientists do not advance knowledge that they are biased to thinking is right, it is in place to avoid confirmation bias.

Nafisa also used examples of incidents in the history of science, where the knowledge changed over time as the field progressed to gather more evidence and began to think about the problem differently. When setting the context for students to critique each other's EPs, she used the example of how vaccination for chickenpox was developed and linked it to the development of vaccination for COVID -19.

> Before you were born, the only way to get over chicken pox was to get it. It took time for scientists to test and retest until they figured from the people who had the disease the antibodies required to fight it and create a vaccine from it. Same with COVID [..] They are still figuring it out. But that's okay! because in science, nothing is necessarily a hundred percent because there are new developments.

In the above examples, Nafisa used historical narratives to communicate that scientific knowledge is never absolute. It changes in the face of new evidence. She communicates that EPs make the processes reliable for a certain period and that they are in place to ensure that biased perspectives or one person's agenda are not used to establish knowledge. She tackled ambiguity by using examples that normalized the iterative nature of scientific knowledge and by redirecting students' attention to critically examine the EPs used by scientists to make the claims.

Authority: Providing student choice while retaining invisible authority on EPs

Nafisa created opportunities for students to actively engage and lead the knowledge building processes by legitimizing the criteria and negotiations students engaged in to evaluate EPs inside the classroom. She ceded her authority as the bearer of the 'correct' knowledge, by verbally using sentences that positioned students as scientists and thereby communicating their capacity to actively drive the decision-making process within their small groups. For example, when a group of students asked which mitigation factor they should investigate, Nafisa responded, "You can choose any two mitigation factors of your choice, but you need to tell me why! And how will you investigate it? You are scientists so tell me how these factors will help you generate multiple hypotheses?" In this quote, Nafisa emphasizes that they have the agency to investigate the mitigation factor of their choice. She instead redirects their attention to justify the rationale behind the choices they make and to focus on explaining why they made certain decisions around EPs such as running a certain number of trials, and the nature of the control group. By doing so she dissolves her authority as the figure whose criteria need to be met.

Interestingly, while she ceded most of the authority on decisions made about the selection of mitigation factors, the trials to run, and the control group to be selected. She retained authority on the broader criteria of the EPs that should be met to design a good scientific experiment. For example, when setting the context for experimental design, she mentioned that every group should meet the criteria of EPs they negotiated earlier as a class as good practices such as having two hypotheses, running multiple trials, and recording their methods. She noted, "Remember, you have two different hypotheses and that means for each hypothesis you're going to have two different plans [...] but remember, this is your plan and we're going to carry out your plan. And you can always change." In this quote, Nafisa reiterates that students have the choice to design and change the experiments they saw fit while emphasizing that these choices should be negotiated within the broader EPs that were socially negotiated as the best practices to follow in class. Similarly, in another video of classroom implementation, she communicated that while students are being asked to critique their peer's designs, she has already graded their designs but made these invisible because she does not want to influence students' opinions about their peer's designs. She said,

> [M]any times scientists receive feedback from their colleagues throughout the process because they have to eliminate bias, okay? So it's not what you think or what you feel, but based on data [...] I didn't put a grade because I don't want to influence your critique of your classmate's design.

The above examples show that the teacher ceded authority in terms of choice in designing individual experiments but retained an invisible authority on whether the broad parameters of EPs that the class had negotiated as good practices were being retained or violated. She justified the maintaining of invisible authority as a way to communicate that while science is subjective (e.g., it is shaped by scientists' choice of the question to pursue, and methods to study) this negotiation occurs within a larger realm of what scientists have established as good EPs or measures to study processes, in her post-interview. She positioned EPs as the authority to defer to instead of her as the teacher or the more knowledgeable one in the classroom.

Curriculum: Focusing on ways of knowing instead of what to know

Nafisa created an *epistemically authentic* environment using a curriculum that explicitly focused on EPs. The learning objective of the unit was on understanding *ways of knowing* scientists use, by engaging with EPs rather than finding the one correct mitigation strategy that could resolve the epidemic students were investigating. The teacher noted in her post-implementation interview that the primary focus of the curriculum remained on the process of evaluating good scientific experiments from bad ones.

> Unlike the lab experiments we run, where students usually just follow a manual imitating scientific practices. I see students actually engaging with scientific practices in this unit because we are not focusing on the content, but on the skill of how scientific knowledge is established […] like changing and tweaking their predictions and using the class criteria of good practices to evaluate their decisions.

In the above excerpt, Nafisa points out this curriculum stood apart from other traditionally used practice-based curricula such as lab experiments because students weren't following a prescribed standard of instructions for emulating EPs. Instead, students were actively making predictions and revising them based on the evidence they collected from the simulation. Additionally, Nafisa pointed out that not having access to which of the mitigation factors was most effective in tackling the pandemic that students were investigating, helped keep the focus of instruction on the EPs. In her post-implementation interview she noted,

> I didn't know the answer myself. The curriculum did not tell me if vaccination or masking or distancing was the most effective. So, I guess there wasn't an answer I could accidentally nudge students towards. When students asked me questions, I would ask them to find their answers in the methods they were using.

The above excerpt indicates that the explicit focus of the curriculum on EPs allowed Nafisa to retain her students' attention on EPs and the nature of scientific knowledge. Not having a predetermined right answer ordained by the curriculum helped Nafisa retain the focus on EPs instead of scaffolding students to design experiments to get the predetermined right answer.

Evaluation: Using socially negotiated criteria for assessing EPs

Nafisa crowdsourced the criteria for evaluating EPs from her students and she used this class criteria recurrently for students to evaluate their own designs and critique their peers' designs. She had students at the beginning of the unit brainstorm and negotiate a list of EPs they considered to be parameters of a well-designed scientific experiment. This included parameters such as reporting the number of trials as an attempt to communicate all evidence collected, designing experiments that tested multiple hypotheses to prevent confirmation bias, etc., These were displayed on the google slides throughout the lessons - especially during the time when students were asked to critique others designs and revise their own. In one of the videos of classroom implementation, when the students asked Nafisa to check their experimental designs to see if they are doing them right, she pointed to the slide that had the class criteria on good scientific experiments and told the students that "The answer does not lie with me. Check if your design meets the criteria you set as a class, [...] look at the critique you got from your peers. Go talk to them and ask if it looks okay to them."

On another occasion, she prefaced the need for students to collect and record the evidence they were referring to make the arguments about the effectiveness of their chosen mitigation strategy. She guided students to take screenshots of their trials from the simulation and record them on their final poster so that other scientists can make sure that they are not making up data to prove their hypothesis correct. The teacher told the whole class, "Remember, you cannot convince people without even running an experiment because [...] We need some facts. We need to know that you're just not saying this is what I want to do, but you have some proof that this might work." Nafisa's implementation of the curriculum used evaluative strategies that were socially negotiated within the class, which dissolved any impression that the right answer lay with the teacher. This allowed an environment where students were more deeply engaged with EPs than attempting to find the answer that the teacher thought was right. She also connected this practice of referencing a socially negotiated list of practices to evaluate EPs to the real-world practice of peer review used by scientists. She mentioned that scientists critique other scientists on the EPs used to establish knowledge. When setting the context for peer critique she gave the following instruction.

> So, what you have at your tables, are your list of good scientific practices. You may use them to help you determine if they are carrying out good scientific practices [...] because scientists

> always give each other advice, right? Scientists do not work alone. So other scientists in class are going to see your plan and give you some advice or suggestions. They will critique to improve your design. They use the criteria we all agreed on are good practices in this class.

In the above examples, Nafisa communicates that the criteria of evaluation are the EPs that students used to design their experiment, and the parameter for evaluating if these EPs are 'good' or 'bad' is by repeatedly referring to criteria the class had negotiated as signs of a good experiment. She communicates to students that the process of peer review is in place to prevent biases and that scientists do not work in isolation. This communicates the socially negotiated nature of scientific knowledge. That scientific knowledge is generated within a larger culture, the norms of which are upheld by the scientists through the process of constantly critiquing emerging research by evaluating the EPs used by other scientists.

Support: Normalizing making wrong predictions

Nafisa helped students navigate negative emotional experiences of being wrong or being lost while engaging with ambiguities by normalizing these experiences. She used real-world examples of scientists changing their claims based on new evidence and reiterated that the process of proving predictions wrong is a way of ensuring EPs are not violated by scientists. For example, where students appeared frustrated on getting their predictions about their chosen mitigation strategy, masking, wrong. The teacher told the group,

> All scientists have a plan, okay? And sometimes their plan changes. So, I want you to take that into consideration. [J]ust to give you an idea, initially, when the vaccine was introduced? How many people do you think they tested it on before introducing it, and how many times did they run those tests?

On another occasion, when setting the context for students to provide feedback on each other's findings. She mentioned that the focus should not be on if the group's prediction came true, it should be on how they investigated their mitigation factors and made sense of the data. She reiterated that it is okay if the group's findings demonstrated that their data proved their respective hypothesis wrong.

> So what you're going to do today is we are actually going to give each other feedback. We're gonna be honest because it's always a good practice to notice if you or others as scientists did not get something correct, it's how you do good science.

In the above examples, Nafisa creates an environment for students to feel okay with being *wrong* about their predictions or hypotheses. She normalized the process of making the *wrong* predictions with personal narratives that normalized the idea that scientists change their claims based on evidence they see, which eased students' frustration of finding and reporting data that did not align with their hypothesis.

Discussion

This paper contributes to the recent calls to investigate curricula that teach EPs in formal classrooms, specifically the supports that result in the creation of *epistemically authentic* environments in science classrooms (Chinn et al., 2021; 2020; Muis et al., 2016). Our findings affirm assumptions that attending to multiple salient features of an environment such as curriculum, assessment, and evaluation concurrently and intentionally directing them to emulate EPs scientists do in the real world is an effective way to create an *epistemically authentic* environment. We found that a curriculum that explicitly focused on EPs where students actively engaged in a scientific investigation where outcomes were emergent and not predetermined facilitated the creation of an *epistemically authentic* environment. The epidemic unit Nafisa used did not focus on students' ability to find the right mitigation factor. There was not one right answer the teacher could guide students to, therefore the focus of instruction remained on the EPs scientists use to establish knowledge (e.g., designing systematically controlled experiments, socially negotiating the validity of claims through peer review, and revising predictions based on evidence). Our findings provide empirical evidence to advance the existing hypothesis that engaging students in curricula where teachers explicitly highlight ambiguity and engage students with paradoxical perspectives of the ways in which scientific knowledge is established (Chinn et al., 2020; Muis et al., 2016) - is an effective way to engage students with EPs in science classrooms.

Our findings suggest the importance of attending to distributed instructional authority in the classroom when creating an epistemically authentic learning environment. Our findings align with previous research (Author et al., 2020; Stroupe, 2014) that indicates providing students with authority to negotiate the knowledge building process that occurs in classrooms can successfully afford students to engage with EPs. Nafisa consistently redirected questions about the "correctness" of students' experimental design to the class criteria of good EPs the students had negotiated early on in class. She used the socially negotiated EPs as the evaluation criteria to consult - she did so by ceding authority to students to provide critiques and recommendations to each other's designs but by retaining an invisible authority on the border parameters of EPs. Our findings also reveal that instructional supports are necessary to address students' emotional reactions when engaging with e*pistemically authentic* environments. Previous research recommended teachers to explicitly model resolution strategies or provide real-world examples that normalize the negative emotions students may associate with getting their predictions wrong (Muis et al., 2015). In our study, Nafisa provided emotional support in the form of linking the ambiguity students experienced to lived experiences with COVID-19. She repeatedly emphasized how scientists conduct experiments to find the truth and not necessarily to prove their predictions right, students in the class felt comfortable reporting their methods even when they nullified their predictions. Previous research has shown that students struggle to engage with this complexity of normalizing "wrong predictions" (Cottone et al., 2022). This indicates that emotional support can help students grapple with the tension they may experience when pursuing directional goals (i.e., goals that promote more inquiry) instead of accuracy goals (i.e., goals of finding the right answer) when creating an *epistemically authentic* environment. Future research will examine how this environment resulted in improving students' epistemic performance in class.

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Teachers' Engagement with Analysis Outputs of Large-Scale Identity Productions as a Move Towards Culturally-Informed Curriculum Development

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Abstract: We previously demonstrated that insights into students' socially shared knowledge and identity expressions could be gained through analysis of large-scale identity artifacts - productions shared by students with the world via social media platforms or more hybrid spaces such as writing or audiovisual competitions. Here, we take a step further and explore how engagement with these artifacts could inform teachers' design work in culturally-informed ways. We now address this question in context. We designed a workshop for in-service public school teachers focused on helping them engage in planning that is centered on students' everyday lives by drawing on the analysis outputs from our previous work, including an outline of top topics students wrote about in essays submitted to a national writing competition in a Global South country and a subset of those students' essays. Our findings suggest such analysis outputs can play a number of roles in teachers' culturally-informed planning.

Introduction

It is well established within educational research that teachers need to build instruction that draws on students' cultural resources developed in their out-of-school experiences for their potential to improve teaching and learning for both children and adults, and for those from both dominant and non-dominant backgrounds (Gay, 2002; Gutiérrez & Rogoff, 2003; Moll et al., 1992; Ladson-Billings, 1995). By not recruiting students' cultural resources, educators miss crucial opportunities to support student learning and might, even if inadvertently, reinforce a deficit framing of marginalized students, their families, and their communities (Gutiérrez, Morales, & Martinez, 2009). Over the last three decades, two pedagogical frameworks – Funds of Knowledge (FoK; Moll et al., 1992) and more recently, Funds of Identity (FoI; Esteban-Guitart & Moll, 2014) – have been highly influential in providing guidance for teachers to capture students' cultural resources and capitalize on these in their instruction. The Funds of Knowledge approach focuses on the collective bodies of knowledge and skills that students develop through their participation in the practices and lived experiences of their families – their *funds of knowledge;* whereas Funds of Identity, which builds on the FoK approach, focuses on "whatever and whoever" (Moll, 2016, p. 48) students perceive as meaningful to self-definition, self-expression, and self-understanding, and that can include their funds of knowledge (Esteban-Guitart, 2012; Esteban-Guitart & Moll, 2014).

While FoK researchers' original approach called for teachers to visit students' families and engage in interviews and ethnographic work (Moll et al., 1992), many other methods have since been proposed for teachers to learn about their students' funds of knowledge, including, for example, having students discuss local issues (Zipin, 2009; Zipin et al., 2012); giving students opportunities to share personal experiences during classroom instruction (e.g., Barton & Tan, 2009; González & Moll, 2002); calling on students to apply their cultural knowledge (e.g., Maher et al., 2001); sharing meaningful artifacts in the classroom (e.g., Hughes & Greenhough, 2006), etc. FoI researchers have proposed complementary methods to learn about students' funds of identity/funds of knowledge, especially through the use of *identity artifacts*: student productions that constitute visions, expressions, or understandings of self (Esteban-Guitart, 2012; Esteban-Guitart & Moll, 2014). Among the techniques and procedures used by FoI researchers to help teachers learn about students were, for example, graphical representations about people, institutions, activities, and hobbies that are most important or significant to students, as well as photographs of participants that would alow teachers to learn about students' routines and ways of life (Esteban-Guitart, 2012). As happened with FoK, a number of different strategies have been proposed to teachers to recognize students' funds of identity. These include, for example, personal diaries (Esteban-Guitart, 2012), poems (Subero et al., 2015), photos (Marsh & Zhulamanova, 2017), maps (Moulton, 2018), meaningful artifacts from students' life experiences (Zipin, 2013), and/or identity drawings (Ordóñez et al., 2021).

In previous work (Coelho & McCollum, 2021), we proposed a new type of artifact that could aid teachers in crafting a repertoire of knowledge about their students: the outputs of automated analysis (via structural topic modeling) of student-produced essays. We frame this as part of a discussion of how teachers might make use of the outputs of automated analysis of large-scale identity productions that are shared by students with the world, be it through social media platforms or through productions that circulate in more hybrid spaces, such as, for instance, the competition essays we consider. While FoK and FoI methods have their merits and present excellent options when feasible, teachers need as many strategies as possible as some are time consuming (e.g., visiting families), and as students will not always be willing to volunteer information about themselves and their families or communities to teachers (Moje et al., 2004). Further, we argue that the use of the same strategy over and over may not always be productive for teachers, may be tedious for students, or may not work well for all teachers across the curriculum. As such, we believe that teachers' toolkits should be continually expanded to include complementary strategies.

We see great potential in the automated analysis of large-scale community-produced identity productions to elucidate patterns about students that lie outside the realm of unaided human perception and which no feasible amount of manual analysis could bring to light. By analyzing a large corpus of student essays submitted to a national writing competition in a Global South country using machine learning techniques, we have previously demonstrated that insights into students' socially shared knowledge and identity expressions could be gained through analysis outputs in the form of a collection of topics and a smaller corpus of associated essays (Author & Author, 2021). In the current study, we were interested in addressing the following question: What role do the analysis outputs of community-produced identity artifacts play in setting teachers up for designing culturally-informed learning experiences? Stated differently, how were teachers triggered by these analysis outputs? Ultimately, we are interested in understanding and answering a larger question: How and why might reviewing essays (and the topics thereof) written by students who are not a teacher's own students but who may navigate similar spaces, and who may share similar experiences, practices, and communities, support a teacher's design work in culturally-informed ways?

To address these questions in context, we designed a workshop for in-service public school teachers focused on helping teachers engage in planning centered on students' everyday lives. In the first three weeks of the workshop, teachers engaged with the analysis outputs in the form of tables that outlined top topics students chose for their essays (29 topics total), as well as a subset of students' essays (10 essays per topic; 290 essays total).

Method

Research context and participants

The context of this study was a three-week, nine-hour unit that was part of a seven-week, 21-hour workshop for in-service public school teachers from different disciplines, held online over Zoom, due to limitations on in-person field research during the Covid-19 pandemic.

Eleven public school teachers from different school districts, school sizes, and disciplines (two language arts teachers, six science teachers, one history teacher, and three math teachers) from a state in a Global South country were selected to participate in the study. After receiving ethical approval from the Institutional Review Board, we approached the state's Department of Education requesting their permission to allow teachers from different school districts to participate in the study. We asked the Department of Education to select teachers who they believed are especially committed to working with disadvantaged students under the assumption that, given teachers' dispositions and experience, they would be more likely to join the study as well as to make contributions to the design of the workshop, as this was one of the goals for a concurrent study seeking to study the environment designed to support teachers' work toward culturally-informed curricula with an eye toward progressive refinement.

After receiving recommendations from the principals of 15 schools recognized for excellence (the Department of Education interpretation of our selection criteria), the State Department of Education compiled and sent to us a list of 26 potential candidates. All 26 were invited via email for an interview prior to the beginning of the workshop. Of those, 16 accepted the invitation and were interviewed. The goal of the interview was to learn more about the teachers' backgrounds as well as their teaching philosophies and practices so as to inform the selection of a diverse pool of teachers and thereby capture a broader range of experiences and perspectives.

The final 12 teachers selected had anywhere from 6 to 35 years of teaching experience and included six women and six men. With the exception of one teacher, who taught grades 6, 8, and 9, most teachers taught high school students at the time of the study, with some of them also teaching in one or more grades from 6-9. Teachers averaged 33 students in their classrooms. About six teachers lived in the capital of the state or in the capital metropolitan area. The other five lived in small sized cities in the countryside of the state. The majority taught in urban schools, with those living in smaller cities reported having a greater average number of students living in rural areas. All teachers were asked to sign an informed consent before the beginning of the study. Given the time intensiveness of the interview and workshop, each teacher was compensated $10 per hour for all activities completed as part of the study as a means of incentivizing them to remain in the study over time. All but one teacher completed the entire workshop series, dropping before the beginning of the first workshop meeting.

The workshop was focused on using the analysis of large-scale identity artifacts to help teachers engage in planning that is centered on students' everyday lives. More concretely, the workshop was developed to help teachers in state in of a Global South country (from hereon, State X) redesign an existing curricular unit and adapt/complement it so that it incorporates some aspect(s) of students' out-of-school experiences. The workshop was divided into two units. In the first unit of the workshop, which is the focus of this study, one core activity was designed to support teachers to achieve the above mentioned goal: a) having teachers engage with and learn from outputs of automated textual analysis applied to a large corpus of essays (17,936 total) written by students from State X who participated in the Portuguese Language Olympics (PLO) between 2012 and 2019. More specifically, teachers were given access to the analysis outputs in the form of tables that outlined top topics students chose for their essays (29 topics total, e.g.: "Violence against Women, Children, and LGBTQ people," and "Water: Scarcity, Drought, and Misuse"), as well as a subset of students' essays (10 essays per topic; 290 essays total).

As far as the ethics of using this data in this way are concerned, it is important to note that teachers and students sign agreements to transfer ownership of the data to the institution that organizes the Portuguese Language Olympics, agreeing to have their essays published on a range of outlets. To further address the issue of privacy and data management, all essays used in our study were anonymized, including references to schools and students. Additionally, teachers who participated in the study were asked not to share the data outside of the study. It is also important to note that, despite the data being produced for a different initial purpose, the Portuguese Language Olympics' mission is to make students' voices heard, and we believe that our study supports this goal while protecting the privacy of the students; repurposing this data to support teachers in designing curricula and lesson plans ultimately benefits, even if indirectly, the students who produced the essays.

Timeline, units and activities for the first unit are presented in Table 1. The first unit consisted of three meetings of 90 minutes each, distributed across three weeks. Teachers also had 90 minutes of asynchronous work per week.

Table 1
Workshop timeline and activities

Week	Event	Content/Activities
1	Meeting 1	Introduction to the workshop; Community building activities.
1	Homework 1 (asynchronous)	Teachers were asked to read and select topics they considered most relevant to their own students. They then selected and read a collection of essays associated with those topics. After that, they were asked to summarize the situations and experiences described in those essays. Next, teachers reflected on questions such as: What comes to your mind when reading about these topics and associated essays? Why? Do you think about your own students when reading about these materials? Why or why not?
2	Meeting 2	In small groups, teachers were asked to discuss what stood out to them about topics and essays, any relevance to their students, and any connections between situations described in the essays and their students. As a group, we discussed the importance of learning goals, setting up the stage for Homework 2.
2	Homework 2	Teachers were asked to describe their learning goals for their curriculum unit.
3	Meeting 3	In small groups, teachers were first asked to think about how to improve Homework 2. Then, teachers gave feedback to each other on their planned curriculum goals.
3	Homework 3	Teachers were asked to revise their learning goals based on the peer feedback received during Meeting 3.

Data sources & approach to data analysis

The data used in this study consisted of the following: 1) transcriptions of three 90-minute video recordings (recorded via Zoom's integrated recording feature) and 2) 11 teacher workbooks/reflective diaries, in which teachers documented their reflections about their own students based on their reading of topics and essays.

To answer the study's research question, the first author first mapped all instances where teachers talked during the two meetings in addition to each teacher's individual workbook. This process was done for all 11 teachers, so the unit of analysis consisted of two documents for each teacher (22 documents total), one containing a set of excerpts from the meetings and another one composed of the teacher's workbook. The data were then uploaded into NVivo, a qualitative analysis software package that allows for coding and analysis of documents. Next, the first author coded each teacher's documents individually and, as she progressed with the analysis, constantly looked for patterns in the data. After deciding on categories to label the patterns found in the data, the author shared an analytical journal with the second author and three other researchers, containing raw data passages and preliminary analytical findings. The second author and external researchers were asked to comment on the first author's interpretations. Categories were revised based on their feedback and the final phase of analysis resulted in three learning processes that teachers used to learn about their students through engaging with the analysis of community-produced artifacts, namely.

Findings and discussion

A crucial aspect of implementing culturally-informed instruction is the need for teachers to build knowledge on their students' cultural resources– including students' funds of knowledge and/or funds of identity – and attend to those resources in the classroom. Teachers who participated in this study were invited to engage with topics and associated essays produced by students whose macro-communities (state, country, area) overlapped with those of the teachers' own students. Analysis of the data suggests that topics and essays played a number of roles in teachers' planning. While the topics and essays served multiple functions for every individual teacher, in the analysis we present here, we group teachers based on which of the following three functions was most prominent for each of them: a) topics and essays as a basis for analogical mapping; b) topics and essays as tools for brainstorming and ideation; and c) topics and essays as a platform for dialogue with students' voices. Below, we trace illustrative examples of how each of these functions were apparent in different teachers' participation in the workshop.

Topics and essays as a basis for analogical mapping

For four teachers (two math, one history, and one language arts teacher), topics and essays functioned as a basis for analogical mapping (Gentner, 1989). The issues and situations students described reminded teachers of some prior experience stored in memory, sometimes changing the way they thought about one or both situations. These teachers mapped elements of the topics and essays to the substantive nature of the lived experience between a child and their place, and further mapped this onto their own students' situations. For example, Ricardo, a history teacher, selected to read essays in which students shared their concerns about their most immediate social reality (the daily life of their neighborhood or city) and about the greater reality of their state and country (issues related to health, education, violence, etc.). He provides a number of examples of how topics and essays could function as a basis for analogical learning. During a brainstorming group activity, Ricardo shared the following:

> *I selected texts that are very connected to certain aspects of the country's reality, which if we stop to think about it, citizens in general should have access to education, basic sanitation, or safety in relation to crime. In my homework for this week, I highlighted one thing, let's put it that way…what I realized is that they (my students) know what's going on around them, they have a certain awareness of the absence of public power in several areas – that the school and the health center are both falling apart, that the little square in the neighborhood, which could serve as a leisure space, is all destroyed, plundered, taken over by crime, etc. …and they worry about it, they feel this insecurity in their daily lives….**a very interesting text that talked about this issue … if we stop to think about the basic right of freedom of movement, the right to come and go ... it seems to me that the text was from (city), from a student from (city), and he talks about how this right is denied to him, because if you leave your house, you can be the target of an assault, a violent action, whatever**…* (Meeting 2, First Activity: Group discussion of topics and essays; connections to students' lived experiences)

In this segment, Ricardo focuses on a specific essay that caught his attention, in which a student claimed that a high crime rate in his neighborhood is a denial of his basic right to freedom of movement. Ricardo draws an analogical connection between this essay's author and his own students and the ways they have basic rights denied to them. Later in the same activity, Ricardo discusses how he applied this analogical insight in his 12th-grade classroom during a lesson on the military dictatorship in 1960s in the country in which Institutional Act #5 (AI-5) was brought up:

> *… we got into how the AI-5 suspended the right to habeas corpus, which is the mechanism that in practice protects the citizen's right to come and go, and I started to discuss with them… what*

> *is this right to come and go…in what situations is your right to come and go denied? Why is the habeas corpus an important legal mechanism? And I was saying that it prevents illegal arrests, for example…a given authority, when it takes away your right to come and go, what does that mean? It arrests you, puts you in jail, right? The authority has to substantiate the reasons why it is arresting you, which law you violated….so habeas corpus exists because of that and it is such an important mechanism, that I don't know if you (teachers) know...any citizen can ask a judge, it doesn't have to be a lawyer…so I made this relationship, because I said, the text I read about this issue of* ***being able to walk freely*** *around (city) caught my attention…* (Meeting 2, First Activity: Group discussion of topics and essays; connections to students' lived experiences)

In a different brainstorming activity, Ricardo makes explicit the connections between the situation described by the essay's author and concepts from his discipline, such as dictatorship and democracy. Using the essay as a starting point, Ricardo shares that he wants students to understand several big ideas around democracy and dictatorship through helping students reflect on their own rights. In the following excerpt, for example, he connects a situation described in an essay that was previously brought up in the workshop with concepts of his discipline in articulating goals for students. Specifically, he wants to help students understand that governments can violate citizens' rights both by omission (in a democracy, as evidenced by the student's essay) and by abuse of power (in dictatorial regimes).

> *… my students will understand that a simple basic right of a democracy, such as peacefully gathering to demand from public authorities the resolution of a certain problem, or to complain about rights being violated, becomes a crime against the state that must be suppressed. This is in the context of dictatorship.* (Meeting 3, Second Activity: Feedback in groups on teachers' curricular unit goals)

Ricardo plans to invite students to investigate and reflect on whether their basic rights are being denied; to help students understand what a democracy is and how it works; and to give students the tools to change their realities.

> *I circled back to this topic a lot, so that students would have something lasting, which would be the functioning of a democracy itself. Even if later on … they forget those details, for example, what happened during the military dictatorship, the redemocratization process, … they have the ideas of … how a democracy works at a basic level.* (Meeting 3, Second Activity: Feedback in groups on teachers' curricular unit goals)

Ricardo's engagement with topics and essays illustrates how these can function as a source of new learning through analogical thinking. It also evidences how these can support the design of learning experiences that are inextricably linked to students' lives, just as identity artifacts produced by students during classroom instruction would under funds of identity approach (Esteban-Guittart & Moll, 2014). Through a series of analogical reasoning moves departing from one single essay, historical events in Ricardo's planning become inextricably linked to his students' daily lives.

Topics and essays as a tool for brainstorming and ideation

For three teachers (one math, one biology, and one geography teacher) topics and essays served primarily as a tool for brainstorming. It was not a specific topic or essay that called these teachers' attention and motivated their decisions; instead, brainstorming exercises played a bigger role in their planning, including exercises that prompted teachers to explore possible connections between topics or situations described in essays and the curriculum, working in both directions (that is, from essays to curriculum and vice versa). Bruno (a math teacher) exemplifies the use of topics and essays as a brainstorming and ideation tool.

In developing his plan for a curricular unit about percentages, Bruno's first idea was to work with percentages in the context of public investment and economic development, but he later shifted his plan toward focusing on percentages in the context of daily purchases. His first mention of working with percentages in the context of economic development is developed dialogically with colleagues:

> Bruno: Shall we brainstorm one with percentages?
> Rita: Let's do it.

Paula: That's cool too. I like the idea of working with probability too – I think it's a very good topic, but let's go with percentages …
Bruno: Yeah, because percentages…we would be able to use it with any of the topics (from the essays) that we choose.
Paula: I think so too.
…
Bruno: I could teach percentages in the context of … Ok, so, I think percentages cover a lot of these topics. We can cite more than one here.
Paula: Many.
Rita: Public investments.
Bruno: Public investments.
Rita: Economic development.
Rita: Economic development.
(Meeting 2, Second Activity: Brainstorming connections between disciplinary learning and students' lived experiences in groups)

In the above exchange, Bruno invites the two other teachers in his group to generate ideas collaboratively, and they welcome his invitation. Four classic guidelines in brainstorming research (e.g., Osborn, 1963) can be observed in the group exercise. The first of them is *freewheeling*; Bruno seems comfortable sharing his ideas, no matter how wild they are. He starts with curriculum content in mind (percentages) and moves freely through many more ideas, such as public investment and economic development. Here, we are seeing the second classic guideline for brainstorming: *quantity*, which encodes the notion that, the more ideas there are, the higher are the chances of arriving at good ideas. In this case, these ideas come from the topics that Bruno was presented with, highlighting once again the potential for this type of engagement with outputs to support teachers in designing instruction that engages with issues that students seem to care about.

In a later brainstorming activity, Bruno discusses his decision to change his plan while working and reflecting on his curricular unit, bringing it – even if not intentionally – closer to what students actually experience in their daily lives:

> *Do you understand? My initial idea was to work with a percentage of profit and loss. I proposed the topic of public investments, economic development, economy of the region. Even thinking about a somewhat political side, of city hall policy, of the city, economy of the region and of the city, even thinking about a public policy even with this profit and loss. Then I started writing it down and saw that I was proposing something that had nothing to do with politics anymore, you know? I've already put it into percentages in general, including, for example, you arrive at a store and make an analysis of whether that purchase you are going to make is worth buying in cash or dividing it ten times. Then I started framing the situation in that sense, you know?* (Meeting 3, First Activity: Brainstorming connections to students' lived experiences in groups)

Bruno's decision to change his plan is supported by another teacher at the end of the group activity, who explains back to him what he is doing, which is actually getting closer to students' experiences. The following segment illustrates two other guidelines for brainstorming: *combination and improvement* by other participants and *criticism being deferred* to until after the group activity.

> *Bruno, I think you should ask this question more about the students' daily life, this percentage, just like you did, in the second case. So, putting it this way, the student will make a purchase, he has X discount, you say "is it feasible to pay in cash, in installments, the increase." I think it makes more sense for the student. Even for the student's understanding from what he has, from his daily practice, because sometimes he will think, "Why do I have to learn percentages? Where am I going to apply this here?" And it is present all the time in his life.* (Meeting 3, First Activity: Brainstorming connections to students' lived experiences in groups)

These passages show how a teacher draws on topics (analysis outputs) to bring his plan closer to his students' lives, strengthening the evidence that engaging with analysis outputs can support instruction connected to students' lived experiences.

Topics and essays as a medium for dialogue with students' voices

Finally, for four of the 11 teachers, topics and essays served mainly as a platform through which they entered a conversation with students' voices and built knowledge around, among other things, the importance of inviting students' worlds into the classroom, their own role in their students' lives, and the school's role in dealing with social issues through making space in the classroom for students to discuss topics that are relevant to them and to society as a whole, but which are usually not considered part of the official curriculum and are often treated as taboo topics. Here, analysis outputs served as the medium for *a knowledge building dialogue* (Wells, 2000), allowing teachers to construct new knowledge and understanding through information from these sources that went beyond teachers' past experiences. Ferrnando, a biology teacher, exemplifies how analysis outputs served as a platform through which he could reflect on the importance of making connections to students' lived experiences. When asked whether he thinks about his own students when reading these artifacts, he shared the following in his workbook:

> *Yes, it feels like these essays were written by my own students. I saw a similar experience when I did a survey about their experiences and practices in the beginning of the school year. The diversity of ways of seeing things highlights how students see the world. Often these students do not verbalize it (because they do not have the opportunity to do so) in the classroom*. (Homework 1, Answer to "Do you think (or not) about your own students when reading these materials?)

That the analysis outputs ignite reflection in Fernando becomes even more evident when Fernando is asked what comes to his mind when reading selected topics and essays:

> *Reading students' essays on such diverse topics highlights how students approach the same topic in so many different ways, and have so many different views about the same issue. This exercise can open up possibilities for approaches not thought of before by the teacher.* (Homework 1, Answer to "What comes to your mind when reading these materials?)

Similarly, when asked to reflect on his main takeaways from the exercise, Fernando articulated that reading students' essays and thereby learning about students' ideas on a given topic can help teachers design instruction that is closer to – and thereby more relevant to – students' experiences.

> *It is important to read students' conceptions about certain topics before preparing lessons on that topic. Based on students' ideas and conceptualizations, it is possible to approach certain themes in a way that brings them closer to the students.* (Homework 1, Answer to "What are your main takeaways from this exercise?)

Fernando's reflections highlight the potential that this sort of engagement with students' voices through topics and essays may have in bringing teachers closer to adopting culturally-informed teaching practices and/or philosophies.

Conclusion

In this paper, we have discussed how having teachers engage with analysis outputs of large-scale identity productions can support teachers' design work in culturally-informed ways. Our findings suggest that such an approach has great potential to complement teachers' toolkits and enkindle culturally-informed curriculum design. Through engaging with texts, teachers in our study recruited three separate but intertwined learning mechanisms to build new knowledge: analogical mapping, brainstorming, and dialogue. To capitalize on this potential, future research should use these insights to inform the design of learning experiences for teachers that incorporate the analysis of large-scale identity artifacts as part of supporting design work toward culturally-informed instruction.

The particular forms that such large-scale artifacts might take is still an open field. In the current project, we rely on automated analysis of a corpus of student writing to produce the artifacts that then get taken up in teachers' learning. We believe that such automated analysis is quite powerful, and can be useful in overcoming barriers that teachers might confront in attempting to assimilate all the details of thousands of student productions in the absence of such automated approaches. That said, automated analysis is not the only potentially fruitful way to arrive at such artifacts, and future work can further explore the possibilities here. Additionally, future work can explore varied combinations of methodologies, types of large-scale identity productions, types of analysis outputs, and teacher populations so as to see how globally applicable these findings are and where they might need to be further tailored. In our own future work, we plan to delve into the details of how teachers *use* learning like that explicated here to design learning experiences in culturally-informed ways.

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Perspective Taking Interventions and Socioscientific Issues: The Case for Cautious Optimism

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Abstract: Perspective taking has been identified as a key skill in navigating the contentious socioscientific issues that threaten society. There has recently been a surge in interest in understanding how best to support perspective taking in science classrooms. This paper advocates for an optimistic, but cautious approach to the design and evaluation of perspective taking interventions. Although there is reason to be enthusiastic about the future of these interventions, there are also pitfalls associated with perspective taking in contexts like socioscientific issues. This paper concludes with recommendations to help address those concerns.

Introduction

The world is facing grand challenges like climate change, the COVID-19 pandemic, and environmental degradation. These issues (i.e., socioscientific issues) have profound social implications and adequately addressing these issues requires the understanding and application of scientific knowledge (Sadler, 2004; Zeidler, 2014). Because of the complex nature of these issues, straightforward solutions are rare if not non-existent, as they implicate a wide variety of people and institutions (i.e., stakeholders), often with competing interests (Sadler, 2004; Zeidler, 2014). Simple solutions that appear optimal may, in fact, present grave consequences for others implicated in the issue. For example, whereas moving away from coal is an important step in addressing climate change, it also necessarily involves taking away the livelihood of entire communities. Advocating for the divestment in fossil fuels without considering and constructing a means of addressing the economic strife it will create is myopic at best, cruel at worst. As a result, these issues are inherently moral and often politically fraught. Addressing socioscientific issues necessarily requires engagement with the ethical considerations when designing just solutions (Sadler & Zeidler, 2004; Zeidler, 2014).

Science education is well positioned to address these issues. Science learning experiences can be structured to create a supportive environment for students to engage with these issues and develop the skills needed to apply scientific knowledge to improve the lives of others (Sadler, 2009). However, traditional science instruction can miss the social context that is critically important to understand when navigating socioscientific issues. If the knowledge is to be applied, it is not enough to simply use these issues to generate superficial interest in the science content: students must actively engage in the sociocultural practices of science and civic discourse that are required to navigate these issues beyond classroom walls (Sadler, 2009; 2011). Thus, the dual goals of socioscientific issues-based education should be to help students learn about the issue and prepare them to engage in civic discourse that leads to solutions that improve society (Sadler, 2009; 2011; Zeidler, 2014).

Perspective taking is thought to be a crucial skill in these contexts. Recent studies suggest that perspective taking may be a prerequisite to higher-order reasoning about socioscientific issues (Romine et al., 2017; 2020). Perspective taking has also been explored as a way of promoting empathy for disagreeing others (Herman et al., 2020, 2021), something that feels to be in increasingly short supply in the current sociopolitical context. Perhaps unsurprisingly, there has been a recent movement to more deliberately explore how perspective taking occurs in socioscientific issues-based contexts, and how it may be supported during instruction (e.g., Herman et al., 2020, 2021; Kahn & Zeidler, 2016, 2019; Newton & Zeidler, 2020). Doing so will not be without challenges, however. Herman and colleagues (2020) have noted the need for more a rigorous approach to understanding how students engage in perspective taking in authentic contexts, acknowledging the limitations of self-report measures and fictitious contexts that are often used in research and instruction.

The purpose of this conceptual paper is to argue that perspective taking interventions should be subject to a high level of scrutiny due to the high stakes, contentious nature of these issues. I begin by discussing the role of perspective taking in reasoning about socioscientific issues. Next, I discuss promising examples of perspective taking interventions in the context of contentious social issues. I then qualify this optimism, identifying several potential challenges that may hinder the success of these interventions in socioscientific issues-based contexts. In doing so, I advocate for particular attention to be paid to the accuracy of inferences made by students, and the pragmatic consequences of those inferences. I conclude this paper with recommendations for future directions, focusing on how we might design and evaluate perspective taking interventions in educational contexts.

Literature selection

Although I argue that the studies presented in this paper raise concerns worthy of our attention, this paper should not be taken as a systematic review. The purpose of this search was not to provide a comprehensive overview of perspective taking research. Instead, I present select studies outside the field of science education that illustrate challenges associated with perspective taking that may be of interest to the science education community. Articles were identified through database searches and bibliography mining. During this process, I paid close attention to studies and lines of research that illustrate challenges associated with perspective taking in contexts like those covered in socioscientific issues-based instruction. Articles that fit these criteria were evaluated closely, with articles whose methods were either unclear or lack in rigor being excluded.

Socioscientific reasoning and perspective taking

Sadler and colleagues (Sadler et al., 2007) have identified socioscientific reasoning as a key construct that underlies engagement with these issues in the real world. This construct is comprised of four key competencies:

- understanding and appreciating the inherent *complexity* of the issue that must be considered when designing solutions,
- engaging in apt *perspective taking*: identifying and considering the positions, interests, and concerns of stakeholders who are implicated,
- recognizing the need for ongoing *inquiry*, noting where more information is needed and re-evaluating positions as new knowledge is constructed,
- and exhibiting *skepticism* towards new information, evaluating it for potential biases and the overall quality of the arguments supporting the knowledge claims made by the authors.

Kirk & Sadler (2023) argue that for perspective taking to be aligned with the goals of socioscientific issues-based education (i.e., promoting civic discourse and solution finding), it must honor the experiences of potentially disagreeing others, establish genuine understanding, and orient students towards finding common ground and ethical solutions. Perspective taking is positioned both as a practice for learning about the issue in question as well as a skill to develop for navigating these issues beyond the classroom. In the classroom, when students learn about the experiences of various stakeholders from their perspectives, it helps them understand the challenges of finding a solution (Sadler et al., 2007; Sadler & Zeidler, 2005). Outside of the classroom, simulating other perspectives can be used to anticipate counterarguments and craft rebuttals when engaged in civic discourse, argumentation, and advocacy (Sadler & Donnelly, 2006), as well as promote the moral and emotional sensitivity needed to engage in productive dialogue around the issue (Fowler et al., 2009; Zeidler, 2014).

Kahn & Zeidler (2017; 2019) argue that apt perspective taking involves not only identifying where one stands on an issue, but also the reasons behind that stance. By their definition, it is entirely possible to predict where an individual stands on an issue without meaningfully engaging in perspective taking. For example, one could rightfully predict the position an individual would hold on fossil fuel divestment based solely on the information that they live in a coal-mining town, and geopolitical stereotypes. However, in doing so one omits the visceral experience of managing the anxieties that come with financial hardship, and uncertainty about what that decision means for the future of themselves, their family, and their neighbors. Perspective taking in the context of socioscientific issues necessarily involves engaging with the cognitive and affective experiences of others (Kahn & Zeidler, 2019). Doing so contextualizes the positions of others they may disagree with. Supporting students in grounding their perceptions of others in the legitimate concerns of stakeholders through perspective taking invites the understanding needed to make compassionate decisions.

Although perspective taking interventions should result in accurate inferences about the positions stakeholders are likely to take on an issue, this information is not sufficient to evaluate the quality of an intervention. Perspective taking interventions should also be evaluated based on how closely insights from student perspective taking aligns with the experienced reality of a target-other (i.e., the reasons behind the position). Additionally, researchers should attend to whether an intervention results in behaviors that support the pragmatic goal of preparing students to positively transform society (Zeidler, 2014).

Perspective taking interventions: The case for optimism

Because perspective taking interventions have not received much attention to the science education community until recently, Kahn and Zeidler (2016) have noted the need to attend to research on these interventions beyond science education contexts. Indeed, there is a growing body of empirical evidence that demonstrates the value of perspective taking interventions in the context of pressing social issues (e.g., Shachnai et al., 2022; Todd et al., 2011; Tompkins et al., 2015). For example, Shachnai and colleagues (2022) found that engaging in perspective taking through pretend play may help address gender disparities in science fields by supporting young girls' persistence in difficult science tasks. Children were assigned to one of three groups, a control group, a group where they were exposed to descriptions of a gender-matched science role-model, and a condition where they were asked to pretend they were the scientist they had just learned about. The children then participated in a challenging science game. Persistence was measured based on how many trials of the game children were willing to participate in before expressing the desire to "do something else." Although boys persisted longer in the game, girls in the pretend-play condition persisted significantly longer than girls in the other two conditions. Perspective taking, not simply learning about role models, helped young girls persist in a field that continues to grapple with representation issues. The findings presented in this study demonstrate that meaningful behavioral change can be obtained as the result of perspective taking.

Perspective taking can also help increase empathy for others in the context of potentially divisive social issues. For instance, Tompkins and colleagues (2015) explored how perspective taking interventions can be used to shape beliefs about outgroups. Specifically, they set out to study whether perspective taking interventions can be leveraged to reduce prejudice against transgender persons. Participants in the perspective taking condition watched a 15-minute documentary of a transgender child before being asked to imagine that they were themselves transgender and craft a letter coming out to their parents. In the comparison condition, participants were educated on the diagnostic criteria for gender-identity disorder followed by an interview with an expert in gender identity disorder in an intervention that lasted 15 minutes. Following this, comparison-group participants were asked to write down all the information they could recall about gender identity disorder. Individuals in the perspective taking condition demonstrated a significant decrease in their levels of genderism and transphobia, whereas those in the education condition increased in this measure. Individuals in the perspective taking condition also reported being significantly more willing to have transgender persons in their close social network following the intervention, whereas those in the education condition exhibited no change. Decreases in prejudice and willingness to include outgroup members in one's social network are indeed desirable outcomes that are aligned with the goal of promoting civic discourse around contentious issues.

Perspective taking has also been explored as a way of disrupting implicit racism. Todd and colleagues (2011) asked participants to clearly visualize the experience, thoughts, and feelings of a Black man experiencing discriminatory treatment while watching a short video or participating in a short writing task. These participants demonstrated a reduction in measures of implicit racism in comparison to control groups and groups who were asked to evaluate the situation objectively. These differences were observed through a diverse array of instruments, including computer-based measures (e.g., Implicit Attitudes Test), self-reports (e.g., feeling thermometers), behavioral measures (e.g., seating distance), and the subjective experience of Black experimenters in interaction with participants. These findings suggest that not only did the perspective taking intervention result in measurable shifts, but also that those shifts translate to positive, real-world behaviors that can be felt by others.

Interventions that positively shape the ways people persist in difficult tasks and orient towards outgroup members are desirable and present promise for supporting outcomes aligned with the goals of socioscientific issues-based instruction. It is particularly promising that the interventions presented in the preceding papers echo some of the recommendations made by scholars advocating for perspective taking in science classrooms (e.g., Kahn & Zeidler, 2016; Newton & Zeidler, 2020). Taken together, these papers suggest that perspective taking presents unique benefits that may not be felt through approaches which emphasize objectivity (Todd et al., 2011) and knowledge alone (Shachnai et al., 2022; Tomkins et al., 2015).

Challenges in contentious contexts: The case for caution

Despite the promising findings outlined in the previous section, it should be noted that these results may not readily translate to other contexts that are, perhaps, more analogous to the socioscientific issues that are commonly addressed in science classrooms. Whereas the studies above certainly involved participants engaging with politicized social issues through perspective taking, they did so outside of a competitive context. Participants were not engaged in debate with the individuals they were assuming the perspective of. These contexts present different environmental cues that have the potential to shape the ways perspective taking occurs and the associated outcomes. The often competitive, politicized, and moral dimensions of socioscientific issues are important for students to directly engage with during instruction (Zeidler, 2014). Thus, it is important to consider how perspective taking interventions behave in these contexts specifically.

Accuracy matters

Apt perspective taking involves being able to accurately infer the content of another person's psychological experience (i.e., empathic accuracy; Ickes, 1993; Myers & Hodges, 2008). It is important to note that empathic accuracy should be differentiated from empathic concern, a construct that has been better explored in the context of science education (e.g., Herman et al., 2020, 2021). Although empathic concern may motivate an individual to help others (indeed a positive outcome), empirical studies suggest that these two constructs are uncorrelated (Myers & Hodges, 2008). Just because an individual demonstrates concern for the wellbeing of another does not mean they are generating accurate inferences about the thoughts and feelings of that person.

Despite empathic accuracy research suggesting we are far from expert mind-readers, Myers and Hodges (2008) argue that in most situations, our reliance on stereotypes and heuristics leads to accurate-enough inferences. There are times when this approach results in problematic outcomes, however. Perspective taking that is grounded in inaccurate representations of the target-other can have damaging repercussions. For example, Lees and Cikara (2020) demonstrated that in competitive political disagreements, people tend to hold overly negative, inaccurate judgements of the perceptions and motivations of outgroups. It is important to note that participants in this study were not necessarily failing to predict the attitudes held by outgroup members. Rather, they were over-estimating the extent to which the outgroup harbored negative feelings towards the participants' ingroup, and over-estimating the motivation of the outgroup to engage in obstructive behavior. These misconceptions can further the divides that make conflicts intractable. As such, ensuring that perspective taking interventions are grounded in accurate knowledge should be of paramount importance. Failing to do so can lead to results that are antithetical to the mission of preparing students to engage in discourse that supports the design of equitable solutions to problems facing society.

Accuracy: Necessary but not sufficient

Even if perspective taking is grounded in accurate representations and yields accurate predictions, it may not lead to desirable outcomes (Epley & Caruso, 2008; Epley et al., 2006). In a study of how participants engage in resource allocation tasks, Epley and colleagues (2006) found that asking participants to adopt the perspectives of others exacerbated selfish behavior in competitive contexts. It is worth noting that one experiment in this study leverages a dilemma where individuals are asked to determine how to manage harvests in a stressed fishery. Wildlife and water management issues are examples of typical socioscientific issues taught in environmental science contexts (e.g., Newton & Zeidler, 2020), suggesting a degree of ecological validity despite its laboratory context. Although participants demonstrated a decrease in egocentric framing when evaluating fairness, participants in competitive contexts ended up taking *more* resources when given the opportunity than their non-perspective taking counterparts. Despite participants articulating an understanding of fairness, their behaviors were incongruent with sustainability goals. These results were then replicated using different contexts through four other studies.

Epley and colleagues (2006) attribute this to *reactive egoism* whereby perspective taking leads people to infer self-serving motives of competitors, driving self-serving behaviors regardless of fairness. Reactive egoism is diminished in cooperative contexts, but these findings point out the dangers of treating perspective taking as a goal in itself. Although participants did indeed engage in perspective taking, the repercussions of doing so actively worsened outcomes. Many socioscientific issues are experienced as zero-sum games rife with politicization and partisanship. Perspective taking in these contexts may occur with fidelity, but at the expense of positive outcomes. As such, evaluations of perspective taking interventions should consider whether those interventions result in pragmatic actions that impact society in desirable ways, not simply whether participants can predict and articulate the position of others.

Future directions: Evaluating perspective taking within the classroom

Currently, there is a dearth of instruments designed to measure perspective taking in educational contexts to the extent discussed above. As noted by Herman and colleagues (2020), self-report measures and assessments that rely on students taking the perspective of invented characters omit critically important facets of the perspective taking experience. How well these assessments speak to students' ability to engage with the perspectives of real-world stakeholders is unclear. Invented characters are themselves abstractions, devoid of the depth that makes perspective taking such a challenging yet impactful experience. They reflect the biases and assumptions of the creators, not necessarily the populations they aim to represent. If we wish to understand how well students' inferences reflect the nuanced concerns and experiences of real-world people, we should strive to co-construct perspective taking assessments with actual stakeholders. Likewise, we should pay particular attention to whether these predictions translate into behaviors conducive to civic discourse and solution finding.

Addressing the concerns outlined above certainly poses a genuine measurement challenge, but not one that is insurmountable. For example, the methods used to assess empathic accuracy developed by Ickes and colleagues (Ickes, 2001; Ickes et al., 1990) holds promise for educational research. This approach compares the actual thoughts and feelings of a target person with the inferences about those thoughts and feelings made by the perspective-taker. To do so, a target person is videotaped in an interaction. The target person then watches the videotape, pausing the tape when they remember having a particular thought or feeling and recording that experience. The perspective-taker then watches the video. The tape is paused at each point where the target other recorded their experience and the perspective-taker is asked to infer what the target other is thinking (Ickes et al., 1990; Myers & Hodges, 2008).

Although this method has been shown to be both reliable and valid (Ickes et al., 1990; Myers & Hodges, 2008), these methods are highly labor-intensive, require careful planning and multiple, trained coders to successfully implement, and require direct collaboration with stakeholders whose perspectives one wishes to foreground. Likewise, this laboratory-based approach can rightfully be critiqued for being removed from the sociocultural context these perspective taking experiences are situated within. Thankfully, this is not a new problem for educational research. It is not uncommon for design studies to involve both laboratory and naturalistic components, placing these findings in conversation with one another to refine both the product and theory (Brown, 1992; McKinny & Reeves, 2018).

The approach detailed by Ickes and colleagues (Ickes, 2001; Ickes et al., 1990) is well suited to inform design studies. Socioscientific issues-based research and instruction often incorporates partnerships with stakeholders (e.g., Newton & Zeidler, 2020). Because much of the infrastructure and rapport already exists, the additional work required of stakeholders to craft these assessments is relatively small compared to situations where these partnerships may not already exist. Additionally, this approach also grounds evaluations of these interventions in the real-world thoughts and feelings of stakeholders, rather than fictitious, abstract characters that emerged from the researchers' own biases and assumptions. The act of interviewing and co-constructing the instrument can itself yield valuable data that can inform curricular design decisions. Researchers will have an instrument that was co-created with real stakeholders that can help ensure curriculum honors their experiences and attitudes. Stakeholders are given agency over their story, and how that story is used for research.

Observational studies of students engaged in learning experiences can be used in tandem with the laboratory-based studies outlined above to explore how students approach the solution-finding process. Particular attention should be paid to student discourse as students engage in authentic culminating activities. Are students using deficit framing and stereotypes when discussing the perspectives of others? Or are they demonstrating empathic concern, exploring the genuine concerns of disagreeing others, and appreciating the reasoning that led to those positions? Similarly, do students adopt a "scorched earth" or "zero sum" approach to solution-finding whereby they attempt to maximize immediate returns for those who share their position? Or do students attempt to understand the needs of other stakeholders, working to find a solution that satisfies the needs of many while minimizing collateral damage? These findings could be placed in conversation with laboratory-generated data using methods like those detailed by Ickes and colleagues (Ickes, 2001; Ickes et al., 1990) and the resource allocation games used by Epley and colleagues (2006). Doing so can refine our understanding of how, when, and why the phenomena observed in the lab are likely to replicate in the real world.

Conclusion

Given its central role in socioscientific reasoning, the current calls to better understand how perspective taking can be supported in socioscientific issues-based learning experiences are well-justified. Perspective taking interventions present promising opportunities to enrich our students understanding of the world as well as prepare them to rise to the challenge of addressing pressing issues that face society. However, due to the nature of the issues at hand, perspective taking interventions may not result in the outcomes they intend to support; in some contexts, these interventions may actively go against those outcomes. Special attention must be paid to the accuracy of knowledge recruited by students when engaging in perspective taking, as well as whether perspective taking results in behavioral outcomes aligned with the pragmatic goals of socioscientific issues-based instruction.

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Investigating the Efficacy of an Ontological Framework for Teaching Natural Selection Using Agent-Based Simulations

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Abstract: Integrating agent-based models (ABMs) has been a popular approach for teaching emergent science concepts. However, students continue to find it difficult to explain the emergent process of natural selection. In this study, we employ an ontological framework–the Pattern, Agents, Interactions, Relations, and Causality (PAIR-C)–to guide the design of the ABM simulation module. This study examines the effects of the PAIR-C ABM module versus the Regular ABM module on fostering students' understanding of natural selection. Drawing on pre-posttest data, we found that students in the Intervention group had a better causal understanding when explaining natural selection than the Control group. This paper sheds light on applying an innovative framework to designing effective agent-based simulation modules to teach emergent science concepts.

Introduction

The learning of natural selection has been a challenging concept for learners to grasp. Not only naïve learners, but even advanced learners at the postsecondary level also often hold robust misconceptions in explaining the process of natural selection (Bishop & Anderson, 1990; Gregory, 2009). To address this challenge, many researchers and practitioners have used agent-based models (ABMs) or simulations to teach evolution and natural selection over the past decade (Dickes & Sengupta, 2013; Wagh & Wilensky, 2018).

ABMs are computer simulations used to study individual agents' interactions and how they give rise to unpredictable aggregate patterns (Wilensky & Rand, 2015). A substantial number of studies have explored various approaches toward integrating ABMs into learning evolutionary concepts and natural selection. For instance, researchers have taken a hybrid approach of using multiple external representations (aka. MERs-complemented approach) to complement ABMs in explaining emergent phenomena (Basu et al., 2015; Chi et al., 2012b). Although students' conceptual understanding of natural selection can be positively improved by participating in the MERs-complemented approach, the degree to which learning is improved remains limited. Students continue to have inadequate understanding and robust misconceptions, especially when explaining the causal mechanisms for the process of natural selection (Chi et al., 2012a; Su et al., 2021; Peel, 2019).

Researchers (Chi et al., 2012a; 2012b) thereby propose that developing a correct understanding of natural selection (e.g., how an outcome, such as "darker moths" or "long-neck giraffes", becomes common) requires being able to explain how and why agent-level behaviors could give rise to pattern-level outcomes, referred to as the inter-level causal relationships. Moreover, it is important to distinguish inter-level causal relationships from agent-aggregate complementary relationships or input-consequence relationships. Understanding the agent-aggregate complementary and the input-consequence relationships can be less challenging because neither of them considers all the interactions between agents nor emphasizes the nonlinear, dynamic causal relationship between agent-level interactions and pattern-level outcomes. This paper posits that using ABMs without explaining inter-level causal relationships is not likely to result in a deeper understanding of the emergent process of natural selection.

Building on early works, authors recently proposed an ontological framework - the Pattern, Agents, Interactions, Relations, and Causality (PAIR-C) framework - to explain the root causes for misconceptions and support instructions on inter-level causal relationships (under review). Therefore, this paper aims to show the efficacy of integrating the PAIR-C framework into teaching the emergent process of natural selection using the MERs-complemented ABM approach. Specifically, it compares the effect of the PAIR-C ABM module with a Regular ABM module on facilitating students' deeper understanding of inter-level causal relationships when explaining the emergent process of natural selection. The paper focuses on addressing one major research question: What are the effects of the PAIR-C ABM module versus the Regular ABM module on fostering students' understanding of natural selection?

Theoretical framework

The PAIR-c framework

The PAIR-C framework identifies five dimensions to describe a science process: **P**attern, **A**gents, **I**nteractions, **R**elations among the interactions, and the **C**ausal relationship between the agents and the pattern (Chi et al., under review). A Pattern describes the overall changes by a process that is often visible and meaningful, Agents are elements that participate in the process which produces the pattern, Interactions refer to how the agents of the process interact, Relations compare some agents' interactions with other agents' interactions, Causality refers to the causal relationship between the agents and the pattern.

PAIR-C also deduces seven features from the Relations and Causality dimensions (first column, Table 1). Among them, there are four *Interaction features* (Feature 1-4, Table 1) identified from the **R**elations dimension. These four *Interaction features* are often perceptible and can provide learners with visual cues to recognize an emergent process (Features 1-4, Table 1). To further illustrate this point, we use the emergent process of ants foraging for food as an example. When ants search for food, they all walk around, emit, and follow pheromones (Feature 1: have the same set of actions). They can follow or stop following any other ant (Feature 2: bi-directional interactions with random others). At any moment, ants can follow other ants without any specific order (Feature 3: occurs simultaneously). Whether an ant follows another is independent of whether another ant follows yet another ant (Feature 4: independent).

In addition to the four *Interaction features*, three other *Inter-level features* (Feature 5-7, Table 1) are identified from the **C**ausality dimension. These *Inter-level features* also cluster multiple attributes as implications of the same feature. For instance, feature 5 specifies some critical attributes of a converging pattern. One is that the initial pattern has no resemblance to the final pattern (e.g., the initial pattern of ants foraging for food is a random distribution of ants. It does not resemble the final pattern of ants forming a single line). Feature 6 clarifies the method to compute the resulting Pattern by adding positive and negative numbers or by averaging out the magnitudes and directions within each unit of time (e.g., the single-line pattern of ants is computed by averaging all the ants' distances and directions - towards and away from the line - at each unit of time; it is the proportion of ants staying on a single line increasing over time, not the absolute number of ants on the single line increasing in each time). Moreover, some of the attributes that describe inter-level causal relationships (i.e., "i. decentralized", "ii. equivalent status", "iii. unintentional", "iv. not teleological", "v. no direct effect", and "non-matching") are classified as implication features for the **C**ausality dimension (see Feature 7a and 7b).

Overall, the PAIR-C framework provides a clear guideline for qualitatively describing and quantitatively computing the causal mechanisms for emergent processes. It is hypothesized that by grasping these PAIR-C features, students can correctly describe and explain inter-level causal relationships for emergent processes.

Table 1

The Seven PAIR-C Features for Describing and Explaining Emergent Processes

Interaction Features	Dimension IV: **R**elations among the agents' interactions
Feature 1	Same set of interactions
Feature 2	Random, bidirectional interactions
Feature 3	Occur simultaneously
Feature 4	Occur independently
Inter-level Features	Dimension V: **C**ausal relationship between the Agents-pattern
Feature 5	Converging change a. The initial pattern has no resemblance to the final pattern b. The changing pattern reflects the interactions of *all* the agents' interactions
Feature 6	Collective summing a. Adding positive & negative numbers within time b. Net effect: Adding magnitudes & directions within each time unit, then comparing across time units (e.g., proportion change)
Feature 7a	All agents are responsible for the pattern i. Decentralized, distributed control ii. Equivalent status iii. Local goal: Unintentional iv. Not teleological/not purposeful v. No direct effect
Feature 7b	No alignment (non-matching) between the agents and the pattern

Using PAIR-c to evaluate ABM integration efforts

In this section, we use the PAIR-C framework as an analytical lens for evaluating previous ABM integration efforts. We also analyze what PAIR-C features were present or absent in previous studies and consider how including/not including such features might affect students' learning outcomes.

In Dickes & Sengupta (2013), after interacting with a Birds & Moths ABM simulation, all students could provide agent-aggregate complementary explanations in which they explained aggregate-level outcomes using the agent perspective. For example, in reasoning the aggregate-level outcome of darker moths becoming more common, students state "the dark moth population will go up because they will have babies because they're not eaten." (p.932, Dickes & Sengupta, 2013). However, this causal statement was not necessarily correct even though it explains an aggregate-level outcome (i.e., dark moth population goes up) in terms of agent-level behaviors (i.e., dark moths have babies, dark moths are not being eaten). Similar statements could be found in students' utterances sampled in other studies (Dickes et al., 2016; Wagh & Wilensky, 2018). According to the PAIR-C framework, these agent-aggregate complementary explanations tend to focus on a subgroup of species (i.e., the dark moths) without considering all interactions between all species at the agent level (i.e., the dark moths, the light moths, and the birds who prey on moths). The causal statement seemed to distinguish dark moths' behaviors from other moths as they have special abilities to have babies and avoid being eaten. Moreover, these statements tend to attribute the aggregate-level outcome as static rather than explain how the agent-level behaviors give rise to the aggregate-level outcome by considering all the interactions among the agents. Therefore, agent-aggregate complementary explanations do not necessarily subsume a correct understanding of inter-level causal relationships. Compared to these student explanations, a more sophisticated causal explanation should state "the dark moth population will go up because in most generations dark-colored moths survive from being spotted by birds and those survived can reproduce, compared to light-colored moths who have lower survival and reproduction rates (due to industrial pollution, trees became darker with soot and thereby dark-colored moths could blend in the environment more easily than the light-colored moths). Over many generations, dark-colored moths will become more common." Since previous studies already used models with multiple breeds of agents governed by the predator-prey relationship (e.g., both birds and moths are shown in the ABM simulations), explicit instruction on the *Relations among the agents' interactions* (i.e., having the *same set* of interactions: all moths can reproduce with each other and can be eaten by birds, see Table 1 Feature 1) should be available to students.

Existing efforts also reveal that researchers often used ABMs to teach the simple idea of "interactions or relations between agents" rather than using ABMs to teach "Relations among the agents' interactions". For example, Basu et al. (2015) used a Saguaran ecosystem model to teach students about the relations between agents (e.g., "Doves eat seeds of the cacti", "Rats eat pods of the ironwood trees", "Hawks prey on rats", "Hawks prey on doves", etc.) without mentioning the relations among the interactions, such as whether one interaction can occur at the same time (*i.e. simultaneously*) as another interaction (missing Feature 3 from Table 1). Their study showed that understanding the interactions between agents did not help students reason in causal chains unless they were scaffolded to notice the *simultaneous and bidirectional* nature of interactions. When asked, "Knowing that hawks eat rats and rats eat pods, what would happen if hawks were removed from the ecosystem?", all students in their study initially stated that "If there were no hawks to eat the rats, rats would increase. So, pods would decrease and disappear soon." What was missing in students' responses was the ability to reason further about the consequences of the lack of pods on the population level of rats (missing Feature 2 from Table 1). To remedy this issue, Basu et al. (2015) later introduced an external representation tool (i.e., the causal map) as a complementary approach to scaffold students' understanding of the bidirectional nature of the food chain causal relationships. By visualizing the bidirectional interactions between pods and rats, hawks and rats using the causal mapping tool, students showed significant improvement in their causal understanding of the Saguaran ecosystem.

Recent efforts used multiple external representations (MERs) to illustrate PAIR-C features and complement the use of ABMs (Su et al., 2021). A pilot study modified ABMs by adding "links" as visual cues to represent agent interactions within the model and later generated enhanced visual representations in the form of videos, animations, and screenshots to show and prompt students about all four *Relations among the agent's interactions* features. However, results showed that there was no significant difference in pre-post test scores between the Control and the Intervention group. Although most of the PAIR-C features were illustrated throughout the simulation module in the pilot study, one limitation was that the PAIR-C instruction was not explicit in teaching ideas about inter-level causal relationships. Therefore, to facilitate students' deeper understanding of natural selection, there is a need to explicitly teach the *Inter-level features*, especially the "converging change" and "collective summing" causal mechanisms through the MERs-complemented ABM approach.

Methods

Participants and settings

The study took place at a Southwestern University in the United States. Participants were a diverse group of online students enrolled in a 7-week technology literacy course, majoring in Education (n = 29, 58%), Social Studies (n = 13, 26%), and Arts & Humanities (n = 8, 16%). Participants were predominantly juniors (52%), sophomores (22%), and seniors (16%). The gender distribution was 76% female students, 22% male students, and 2% non-binary. The average age of the participants was 27.4 years with a standard deviation of 8.91. Participants reported their ethnicity with the following proportions: 68% as White, 14% as Hispanic/Latino, 6% as Asian or Asian American, 6% as Black or African American, 2% as Native American, and 4% as Other. 86% of participants reported having taken 1-2 biology classes at high school, 12% had taken 3 or more biology classes at high school, and only 2% had taken no biology classes at high school. Only two participants reported having heard about and used NetLogo simulation before the study. This paper included a total of 50 participants: 26 in the Control group and 24 in the Intervention group.

Study design and procedure

The study adopted a pretest-posttest randomized block design (RBD). The blocking factor was the participants' scores on the pretest True or False (T/F) questions. The pre-posttest and the surveys were distributed via Qualtrics. This study designed two simulation modules: the Regular ABM Module used in the Control group and the PAIR-C ABM Module used in the Intervention group. To deliver the simulation modules in an online environment, we used NetLogo Web to show the simulation models and Qualtrics to present relevant instructional materials. Participants in both groups received tutorials on how to navigate the NetLogo Web and the Qualtrics-supported instructional page before starting the simulation modules.

Simulation modules

Both simulation modules were about the same length and used the same types of multiple external representations (MERs) including simulation models, explanatory texts, images, screenshots, and videos. We also used prompts to help students actively make connections between MERs by asking them to generate new inferences beyond observing or manipulating MERs. More importantly, students in both groups had the same sequence of activities which allow them to observe, explore, and investigate questions using interactive simulations and MERs. Table 2 presents a detailed comparison between the Regular ABM module and the PAIR-C ABM module and points out the main differences between them.

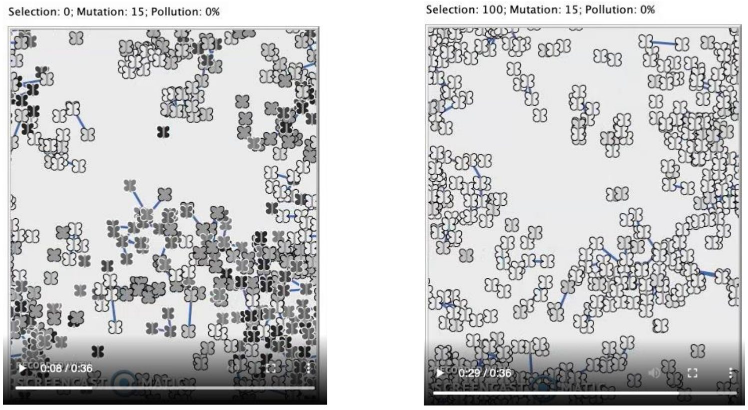
Table 2
Comparison of the Two ABM Simulation Modules

	Regular ABM Module (Control group)	PAIR-C ABM Module (Intervention group)
Overall Use of Multiple External Representations	Both modules use the same amount of MERs at the same location.	
Simulation models:	Both modules use the same interactive simulations - the Peppered Moths model and the Rock Pocket Mice model- and allowed learners to observe, explore, and investigate these simulations at their own pace.	
Explanatory texts:	Provide texts on the five Darwinian principles (such as genetic determination, adaptation, reproductive advantage), conventional definitions, and common misconceptions but withhold information on the emergent properties shown in the simulations.	Provide texts on the seven PAIR-C features and how to apply these features to explain the emergent properties of natural selection caused by mechanistic details of agent interactions (such as inheritance, predation, and reproduction).
Images, screenshots, videos:	All representations were generated from the agent-based models directly and did not contain external visual	Most of the representations were modified and provided visual cues (e.g., blue links were used to

	cues to represent different types of agent-level interactions.	represent mating interaction. See example in Figure 1)
Overall Use of Prompts	Both units use the same number of identical generic prompts that contain the same types of questions.	

Figure 1

Screenshots of the Simulation Video with Different Selection Pressure



Note. The screenshots were taken from the link-visible ABM video used in the PAIR-C intervention group. The video in the control group did not show any links.

Pre-posttest instrument

Understanding of Natural Selection was assessed by the pre-posttest instrument. The pretest and the posttest are identical despite the sequence. Most of the questions were revised from the AAAS conceptual inventory and past AP Biology Exams. The revised items were validated by a high-school biology teacher who was a collaborator with our team and previously taught the PAIR-C framework in his natural selection lessons. The test contained three sets of True or False (T/F) questions with five statements for each set. These fifteen T/F statements were designed in the format of two-tiered questions. The first tier simply asked students to decide whether a statement was True or False. The second tier asked students to explain the statement they picked as False. In our previous experience with T/F explanations, students tend to rephrase or copy the True statement without giving an explanation. Therefore, the pre-posttest in this study only asked students to explain the False questions to reduce the likelihood of guessing while remaining a relatively shorter test. For the True/False selection part of the question, if students correctly determined whether the statement was True or False, they were given a score of 1, otherwise a 0 point. For the open-ended part of the T/F items, we created scoring rubrics for each false item (on a scale of 0, 0.5, and 1).

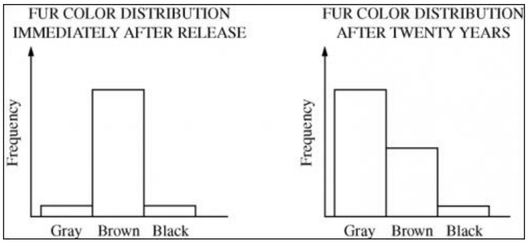
Seven out of the 15 T/F questions were labeled as Shallow which assessed basic understandings of Darwinian principles or knowledge of either agent-level or pattern-level understanding while eight out of the 15 T/F questions were Deep questions that assessed understanding of inter-level causal relationships. For example, the following T/F statement *"Changes you observed in the mice's fur color patterns from the start of the experiment to the end were wholly due to random factors"* was considered a shallow question. The reason was that it did not require an explanation or understanding of how the mice agents' interactions produce the pattern of fur color change, and 64% of the participants answered it correctly in the pretest. In contrast, another T/F statement *"The number of gray mice in the population increases slightly each year for 20 years, which adds up to the pattern of gray fur becoming more common in the population"* exemplified in Table 3 was considered a deep question because it requires a deeper understanding of the inter-level causal relationships. A correct causal explanation of this statement would imply that there was no alignment between the agents and the pattern as well as no continual increase in the number of agents for each generation. Only 20% of participants correctly determined this statement as a false statement in the initial pretest.

The test also contained two open-ended (OE) questions assessing students' understanding of the natural selection process in different contexts (to be referred to as context transfer items). These two context transfer questions were adapted based on Peel et al. (2019). Similarly, we also created scoring rubrics for each context transfer item to assess students' transfer performance on a scale of 0 to 5. For each open-ended item, more than 50% of student responses were scored by the first author and the third author for inter-rater reliability over three rounds (Kappa for the open-ended part of the T/F questions was an average of 0.843, $p < 0.001$, Kappa for OE context transfer questions was 0.925, $p < 0.001$, indicating strong scorer agreement). Table 3 provides examples of the pre-posttest items, the scoring rubrics, along with sample responses from students.

Table 3
Pre-posttest Items

True or False (T/F) Question

Q1. Decide True or False for each of the following statements that explains the change in the frequency distribution of fur color in the mouse population after 20 years, as shown in the figures below. Provide explanations for the false statements you identified.



A. The number of gray mice in the population increases slightly each year for 20 years, which adds up to the pattern of gray fur becoming more common in the population.

Rubric for explaining statement A:
This statement is False.

- ***Score 1*** *if the explanation mentions that the increase is not gradual or continuous by every generation OR refers to the "not align or non-matching" PAIR-C feature.*
- ***Score 0.5*** *if only refers to not enough data or information.*
- ***Score 0*** *if the answer only describes the bar chart.*

Sample responses for explaining statement A:

- S39: "One year there could be a surge of gray mice and one year there could be many dying instead. It is *not a continual increase*."
  Score 1
- S42: "While the grey mice population did increase significantly, *without more data we don't know* that it increased slightly for 20 years."
  Score 0.5
- S38: "The population of mice with grey fur dramatically increases."
  Score 0

Open-ended Context Transfer Question

Q4. How would biologists explain how a living mouse species with claws evolved from an ancestral mouse species that lacked claws?

Rubric:

- ***A score of "5"*** *should be given to responses that mention:*
  - *trait variation present before selection pressure*
  - *random mutations result in trait variations*
  - *mice survive and reproduce*
  - *influence of selective pressure or environment on survival and reproduction rate*
  - *changes occur over time or multiple generations*
- ***A score of "1-4"*** *should be given to responses that contain 1 to 4 key points mentioned above.*
- ***A score of "0"*** *should be given to responses that contain no key point.*

Sample response from S5:

"If one mouse was born with *a mutation in their DNA* which produced claws [score 1 for random mutations]/, once they reproduce there is a *good chance the mutated gene will present* in their offspring. [score 1 for trait variation]/ As the trait is passed down *through generations*, the population of the mutated mouse species would increase [score 1 for over time/generations]/. The claw likely provided a form of defense toward their predators, *making the mice without the claws an easier prey* [score 1 for the influence of selective pressure]. As those with claws *survived at a higher rate*, they also *reproduced at a higher rate* due to the overall lack of mouse without claws in the

population [score 1 for survive and reproduce]/.”
(A total of five points was given to S5’s response).

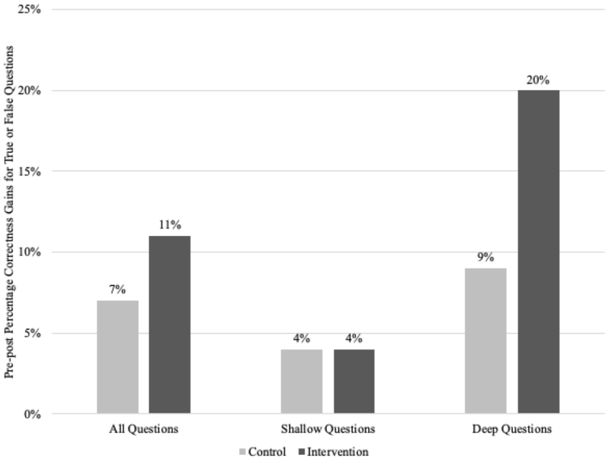
Results & discussion

Results show that student performance on the T/F items improved significantly from the pretest to the posttest for both groups. The control group (N =26) improved from a mean score of 8.94 (SD = 3.09) to a mean score of 10.89 (SD = 2.87), t =2.60, p = .016, with a medium effect size d = 0.51. The intervention group (N = 24) improved from a mean score of 9.31 (SD = 2.78) to a mean score of 12.73 (SD = 4.36), t =4.42, p < .001, with a high effect size d = 0.90. These results indicate that both the Regular ABM simulation modules and the PAIR-C ABM simulation modules used in this experiment could successfully improve students’ overall understanding of natural selection. To investigate group differences attributed to the different simulation module treatments, ANCOVA was conducted using pretest scores as covariates. The result shows that there was a marginally significant difference between the two groups in the overall understanding of natural selection (F = 2.94, p = .093, partial η^2 = .059). This difference is also reflected in the first two columns of Figure 2. As shown in the figure, the percentage of correctness gains was 7% for the control group whereas the percentage of gains was 11% for the intervention group. This result indicates that the intervention group who used the PAIR-C ABM simulation modules had a better performance on the overall understanding of natural selection compared to the control group who used the Regular ABM simulation modules.

Results also show that students improved significantly in answering deep questions from the pretest to the posttest for both groups. The control group improved from a mean score of 2.54 (SD = 2.16) to a mean score of 3.73 (SD = 2.52), t =2.08, p = .048, with a medium effect size d = 0.41. The intervention group improved from a mean score of 2.52 (SD = 2.15) to a mean score of 5.56 (SD = 3.95), t =3.90, p < .001, with a high effect size d = 0.80. These results indicate that both the Regular ABM simulation modules and the PAIR-C ABM simulation modules used in this experiment could successfully improve students’ deep understanding of natural selection. ANCOVA analyses show that there was a statistically significant difference between the two groups in answering the deep questions of natural selection (F = 4.16, p = .047, partial η^2 = .081). This difference is reflected in the last two columns of Figure 2. As shown in the figure, the percentage of correctness gains for answering deep questions was 9% for the control group whereas the percentage of correctness gains was 20% for the intervention group. These results indicate that the intervention group had a significantly better performance in answering deep questions of natural selection compared to the control group after the simulation modules. In other words, the PAIR-C ABM simulation modules were more effective in fostering students’ deeper understanding of natural selection compared to the Regular ABM simulation modules. In contrast, students’ performance did not differ between groups in answering shallow questions (F = .01, p = .934, partial η^2 = .000). This pattern is shown in the middle two columns of Figure 2.

Figure 2

Pre-post Percentage Correctness Gains for All, Shallow, and Deep T/F Questions



To see whether the PAIR-C ABM simulation module could further impact students’ abilities to explain the process of natural selection, analyses were conducted based on their responses to the two context transfer questions. Results show that there was no significant improvement in answering the two context transfer questions from the pretest to the posttest for both groups. The control group improved from a mean score of 1.73 (*SD* = 1.34) to a mean score of 1.77 (*SD* = 1.75), $t = 0.09$, $p = .928$, with a small effect size $d = 0.02$. The intervention group improved from a mean score of 2.04 (*SD* = 1.68) to a mean score of 2.38 (*SD* = 2.36), $t = 0.78$, $p = .445$, with a small effect size d = 0.16. For testing group differences in answering the post-test context transfer questions, ANCOVA was conducted. There was no statistically significant difference between the two groups ($F = 0.70$, $p = .409$, partial $\eta^2 = .015$). Similar results were also manifested in students' responses to the simulation prompt question.

The above findings suggested that the ABM simulation module integrated with the PAIR-C features could contribute to deeper learning of emergent process concepts, such as natural selection. Nevertheless, students in both groups were not able to demonstrate significant improvement in explaining the process of natural selection across different contexts. One reason could be that students did not receive enough instructions on how to use PAIR-C features or Darwinian Principles to elaborate on the process of natural selection in the simulation module. More explicit instructions should be provided to scaffold students learning.

Conclusion

In conclusion, this study shows the potential of using the PAIR-C framework in designing agent-based simulation modules for learning complex emergent phenomena. Using natural selection as the exemplary concept, the PAIR-C framework has its ecological validity as it underscores the importance of understanding the inter-level causal relationships for emergent science processes taught in school curricula. Moreover, our approach of integrating the PAIR-C framework using MERs-complemented ABM seems promising to be operationalized for science instruction broadly. We believe it can impact how science teachers produce curricula, create assessment rubrics, and use computer technologies to help students reach a deeper understanding of emergent causal mechanisms in science processes.

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Exploring Middle School Students' Understanding of Algorithms Using Standards-Aligned Formative Assessments: Teacher and Researcher Perspectives

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Abstract: 'Algorithms' is a core CS concept included in the K-12 CS standards, yet student challenges with understanding different aspects of algorithms are still not well documented, especially for younger students. This paper describes an approach to decompose the broad middle-school 'algorithms' standard into finer grained learning targets, develop formative assessment tasks aligned with the learning targets, and use the tasks to explore student understanding of, and challenges with, the various aspects of the standard. We present a number of student challenges revealed by our analysis of student responses to a set of standards-aligned formative assessment tasks and discuss how teachers and researchers interpreted student responses differently, even when using the same rubrics. Our study underscores the importance of carefully designed standards-aligned formative assessment tasks for monitoring student progress and demonstrates the need for teacher content knowledge to effectively use formative assessments during CS instruction.

Introduction

The demand for computer science (CS) learning opportunities in K-12 is rapidly increasing as it becomes clear to policy makers, educators, and parents that an understanding of computing is essential to success in a technology and automation-rich society. One of the most fundamental CS concepts is the algorithm, an ordered set of precise and clear instructions to solve a problem or generate a desired output. An algorithm is often a first step towards planning the logical flow of a computer program. Algorithmic thinking encompasses knowledge and skills specific not only to CS and programming but also to general problem-solving and computational thinking (ISTE, 2016).

The Computer Science Teachers Association (CSTA) K-12 CS Standards identify 'Algorithms and Programming' as a key CS concept across all grade bands and 'Algorithms' as one of its five sub-concepts (CSTA, 2017). Most state CS standards in the U.S. also include algorithms as a core CS concept (Guo & Ottenbreit-Leftwich, 2020). Algorithms are often introduced in K-12 through simple activities such as students writing instructions for making a peanut butter and jelly sandwich and teachers enacting the instructions. These lessons are appropriate for communicating the idea that computers will execute instructions as written (rather than as intended) but they do not touch upon other important ideas emphasized in the 'algorithms' standards such as representation, interpretation, comparison, testing and debugging of algorithms. In our review of several existing K-12 CS curricula, we have found that many of them do not include the full scope of concepts and practices covered by 'algorithms' standards. CS education research currently provides little guidance on how to unpack the broad 'algorithms' standards, making it difficult for educators to understand the full scope of the standards and the range of skills that comprise proficiency.

A thorough understanding of the algorithms standards is a necessary, though not sufficient, component of teachers' ability to develop and effectively use formative assessments on algorithms (Basu et al., 2022). In addition to content knowledge, a deep understanding of how K-12 students think about algorithms would allow teachers to identify and address student challenges and advance student understanding. Formative assessment tasks that intentionally target individual aspects of algorithms standards can reveal useful information about student understanding and specific challenges on each of those aspects (Basu et al., 2022). The ability to use such standards-aligned formative assessments to measure and support student progress on CS standards is articulated as part of the CS teacher standards (CSTA, 2020). However, there is currently limited literature on K-12 students' conceptualization of, and challenges with, the concept of 'algorithms', and many CS teachers report feeling underprepared to use formative assessments to monitor student learning (Gordon & Heck, 2019).

In this paper, we unpack a broad CSTA middle school 'algorithms' standard, 2-AP-10, "Use flowcharts and/or pseudocode to address complex problems as algorithms" into finer grained learning targets. We then discuss an approach to developing aligned formative assessment tasks (and rubrics) and describe how we used a set of tasks to explore student understanding of, and challenges with, the fine-grained learning targets underlying the standard. Finally, we compare our evaluation of student responses with how middle school CS teachers evaluated the same student responses using the same rubrics and how teachers' own understanding of algorithms informed their evaluation of student responses. By looking at both students' responses and teachers' interpretations, we are able to infer student understanding and challenges as well as explore how teacher knowledge mediates the impact of formative assessment. We are guided by the following research questions:

RQ1: How can formative assessment tasks be developed to examine student understanding on various aspects of the middle school algorithms standard?

RQ2: What can we infer about middle school students' understanding of and challenges with the concept of algorithms from students' responses to standards-aligned formative assessment tasks?

RQ3: How do teachers' interpretations of middle school students' understanding of algorithms compare to researchers' interpretations, when using the same assessment tasks and rubrics?

Theoretical perspectives

Relevant related work

Characterizing and assessing students' understanding of algorithms.

Recent research in CS education includes efforts to assess K-12 students' algorithmic thinking skills and have been situated within a computational thinking (CT) framework (e.g., Basu et al., 2021). These research studies have noted middle school students' challenges with devising algorithms to solve real-world problems (e.g., Wong & Jiang, 2018) and comparing algorithms when the comparison is based on multiple criteria (Basu et al., 2021).

However, there is still limited research on several aspects of the 'algorithms' concept. For example, the middle school standard for algorithms includes the practices of representing algorithms as flowcharts and pseudocode, testing algorithms with a wide variety of inputs, predicting algorithm behavior, and debugging algorithms, many of which are currently under-investigated. Assessments for algorithmic thinking are typically part of broader CT assessments and hence do not cover all aspects of the 'algorithms' concept. Some research on high school students' understanding of algorithms has revealed challenges with using flowcharts to create, call, and manage different sub-algorithms (Rahimi et al., 2018), as well as misconceptions related to the efficiency of algorithms, thinking that fewer lines of code and fewer variables characterize algorithm efficiency (Gal-Ezer & Zur, 2004).

Teachers' content knowledge and pedagogy related to algorithms

While information about how teachers conceptualize algorithms and perceive their own knowledge of algorithms is limited, there have been some studies that explore teachers' understanding of algorithmic thinking in the context of CT. Rich and colleagues found that elementary school teachers who are new to the field of CT associated the term 'algorithmic thinking' with the mathematical term *algorithm* that specifies steps for performing traditional arithmetic operations, and conceptualized algorithmic thinking as "following steps", and "discovering and explaining strategies" (Rich et al., 2019, p. 179). Research has also shown that appropriate professional development (PD) opportunities can expand teachers' knowledge of algorithmic thinking. For example, Yadav and colleagues (2018) analyzed and compared teacher responses before and after a year-long CT PD and found that teachers initially made generic comments about algorithms but were later able to identify and discuss specific characteristics of algorithms such as efficiency, abstraction, and generalization.

Given the fundamental role of algorithms in CS education, researchers have sought to understand how teachers teach algorithms. A common instructional task is having students construct an algorithm in the form of a flowchart or pseudocode to solve a given problem. A study by Vivian and Falkner (2019) found that teachers with high confidence in teaching a digital CS curriculum frequently used algorithmic language, made more connections to learning objectives on algorithms and programming, and were more likely to engage students in algorithm development and manipulation activities before programming. In our current study, several middle school teachers mentioned that their teaching of algorithms was limited to facilitating activities such as instructions for creating peanut butter and jelly sandwiches, because the CS curricula they used did not include specific lessons on algorithms. Teachers remarked that they formatively assessed their students' understanding of algorithms based on completion of project-based activities rather than the knowledge and skills students demonstrated on individual activities.

Evidence-centered design (ECD)

We employed ECD (Mislevy & Riconscente, 2006), a principled assessment design approach, to analyze and unpack the middle school 'algorithms' standard and develop aligned formative assessment tasks. ECD helps 1) define what to measure, 2) identify the evidence needed to measure these goals, and 3) design tasks to produce this desired evidence. The ECD process starts with analyzing the target domain (outlining the scope of the middle-school algorithms standard) and decomposing the standard into a set of finer-grained knowledge, skills, and abilities that students should possess. The ECD process results in a set of assessment tasks that elicit desired evidence on different aspects of the standard as well as aligned rubrics.

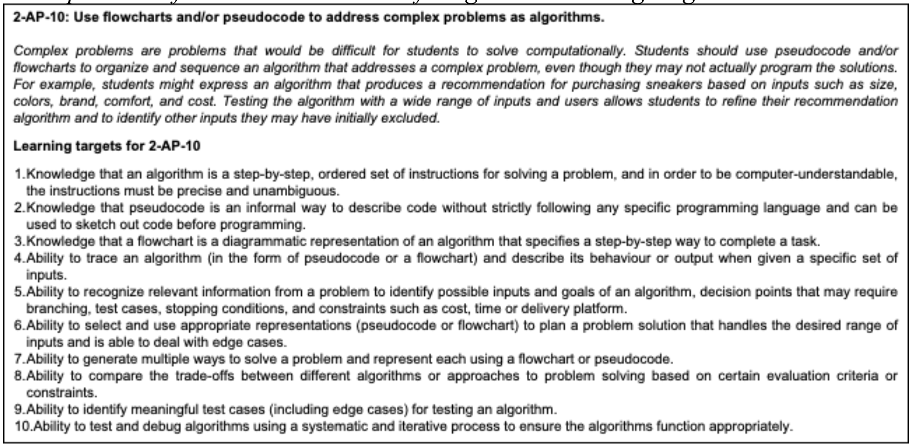
Methods and data sources

Designing standards-aligned formative assessments

We employed the ECD approach to define the scope of the 2-AP-10 standard by clarifying the knowledge and skills expected of this standard relative to elementary and high school 'algorithms' standards. We found that this middle-school standard transitions students from interpreting algorithms in upper-elementary grades to creating algorithms that solve complex problems and testing algorithms using a variety of inputs. The standard focuses on fluency with representations such as flowcharts and pseudocode that represent the steps to solve a problem pictorially or using plain language description. It includes the ability to identify relevant information from a problem description (e.g., inputs, goals and decision points) and translate it into an algorithm, as well as the practices of testing and debugging algorithms. Analyzing the scope of the 2-AP-10 standard helped us to decompose the broad standard into a set of ten fine-grained learning targets (LTs) on which we could individually examine student understanding (see Figure 1). Specific LTs enable teachers and curriculum developers to design targeted instruction and assessment opportunities to check student understanding and help students overcome specific learning gaps (Basu et al., 2022).

Figure 1

The CSTA Middle School 'Algorithms' standard and its description, followed by out decomposition of the standard into ten fine-grained learning targets.



2-AP-10: Use flowcharts and/or pseudocode to address complex problems as algorithms.

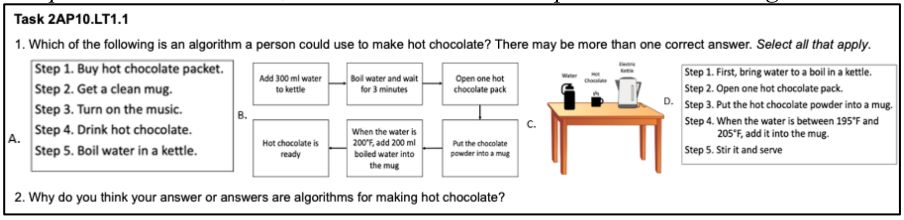
Complex problems are problems that would be difficult for students to solve computationally. Students should use pseudocode and/or flowcharts to organize and sequence an algorithm that addresses a complex problem, even though they may not actually program the solutions. For example, students might express an algorithm that produces a recommendation for purchasing sneakers based on inputs such as size, colors, brand, comfort, and cost. Testing the algorithm with a wide range of inputs and users allows students to refine their recommendation algorithm and to identify other inputs they may have initially excluded.

Learning targets for 2-AP-10

1. Knowledge that an algorithm is a step-by-step, ordered set of instructions for solving a problem, and in order to be computer-understandable, the instructions must be precise and unambiguous.
2. Knowledge that pseudocode is an informal way to describe code without strictly following any specific programming language and can be used to sketch out code before programming.
3. Knowledge that a flowchart is a diagrammatic representation of an algorithm that specifies a step-by-step way to complete a task.
4. Ability to trace an algorithm (in the form of pseudocode or a flowchart) and describe its behaviour or output when given a specific set of inputs.
5. Ability to recognize relevant information from a problem to identify possible inputs and goals of an algorithm, decision points that may require branching, test cases, stopping conditions, and constraints such as cost, time or delivery platform.
6. Ability to select and use appropriate representations (pseudocode or flowchart) to plan a problem solution that handles the desired range of inputs and is able to deal with edge cases.
7. Ability to generate multiple ways to solve a problem and represent each using a flowchart or pseudocode.
8. Ability to compare the trade-offs between different algorithms or approaches to problem solving based on certain evaluation criteria or constraints.
9. Ability to identify meaningful test cases (including edge cases) for testing an algorithm.
10. Ability to test and debug algorithms using a systematic and iterative process to ensure the algorithms function appropriately.

Figure 2

An Example 2-AP-10 Assessment Task Aligned with LT 1 "Knowledge that an algorithm is a step-by-step, ordered set of instructions for solving a problem, and in order to be computer-understandable, the instructions must be precise and unambiguous."



Task 2AP10.LT1.1

1. Which of the following is an algorithm a person could use to make hot chocolate? There may be more than one correct answer. *Select all that apply.*

A.
Step 1. Buy hot chocolate packet.
Step 2. Get a clean mug.
Step 3. Turn on the music.
Step 4. Drink hot chocolate.
Step 5. Boil water in a kettle.

B.

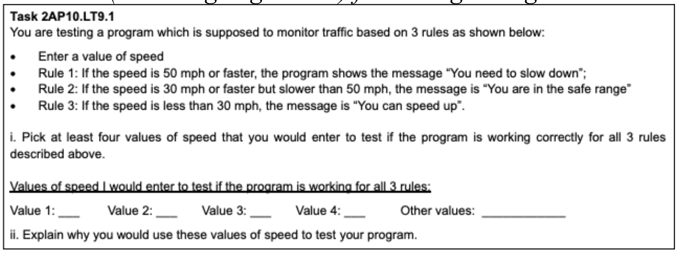
C.

D.
Step 1. First, bring water to a boil in a kettle.
Step 2. Open one hot chocolate pack.
Step 3. Put the hot chocolate powder into a mug.
Step 4. When the water is between 195°F and 205°F, add it into the mug.
Step 5. Stir it and serve

2. Why do you think your answer or answers are algorithms for making hot chocolate?

Next, we followed the ECD framework to develop a set of formative assessment tasks, each focused on eliciting evidence of student understanding on one LT (see Figures 2, 3 for examples). Task formats included multiple choice questions, short-answer prompts, and open-ended explanations. Tasks were short enough to be practical for in-class use to diagnose student understanding of the LTs. Each sub-task was accompanied by one of two rubric types (see Table 1). A RC rubric grouped student responses into Response Categories (RCs) such that each RC was indicative of a certain level of student understanding (a student can be in only one RC). An IC rubric listed a set of Indicated Challenges (ICs) that could be inferred from student responses (a student can have multiple ICs).

Figure 3
An Example 2-AP-10 Assessment Task Aligned with LT 9 'Ability to identify meaningful test cases (including edge cases) for testing an algorithm'.



Task 2AP10.LT9.1
You are testing a program which is supposed to monitor traffic based on 3 rules as shown below:

- Enter a value of speed
- Rule 1: If the speed is 50 mph or faster, the program shows the message "You need to slow down";
- Rule 2: If the speed is 30 mph or faster but slower than 50 mph, the message is "You are in the safe range"
- Rule 3: If the speed is less than 30 mph, the message is "You can speed up".

i. Pick at least four values of speed that you would enter to test if the program is working correctly for all 3 rules described above.

Values of speed I would enter to test if the program is working for all 3 rules:

Value 1: ___ Value 2: ___ Value 3: ___ Value 4: ___ Other values: ____________

ii. Explain why you would use these values of speed to test your program.

Table 1
Rubric for analyzing student responses to Task 2AP10.LT1.1 shown in Figure 2

Rubric for Part 1			Rubric for Part 2		
Student Response	**Possible inference about student understanding**	**Response Category**	**Student Response**	**Possible inference about student understanding**	**Indicated Challenge**
A only	Challenges with order and final goal: Student does not realize that the steps of an algorithm need to be in order/sequential and the last step should be the goal which is making hot chocolate.	RC1	Student does NOT indicate that their selected options contain instructions that are "clear" or "specific".	Student may have difficulty recognizing that an algorithm needs to include a set of clear or specific instructions.	IC1
C only	Challenge with representation: Student does not realize that an algorithm is a process or ordered set of steps to get to a goal state; a static diagram depicting objects is not an algorithm.	RC2	Student does NOT indicate that their selected options contain instructions that are ordered in a logical way.	Student may have difficulty recognizing that an algorithm includes instructions that are ordered in a logical sequence.	IC2
B and D	**Student understands what defines an algorithm and can recognize an algorithm in various forms.**	**RC3**	Student does NOT mention that the algorithm will fulfil the goal of making hot chocolate.	Student may have difficulty recognizing that the instructions in an algorithm need to fulfil the goal of the algorithm.	IC3
B only or D only	Student understands what defines an algorithm but can only recognize an algorithm in certain forms (i.e., flowchart/diagram process or procedure list).	RC4	Students states that the algorithm "makes sense" or that is how they would make hot chocolate.	Student may not recognize that their explanation should include characteristics of an algorithm instead of their personal opinion.	IC4
Any other response	Student may not understand what an algorithm is.	RC5	Student only restates the algorithm without explaining why it is an algorithm.	Student has difficulty understanding the concept of algorithms and/or articulating it.	IC5
			Student states something that is incorrect or not relevant	Student has difficulty understanding the concept of algorithms and/or articulating it.	IC6

Small-scale classroom study

We collaborated with eight middle school CS teachers from an urban school district in the Midwestern U.S. who used code.org's CS Discoveries (CSD) curriculum for their teaching. All teachers had participated in CSD PD offered by code.org prior to participating in our study. The teachers varied widely in terms of overall teaching experience (1-21 years), but they had all taught CS for less than three years. We provided teachers with professional learning in the form of educative resources on unpacking the 2AP10 standard and standards-aligned formative assessments for algorithms. Teachers participated in an hour-long, online, synchronous PD session on algorithms where we introduced them to the 2-AP-10 standard, corresponding state standards, our unpacking of the standard, and the aligned formative assessment tasks and rubrics that we had developed. Throughout the PD session, the teachers were engaged in short activities that provided us with important information about their understanding of and familiarity with the 'algorithms' standard. For example, teachers had to identify the LTs with which a given task was aligned. They were also asked to indicate which LTs they were already addressing during instruction and which they planned to address in the future. Teachers were divided into two groups where each group looked at two examples of student responses to an algorithm task (see Figure 3) and discussed how to evaluate the responses using the provided rubrics or by modifying the given rubrics. Teacher responses and discussions were recorded for future analyses. Teachers took a CS pedagogical content knowledge (PCK) survey before participating in the PD and at the end of the classroom study. We designed the survey to measure teachers' attitudes towards CS, knowledge of algorithms and programming concepts, and ability to interpret student work. For this paper, we analyzed teachers' pre-survey responses to two tasks that asked teachers to interpret and compare students' algorithms and predict possible student challenges.

Here we report on student data from formative assessments administered by two out of the eight CS teachers – Dina and Remi (pseudonyms) – who consented to sharing student work and their evaluation of student work. Dina and Remi administered a subset of the formative assessment tasks to their students, evaluated student responses, and shared both student responses and their evaluations with our research team. We collected student data for 36 students across grades 7 and 8. Most students had taken at least one other CS class in the previous school year, though classes were disrupted by school closures and remote instruction during the global pandemic. At the time of the study, students in both Dina and Remi's classes had completed CSD units 1 and 2 (Problem Solving, Web Development) and were working on CSD Unit 3 (Interactive Animations and Games). We gathered data on student responses to six algorithm tasks aligned with LTs 1, 6, 8, and 9, with each task yielding 15 to 36 student responses. Using the same task-specific rubrics we shared with teachers, we coded student responses to the tasks. For each open-ended prompt, at least two researchers coded student responses into RC or IC categories. Researchers met regularly to discuss discrepancies in their coding until they reached consensus. Memos were recorded throughout the discussion and used to refine the rubrics. We then compared our coding to that of the teachers. We conducted descriptive and thematic analyses (Saldaña, 2016) of our coding of student responses and the comparison findings to explore students' understanding of algorithms and the similarities and differences in how teachers and researchers coded students' responses.

Findings

Students' understanding of algorithms

We summarize our findings about middle school students' understanding of algorithms in terms of the LTs targeted by the tasks we analyzed. These findings have implications for CS instruction, curriculum design, and PD design.

LT1: Understanding what an algorithm is. Analysis of student responses to two tasks aligned with this LT revealed that most students understood what an algorithm is. For example, for task 2AP10.LT1.1 shown in Figure 2, 21 of 35 (60%) students who completed the task were able to identify both options B and D as algorithms for making hot chocolate, while 10 (29%) students identified only one of options B and D. However, only nine of the 31 students who selected options B and/or D could justify their selection(s) to any degree. Explanations often mentioned ordered steps, clear instructions, or achieving the goal of making hot chocolate, but rarely included all aspects (see Table 2).

LT6: Selecting flowcharts representing problem solutions. Students responded to one task asking them to select a flowchart that appropriately represents a delivery robot's actions. Ten of 15 (67%) students who worked on this task could represent the given text-based problem solution for the robot as a flowchart. Among the remaining five students, three struggled with using a decision box and selected a flowchart where the decision box did not have an arrow labeled 'NO' flowing out of it. Two students had difficulty understanding that the steps of an algorithm should appear in the same order regardless of the algorithm representation, whether text-based or pictorial as in a flowchart.

LT8: Interpreting and comparing algorithms. Students responded to two tasks involving comparison of algorithms. The first task involved comparing three simple algorithms for navigating a robot based on time and cost criteria. Most students (23 of 34 or 68%) correctly identified the algorithms that would reach the goal, the fastest algorithm and the cheapest algorithm. However, students found it challenging to compare algorithms based on multiple criteria. Only 37% students could compare the algorithms correctly when considering both speed and cost criteria simultaneously. This finding is similar to that observed by Basu and colleagues (2021) with students in grades 4-6 in Hong Kong. The second task involved comparing two relatively complex algorithms that included user input and compound conditionals. Only 20 of 36 (56%) students were able to correctly interpret the individual algorithms. Several students seemed to have difficulty following the logic of conditional statements in the algorithms. Twenty-two (61%) students were able to compare the algorithms and decide which one to use for solving a given problem. However, few of these students could justify their selection. Seven students gave a fully correct explanation, 2 students gave a partially correct explanation, and 13 students were not able to give any suitable explanation for their selection.

LT9: Selecting meaningful test cases to test algorithms. Student responses to Task 2AP10.LT9.1 (Figure 3) revealed that only 5 of 20 (25%) students could identify appropriate test cases (i.e., numbers in different ranges that would test all three program rules). Several (40%) students identified test cases that only tested one of three program rules, while others tested two of the rules. Only four of 20 (20%) students could justify their selection of test cases by describing how they were trying to test all three rules included in the program (see Table 3 for sample responses).

Table 2

Analysis of sample student responses to Task 2AP10.LT1.1 (Figure 2) using the rubric shown in Table 1.

Selection for part 1	Response to part 2	Possible inferences about student understanding
B, D *(RC3)*	They're both algorithms for making hot chocolate because they're in the correct order and they give the instructions in a stepwise, efficient order that can be easily read and followed through. *(no IC)*	Student can recognize algorithms and understands the characteristics that define an algorithm.
B, D *(RC3)*	I selected both of those answers because they're explaining the instructions clearly. *(IC2, IC3)*	Student can recognize algorithms but may not understand all the characteristics that define an algorithm.
D *(RC4)*	I think my answer is an algorithm for making hot chocolate because this would be how I make my hot chocolate. *(IC1, IC2, IC3, IC4)*	Student can only recognize algorithms written as a list of steps, may not be aware of characteristics of an algorithm, and is using their experiences to explain their choices.

Table 3

Sample student responses to Task 2AP10.LT9.1 shown in Figure 3

Value 1	Value 2	Value 3	Value 4	Other values	Explanation for choice of values to test	Possible inferences about student understanding
55 mph	50 mph	49 mph	30 mph	29 mph, 20 mph	I would use these speeds to see if the program gives each of the three messages only when it is supposed to.	Student is able to identify meaningful test cases to test all three rules (both values in the range and at the boundaries of the rules).
40 mph	30 mph	5 mph	0 mph	-	I would use these values of speed to make sure the program works as it should.	Student is able to identify some meaningful test cases but may not recognize that testing an algorithm requires testing all of its rules or conditions.
49 mph	48 mph	47 mph	46 mph	45 mph, 44 mph	I would use these speeds to see if I need to be exactly on 50 mph to slow down.	Student struggles to identify a full range of meaningful test cases and has challenges recognizing that they need to test the algorithm under different scenarios to make sure it works for all three rules.

Teacher interpretation of student work

Next, we compare our evaluation of student responses with teachers' interpretations of the same responses. Teachers used the same set of rubrics as the researchers, and though they were encouraged to modify the rubrics as needed, neither Dina nor Remi changed the rubric for any of the tasks. Teachers were consistent with researchers when evaluating the multiple-choice tasks, which allowed no room for subjectivity in terms of which rubric category each response corresponded to. For the open-ended tasks, such as selecting meaningful test cases and explaining selection of algorithms, there were several differences in teacher and researcher interpretations of the same student responses. For example, for Task 2AP10.LT1.1 Part 2 (Figure 2) where students explain why they think their selection is an algorithm, teacher and researcher categorization of student responses matched for only 25% of the responses. While researchers considered certain explanations to be inadequate evidence of student understanding of what constitutes an algorithm (e.g., "I chose these because you end up with the right result", "I think my answers are algorithms because they make sense"), teachers did not select any ICs and interpreted those responses to be indicative of a complete understanding of the 'algorithms' concept. When evaluating student explanations that compared two relatively complex algorithms (aligned to LT8), agreement between researchers and teachers was fairly high (agreement on 30 of 36 or 83% responses). In instances where there were disagreements, there was no clear pattern. Teachers appeared to focus only on student explanations and not on students' choice of algorithm when applying the rubric, leading to differences in overall interpretation of student understanding.

For Task 2AP10.LT9.1 (Figure 3), there was a 43% agreement between teacher and researcher evaluations of student responses to part i, where students identified a range of test cases, and a 67% agreement on part ii, where students explained their choice of test cases. Teachers consistently assigned student responses to a category that was indicative of greater student understanding. Though the rubric explicitly mentioned various acceptable values or value ranges for students to use as test cases so that they could test all the rules in the program, teachers could not identify student challenges when students picked distinct values that tested only one or two of the three rules (e.g., "45, 39, 25, 47") or when students picked non-numeric values (e.g., "45, 40, safe range, 40"). For the explanations, disagreements in evaluating student responses seemed to stem from teachers' preference for articulate, logical, and well written explanations, rather than explanations that articulated the need to test all three rules of the program.

Teachers' knowledge of algorithms. While some of these disagreements between teachers and researchers may have been caused by lack of clarity in the rubrics, our analysis of teacher engagement during the PD and teachers' PCK survey responses suggest that some of the disagreement may have also stemmed from teachers' lack of knowledge of the full scope of the 'algorithms' standard. During the PD, when asked about which LTs teachers already use in their instruction, most teachers identified LT1 and LT5, but no teacher selected LT9, indicating that testing algorithms and identifying test cases were not things they associated with 'algorithms.' Additionally, during a PD group activity where teachers practiced applying rubrics to evaluate example student responses to Task 2AP10.LT9.1, we found that teachers struggled to identify negative numbers as legitimate test cases. Also, consistent with what we found when teachers evaluated their students' work, teachers evaluated correct explanations to be inadequate during PD just because they were short and did not provide enough details about the program's behavior. Further, analysis of teachers' pre-PD PCK survey responses revealed teachers' challenges with interpreting and comparing algorithms. These algorithms included nested conditionals or nested loops and were more complex than those featured in students' formative assessment tasks. Most teachers, including Dina and Remi, had difficulty interpreting some of the individual algorithms which then translated to difficulty comparing the algorithms.

Discussion, limitations and conclusion

In response to the current demand for quality CS learning opportunities and useful CS pedagogy in K-12, we offer an approach to unpack a broad CS standard into fine-grained LTs, develop formative assessments aligned with the LTs, and use the assessments to reveal student understanding and challenges related to the standard. Both CS educators and curriculum developers can benefit from this approach by gaining a more complete understanding of CS standards and known student challenges. This approach allows teachers to focus on conceptual understanding of CS standards and formative assessment practices, which they can then leverage in any curriculum to improve CS instruction.

In this paper, we chose a fundamental CS concept, 'algorithms,' and demonstrated our approach by decomposing a middle school CS standard on algorithms into ten discrete LTs. We employed an ECD approach to design formative assessments that capture information about student understanding and challenges for each LT (RQ1). The assessments we developed allowed us to identify common student challenges related to aspects of the 'algorithms' concept, such as comparing, and testing algorithms (RQ2). This work aligns with and adds to a growing literature on middle school students' understanding of algorithms. These are, however, preliminary findings, and we acknowledge that generalizations from this study are limited by our small sample size. Another limitation of our study is that the requirements of our formative assessment tasks did not always align well with typical middle school CS classroom expectations. For example, many of our tasks required open-ended responses and/or explanations of selected responses – something many students were not accustomed to doing in CS class. In many CS classrooms, teachers do not always expect detailed written responses from students and when they do, they often provide students with clear rubrics. Hence, it is unclear whether some student responses to our formative assessment tasks are truly indicative of a lack of understanding or merely reflect students' understanding of classroom expectations.

This paper also adds to the limited literature on middle school teachers' understanding of algorithms and describes how teachers' understanding of CS standards may influence their interpretation of student work and their ability to identify student challenges. While our teacher sample was limited, all teachers in our sample agreed that they did not associate the concept of 'algorithms' with testing algorithms systematically and identifying test cases. Several teachers remarked that they did not introduce their students to algorithmic representations such as flowcharts because it was not covered in the middle school CS curricula they used. Upon examining the types of student responses for which teachers and researchers differed in their interpretation of student understanding of algorithms, despite using the same set of rubrics (RQ3), we concluded that some inconsistencies could be reduced by increasing the clarity of our rubrics, while others needed to be addressed through additional teacher training on the concept of 'algorithms.'

Our findings indicate that middle school CS teachers may benefit from additional PD on the 'algorithms' standard, in particular the concepts of algorithm representation, comparison, and testing and debugging. Merely designing principled formative assessments and rubrics that can elicit evidence of student understanding may not be sufficient to support teachers; teachers also need deep content knowledge to ensure they can use the formative assessments effectively. While it may seem unsurprising that teachers who lack content knowledge are not able to support their students adequately, empirical data to showcase these connections between teacher knowledge and student learning is important in a nascent field like CS education research, especially when many CS teachers claim to learn along with their students and be self-taught. We hope that with a more complete understanding of the 'algorithms' standard, teachers can move beyond just using the peanut butter and jelly sandwich activity to employing a range of activities and assessments that promote a more complete understanding of algorithms.

This work is part of a larger project to support middle school CS teachers with their understanding of five different 'algorithms and programming' standards and their ability to use formative assessment tools aligned with these standards. Next steps on this project will involve similar research using different standards and examining whether the findings in this paper hold with a larger sample of students and teachers.

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Pláticas and Counterstories: Talking and Writing about Experiences of Nondominant Learners in STEM

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Abstract: Grounded in the literature on STEM identities and ongoing endeavors for STEM education to be equitable, just, and humane, this project draws from Chicana/Latina plática and CRT methodological approaches to center the identities and experiences of nondominant learners in STEM. Through the ritual of a shared meal, researchers and study participants were involved in three pláticas to describe their personal backgrounds, STEM identities and experiences, as well as visions for their future. Following this communal experience, researchers and participants collaboratively made meanings of collected data and co-wrote counterstories. With participants and researchers engaged in telling, sharing, and writing stories that have been historically "unheard" and "unmentionable" in STEM fields, this work contributes to the recognition of the heterogeneity of students' identities, values, and agency.

Introduction

For historically underrepresented students, STEM education is often promoted and perceived as a gateway for upward economic mobility and social equality. Paradoxically, they endure profound systemic challenges. Structural issues of access and participation have remained significant, driven by the stratification of socioeconomic status, race and ethnicity, gender and sexuality, language background, disability designation, as well as national origins (NCSES, 2019; Philip & Azevedo, 2017). In addition, mainstream cultures, pedagogies, and spaces are often aligned with dominant values, interests, and experiences to favor Eurocentric, masculine perspectives, thereby discounting the identities of many nondominant groups (see Bang & Medin, 2010; Calabrese Barton & Tan, 2020). Finally, while colorblind and assimilationist policies and practices reproduce social inequality (Bonilla-Silva, 2013), social justice and culturally responsive approaches have been largely rendered irrelevant and as a result under-researched across STEM fields (see Morales-Doyle, 2017). In short, despite the progress made towards equitable opportunities, both in academic and professional realms (NCTM 2000; NRC, 2012), the double-bind faced by nondominant learners in STEM—whereby a high-status field explicitly recruits these students while continuing to marginalize them—remains prevalent.

The current study is situated in a broader university-based science and engineering outreach program–AirProject (a pseudonym). In this program, undergraduate and graduate students from various engineering departments learn to conduct project-based research on air quality topics and later on teach these content and skills to middle and high school students. Education research activities that accompany AirProject are mainly ethnographic, including participant observation, field notes, surveys, and focus-group interviews. The research team has shown how the design of AirProject affords learners ample opportunities to rotate among different roles and responsibilities where they see themselves being both an engineer and an educator (Tran et al., 2022). The current study is an extension of the AirProject's ethnographic research agenda; our team leveraged Chicana/Latina plática methodology and Critical Race Theories' tradition of counterstories to facilitate dialogues, reflection, and storytelling to center the experiences of nondominant students in STEM fields. We asked how do nondominant engineering students identify themselves in and outside of STEM fields? And how do nondominant engineering students articulate their experiences, re-imaginations, and possibilities for transformation in STEM fields?

Literature review and conceptual framing

This study has taken insights from the extant STEM identity, STEM equity, and decolonizing STEM education literature. As in other fields, STEM learning constitutes not only accruing and applying discipline-related knowledge but also concerns how learners engage in specific concepts and experiences drawing from their existing understandings of the world. The notion of STEM identities does not entail a set of fixed, stand-alone traits and instead suggests nuanced, multidimensional, and intersectional characteristics. In particular, scholars and practitioners have critiqued how the dominant approaches to STEM identity often applaud 1) certain traits—ones aligning to white, masculine perspectives—as encoded identification of learners' suitability for a future in STEM and 2) the ideas that STEM pursuits are for some but not others (see Collins, 2018; Rodriguez & Blaney, 2021). Failing to integrate how students of different backgrounds identify with STEM thus imposes ramifications for historically minoritized students who often have to compromise how they see their authentic selves in exchange for the development and identities that are deemed worthy in their disciplines.

Growing research on STEM identities draws from notions of learner agency (Lave & Wenger, 1991) and practice-linked identification (Nasir & Cook, 2009) to explain the dialectical, evolving relationship between STEM learner, identity, and learning across timescales (Polman & Miller, 2010) and social settings (Bell et al., 2017; Pinkard, 2019). In this vein, the *trajectories of identification* framework attends to how a learner's participation in STEM in the present is unfolded by differing experiences and interactions that they have had in the past and by visions of themselves being involved with STEM in the future (Polman & Miller, 2010). This approach unravels the interactions and mediations, both moment-to-moment and overtime, where learners co-construct their learning experiences by drawing and combining cultural identification—encompassing communities, languages, practices, and values—with disciplinary understandings. Examining STEM education and endeavors from identity perspectives counters dispositions of STEM education being objective, acultural, and apolitical. Specifically, scholars have investigated the structures and processes that support or inhibit student agency within the dominant norms, cultures, and practices (Greenberg, 2019; Nasir & Vakil, 2017). In this context, Vakil (2018) argued against discourses that assume female students and students of colors lack genuine interest in technology. The author highlighted that discipline interest and identity are not intrinsic, instead, derive from resources, materials, and ideas that students are introduced to throughout their learning and development.

Education research is pressed to break down its long-established conceptions of what counts as knowledge. Relatedly, Patel (2015) grappled with the role that education research—by upholding narrow notions of objectivity and generalizability—has played in compartmentalizing and stratifying knowledge to center white upper and middle class culture while purposely discounting other ways of thinking, knowing, and sense-making. From here, Patel urged education researchers to clarify ethical implications and responsibilities that their works, as part of a system that is built on inequity and injustice, have in regard to colonial legacies. Decolonizing STEM education efforts, as they concretize critical and historical perspectives of STEM education in relation to socio-political materialities, challenge pedagogies that fragment and compartmentalize learners as disembodied vessels of STEM knowledge. Such efforts lend arguments and evidence for how learners' bodies and emotions are themselves important socio-historical sites of learning, guiding their development, fluency, and change-making across and beyond their disciplines (Takeuchi & Dadkhahfard, 2019).

Methodology

On preceding ethnographic research and relationship-building activities. While the current study was primarily guided by the Chicana/Latina plática and counterstory methodological approach (detailed further below), much of its implementation was scaffolded by the preceding ethnographic research components and relationship-building activities. Tran was introduced to AirProject's students as the program's a research assistant in fall 2022. In the following seven months, Tran joined the class every other week to build rapport with students, as well as to observe and prepare observation notes. She often drew from these notes to report patterns of engagement and learning in meetings with the instructor and research teams. She also delivered a workshop to support students' communication with middle- and high school teachers who they would be collaborating with in the following spring. Furthermore, she accompanied two students on their multi-day trips to a partnered school, one that was located 5 hours from their campus. In Spring 2022, Palomar and McKoy joined the research team to co-design and co-facilitate three pláticas with Tran–in the form of shared meals–engaging eight students (including Aguirre-Marmolejo, Sheperd, Song and five other classmates) who self-identified as nondominant learners in STEM.

On plática. In Spanish, plática means "talk." In research settings, Chicana/Latina scholars perceive plática as a useful and powerful *research method* because its intimate and friendly conversational approach is congruent with the ways of learning and doing in their community's everyday contexts. That being said, following the work of authors who draw from both Chicana feminist epistemological orientation and plática methods, such as Gloria Anzaldúa, Emma Pérez, and Delgaldo Bernal, Fierros and Bernal (2016) contended that plática is more than a tool to support data collection; these authors conceptualized plática as a *research methodology*.

Our study was designed to follow the principles of the plática methodology (Fierros & Bernal, 2016), which fundamentally prioritize how participants can heal from oppressive realities through the process of theorizing their own experiences and envisioning their own futures. At the beginning of each plática, Tran led a cultural rapport passage where she presented her researcher positionality and began to cultivate an agreement for the group dialogue. She invited participants to embrace and respect vulnerability when sharing their experiences, and emphasized the options for them to pause and to prioritize their mental health. Besides, students were asked to arrive to plática with cultural artifacts that represented their identities in general and STEM identification in particular. With all researchers and participants engaging in sharing stories and cultural artifacts, the priority of the conversation was to create a comfortable and safe space for students to share. During the meeting, researchers and participants discussed background and interests, STEM identification and experiences, and perspectives on future careers and possibilities for transformation in STEM fields. Each plática ran between 60 to 90 minutes, were video- and audio recorded and later transcribed for analysis. After each plática, Tran, Palomar, and McKoy discussed impressions and takeaways; and students were asked to respond to a feedback survey.

On writing counterstories. In conversations pursuing the STEM pláticas, the three researchers often talked about the ethics of research practices, specifically noticing how researchers' choices in examining, analyzing, and presenting data will matter to the version of the "truth" that we construct. At the same time, we learned about emerging spaces that scholars from different traditions of story work have facilitated for alternative ways of meaning-making and presenting knowledge (Marin et al., 2020). From here, we took up the CRT approach of constructing counterstories. The narrative-driven and justice-oriented technique informed an analysis process that centers the complex and multifaceted natures of learner identities; unmasks how interlocking systems of power work to dominate and marginalize nondominant communities; disrupts the *majoritarian discourse* (1) that diminishes and erases the histories, presents, and futures of these communities; and finally, makes room for social movement, solidarity, resistance, and transformation (Solórzano & Yosso, 2002).

To prepare data that supported counterstory writing, Tran generated eight separate individual transcripts, each consisting of all quotes voiced by a specific participant. Together, the three researchers rearranged quotes into six categories, including: a) personal background and artifacts; b) STEM identification and learning pathways; c) marginalized experiences in STEM; d) experience with outreach; e) components that have affirmed students' persistence in STEM; and f) components that will determine transformation in their future STEM careers. We invited all participants to re-construct their own counterstories, and five (out of eight) participating students joined our team. The process of collective writing has been as follows: As Aguirre-Marmolejo expressed an interest in writing his own counterstory, he read through the plática transcript to retrace the places, events, and relationships critical to how he identifies personally, socially, and professionally. The writing process about self has encouraged him to embody the craft of storytellers to "go back and forth between the part and the whole" (Fox, 2015, p. 324) of his upbringings, to provide more details, and to emphasize the concerns (about self and community) that co-constituted his STEM learning experiences. The three researchers then met in person to read the draft that Aguirre-Marmolejo had shared with them and provided him with a written note for feedback and clarification. Meanwhile, other students (like Sheperd and Song) who preferred to work with the researchers to co-write counterstories—were asked to read through their individual transcript, identify details (pertaining both human and more-than-human relations) that are important for their stories, and articulate the directions they would like the story to go. The researchers then read the individual transcript as well as comments left by each participant. During this process, researchers and participants engaged in conversations to pick out moments corresponding closely to participant's understandings and experiences with STEM. The researchers built a narrative that weaved these moments together into a telling of self and STEM participation, all in relation to everyday cultural practices. Participants made edits and suggestions for changes, as they ascertained next iterations of the draft.

Findings

Our findings present various dimensions of identities that combine to show how nondominant learners see themselves in their disciplines and future careers. Through dialogues, collective meaning-making, and storytelling, participants and researchers brought together parts and pieces of memories–voiced during and following our pláticas—to make arguments for their belonging and their love for STEM. Here, we present three counterstories, animated with life events, relationships, embodiments, and emotions, all embraced by storytellers to theorize our own experiences of learning and being in STEM.

Story 1. Blessings from the cedar

> I have this little bottle filled with cedar that I keep in my car. Where I come from cedar is something gentle. We entomb it—burn it and say prayers because it is sacred. When I'm driving around and catch glimpses of it on my way to school and work, it is a reminder. I could palpably smell the Navajo reservation, where my parents grew up. I did not grow up on the reservation, though I lived in Arizona for eight years; in fact, it is a place that I had spent time in …longer than many other spaces. My dad has been in the Air Force ever since I can remember which means we did move around a lot, but the cedar still lingers—a connection to a place, a community, a home that will always matter to me regardless of where I am. And I think this, the connection to my dad, is a big reason why I chose a career in STEM. Growing up close to someone who worked on aircrafts taught me what it means to think like an engineer, and how to tinker and build things with curious and critical eyes. That curiosity traveled with me to new places, even when we moved across states and continents.

In eighth grade I was living in Japan, a small town, in the middle of nowhere. The boys and girls club was sponsoring a trip to go to space camp in America. I did not know about it at first, but my science teacher came up to me and said "hey, I heard about this thing. You should apply." The hesitance came flooding in—how was I going to a camp all the way in America? How could we afford it? Who would actually pay for me to go?—But still, my teacher encouraged me and I'm glad he did … because I actually got to go to space camp! I realize that moment with my teacher was the first time I felt valued in a STEM space. I felt seen. At the space camp in Alabama, we were surrounded by planes and models of spaceships. It was where I really started thinking that I, too, could help design and work on these things.

Since then I was pretty much set on a career in STEM. I have been working as an engineer and as of right now, I am a PhD student in Mechanical Engineering. However, thinking back, I have had to work to feel like I belong. Kind of unconsciously, I used to hyperfocus on getting myself ready for work—making sure I looked professional and presentable, making sure I looked like I fit in. I did not want to give anyone, especially in a career filled with folx who do not necessarily look like me, an excuse to undervalue or dismiss me. Maybe it is a mind game—that there is a certain way an engineer is supposed to look—and somehow we internalize that? What I know is that I have to keep fighting that game, because I do belong here—in STEM.

A moment that I have always kept close to my heart was from my first day as an undergrad. There was a big opening ceremony to welcome the freshmen in which the Dean told the story of a former student, explaining that this person came from the reservation. He was Navajo. He studied Mechanical Engineering and designed for NASA's most recent trip to Mars. Hearing that introduction, I sparkled. I was filled with so much energy, so much curiosity. I kept asking myself, "who is this person?" I knew I had to meet him. I have never met anyone, besides my dad, who identified that closely with my background and was doing the exact work that I wanted to do. As I am writing this story, I am now working at the same place with this person, at NASA Jet Propulsion Laboratory, and we are not only colleagues but also friends!

I am never going to forget my time in space camp. Just like I will never forget the sound of my dad's voice when he talked about working on aircrafts. Just like I will never forget my first day being an engineering student, which made such a staple in how I identify with my career. Like the cedar that still hangs over my car dashboard, I carry these stories as reminders of where I have been and how I can make an impact. I keep them close just like prayers for myself, my family, and my community, as through thick and thin, I see them standing with me.

Story 2. Will I ever fit in?

Dear Little Meiou,

Remember the smile on your face the day you learned about the microenvironment of the cell? Remember how your eyes lit up … it felt like your little head was drawing a thought bubble connecting everything your teacher was saying about the structure of the cell? You envisioned yourself as a scientist, wearing a lab coat, with a pipet in hand, moving the solution from one beaker to the other? While this was once a dream, it is now a reality.

Little Meiou, I will take you back to the start of our voyage.

A few years ago, your passion for science and research led you to another part of the globe. Wanting to leave behind what you have been told: "males are typically more motivated and talented in math and science," you left Beijing–your home–to go to the United States. Almost immediately though, the boundaries of being a woman in STEM and the overload of relocating to another country kicked in. You have been known as a chatty person at home; and yet in the new country you were surprised to find yourself quiet. You became nervous with the language barrier. It was not that you did not know what to say, but you were scared to speak and embarrassed by your English.

It took some time for you to realize studying in a foreign country does not only mean more opportunities: working with experienced and knowledgeable professors, fancy equipment, and frontier technologies. It also brought moments when you felt inferior to your peers who were native speakers. It also brought disappointment as you realized the unfamiliarity with the language, custom, and culture had prevented you from joining groups and laboratories. You started to think, was the way how STEM learning is set up in the United States ever prepared for a foreigner, like yourself, to thrive? You started to wonder, "will I ever fit in?" At times, you felt like you did not have either language or companion to process these struggles and hence there was not a space for healing. It was difficult, little Meiou, to be a Chinese woman in STEM, and even more difficult to be one at a predominantly white institution. You have found yourself always learning the unfamiliar, and there yet seems to be more that you need to take on. You did everything you could to go above and beyond: work hard, take initiatives, and be confident. Not only exceeding expectations you have also defied many limitations inscribed for women in STEM. Despite all challenges–you shine.

I wanted to tell you a little about your journey, our journey. While there are constant struggles, you are where you need to be. You are Meiou Song, a Chinese woman who loves science and teaching. You are pursuing a career in Mechanical Engineering, where you and your colleagues are dedicating time to develop low-cost diagnostic technologies to improve healthcare in developing countries. This path is bringing you so much love and joy. And, also! you have met and observed many women, who are from different backgrounds, in your classes and in your labs; they have become your academic sisters and mentors, all determined to support each other to participate and succeed in STEM. “What draws these great women to STEM in a world that prioritizes male scientists and engineers?” You continue to ask.

Your love for science and passion for teaching are the driving force behind your constant resistance. I wanted to let you know that you are following your heart, and that alone is one of the bravest acts you have done. As I write this letter to you, my younger self, my heart is filled with pure bliss, as it knows that I am, in fact, making Little Meiou's dream come true. My dear, stay passionate, curious, and joyful!

Spring 2022, Boulder, Colorado
Meiou

Story 3. The broken ouroboros

The ancient Greek symbol, ouroboros, is often used to refer to an eternal cyclic renewal, a *cycle of life, death, and rebirth*.

While I was born in Leon Guanajuato, Mexico, my conscience was born in East Los Angeles right by the abandoned Sears tower; that is where I have my first memories. In the early 2000s, East LA had a lot of culture that I found amazing. Mobile food stands that sold elotes, paletas, or pan; customized low-riders with hydraulics that made them jump; and lots of Mexican heritage events, all of which were made or hosted by my family and neighbors. I found a lot of comfort in this community because I had great exposure and opportunity to celebrate my roots and my culture. Unfortunately, East LA was not perfect. To be frank, it was more of a war zone at times. Gangs were idolized amongst the youth and occupied the area on every street. Their actions affected everyone. I have many memories of my elementary school getting tagged with graffiti and school maintenance men would paint over it, only for it to happen again and again. I also have memories of my mother tackling me down because there were gunshots fired outside our apartment building. But to me, I did not even know our home was in the “hood.” Maybe the “hood” never bothered me because I thought that this was how the world was for everyone.

As a kid, I really wanted to be an astronaut, like Neil Armstrong. My family, friends, and teachers knew that. Beautifully, they all showed great support, and everyone pretty much told me the same thing every time: “Osmar, you have to *work really hard* and *be very smart* to do that!” By the mid 2000s, my family moved to Albuquerque, a unique place famous for our Hatch Green Chile and *Breaking Bad*. The city hosted tours for the TV series’ hotspots while providing an assortment of green chili flavored snacks to tourists—some of whom thought that New Mexico was in Mexico. People paid money and were very excited to witness a setting for a show that epitomizes my city: addiction, crime, murder, and the recruitment of children for nefarious schemes. Here, my friends and I were young children looking for guidance. Lacking proper role models, wannabe gangsters were the only people that my friends looked up to and felt community with.

Fast forward to college, I spent my days and nights working three jobs while being a full-time engineering student. Meanwhile, some of those friends who did not have much direction ended up in jail, dealing drugs, getting addicted to drugs, or dead. All these people have been my friends since my elementary, middle, and high schools, and regardless of their choices, are some of the best friends I have ever had in my life.

I had a hard time facing this reality.

> Simultaneously, I graduated as a “rocket scientist race car engineer,” literally. Never allowing myself to mourn, I felt completely alone. At some point, I drove beyond burnout.
>
> A couple years ago, I moved to Boulder, Colorado to attend graduate school. While getting through my Master’s program, I slowed down and took care of my mental health. I have been reflecting on my new life–now–a better life, one that my friends would be happy for me to have. Thinking forward, I choose to be a broken ouroboros that stops the toxic traits that have been passed on against my community, generation by generation. This reflection has provided me clarity to pursue a career path as both an engineer and an educator. By helping and inspiring the next generations in different ways, I feel that *I am not alone* when I see others, who look like me and my friends, are thriving and achieving their own potential.

Discussion

Our group, comprising three learning sciences graduate students and three college STEM students, has come together to reflect on our experiences across different STEM environments and co-write our stories. We explain the interrelationship between our identities, learning, and the broader society that we grew up in. Below, we depict what characterizes these stories as counterstories. First, as we (Aguirre-Marmolejo, Sheperd, and Song) tell stories about our own intersectional experiences, we fight the master, “monovocal” (Solórzano & Yosso, 2002) narrative–one that maintains the homogeneity of all learners who identify differently from the normative student population in STEM fields. Aguirre-Marmolejo unpacked a constellation of identities, some tie to his Mexican culture and heritage. Other layers of the constellation were unveiled as he time-traveled to his childhood and adolescence to see a younger self surrounded by best friends, teachers, and family members and as he space-traveled to see various places that he has called home, some associated with gangsters and others called “the hood.” Song’s letter to her younger self echoed complex experiences that accompanied her journey in which she left her home country–China–for the U.S seeking to fulfill her dream to be a scientist. Sheperd’s story surfaced what it means to be a Navajo woman who, for various reasons, did not grow up near the majority of her family who live in the Navajo reservation, and her observation for not having many people of similar backgrounds in her career path. Concomitantly, intersectionality is not solely about issues of identity, and rather a prognostic instrument to interrogate how power is structured and maintained in both learning spaces and broader society (see Annamma & Booker, 2020). In this vein, these stories unmask how gendered, raced, and classed hierarchies have shaped writers’ lives and determined the pain that we endure being distant from our own culture and heritage. Our stories provided examples for how our “intelligence” and “fit” for STEM fields continue to be perceived and mediated in learning and working environments that are wrought with Eurocentric and American-centric ideologies, and how such structure recursively undergirds our own lived experiences under broader projects of pathologization and assimilation. We describe how we grappled with systemic constraints, be they social, linguistic, or political, across these spaces to articulate and assert our whole, complex identities as critical processes of STEM learning.

Our stories depict endurance and resistance. As we traveled to the past, present, and future to assemble our identities, we noticed moments of vulnerability, uncertainty, and lack of confidence, and at the same time, we were reminded of our own power and agency. For instance, while “Will I ever fit in?” is presented as a letter that Song wrote for her younger self, it was also dedicated to her inner child; this writing tended to the stress and worries that Song has been coping with by reminding her of her emotions, hopes, and dreams to make an impact in the world through researching and teaching science. Her letter raised awareness about some contentions that she experienced, being a female, international student in a STEM graduate program; at the same time, it is glistened with an adamant enthusiasm for exploring and strengthening new scientific ideas and practices–what she had repeatedly named during the plática as “bringing me joy.” In this vein, while toiling under constant pushbacks, our endeavors have been fueled by the strong belief and passion that writers have for STEM disciplines and for our own future selves. From contestation comes re-configuration. Realizing our power and agency entails a recognition that STEM participation, while contingent on social and historical circumstances, is neither static, predefined, nor deterministic (Bell, 2017; Polman 2012). The celebration of our STEM achievements neither equates with us losing sight in building solidarity with our communities nor essentializing STEM knowledge as all-knowing. Constructing a holistic and pluralistic view of STEM identities and participation, our group affirms that our persistence in STEM fields has extended beyond a process of enculturation into a specific academic or professional program. Rather, this process has been generative to how we strategize for our positions in our fields, as it is dialectically informed by our various lived experiences in which we concurrently navigated everyday contexts and practices, participated in STEM formal and informal learning curricula, and constructed new identities. STEM identification conjoins with how we build relationships and solidarity with other nondominant learners and colleagues as well as how we promote dialogues, visions, and practices synergetic to the values and ethics of our communities (see Phillip & Azevedo, 2017; Vossoughi & Vakil, 2018).

Our study is motivated by ongoing efforts that cultivate transdisciplinary approaches in STEM education (Takeuchi et al., 2020), moving away from traditional structures of subject-based education to frameworks that composite and integrate heterogeneous ways of knowing (Bang & Medin, 2010; Roseberry et al., 2016). Holding conversations in the format of “every-day talks” and reconstructing counterstories from memories, reflections, and dialogues that have been gathered throughout the length of our collaboration are decisions grounded in a persistence to center the multiple identities and multivoicedness of nondominant learners in STEM. The plática approach has made available a communal space where researchers and participants–all are students from historically marginalized communities–reclaim history and full narratives of our stories, workshop arguments to defend ourselves against deficit narratives, and experience healing. During the writing of counterstories, we experienced a re-location of roles, tasks, and expertise, where how we chose to collaborate with each other destabilized the binary of the researcher versus the researched. Importantly, we have engaged in and sustained the conversations with an understanding that relationships are being attended to and worked on by everyone in the room. Such collective composure has opened a space for *fugitive learning* (Patel, 2019) where we traversed across conventional boundaries of research practices and STEM education to recount unconventional nuances that have brought us to our academic and professional choices. Together, we build a vulnerable, affective space–which rarely exists in our current pathways–to relate STEM to who we are.

Endnotes

(1) “A majoritarian story is one that privileges Whites, men, the middle and/or upper class, and heterosexuals by naming these social locations as natural or normative points of reference.” (Solórzano & Yosso, 2002, p. 28)

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The Role of Positioning in the Ecological Learning of Human Youth Making for Pet Companions

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Abstract: Making engages young people with the material world and reflection-in-action, creating promising science learning contexts. Emphasizing relational and social dimensions of making, we conducted a week-long workshop for middle schoolers who are current and aspiring pet companions. Supporting participants' inquiry into pets' senses and related behaviors, we asked them to work on maker projects meant to improve their pets' lives. Following a qualitative analysis of participants' positioning in relation to their pets, we present case studies of two female participants' positioning. We find that through the process of making, the two participants demonstrated an increased awareness of pets' biology and related behavior and their personal interests in pet care, while also differing in what aspects of human-pet relations they focused on. We conclude that through making, especially in contexts with a robust relational draw, youth become attentive to complex and otherwise difficult-to-notice transactions central to taking care of pets.

Introduction and background

We know that through making, youth sustain engagement with learning processes (Resnick & Rosenbaum, 2013; Washor & Mojkowski, 2010), understand the affordances of designed materials, and learn concepts (Martin, 2015; Bevan, 2015; Kostakis et al., 2015, Peppler & Glosson, 2013, among others). When youth make artifacts that solve their communities' problems, they feel more invested and persevere in finding solutions (Barton, et al., 2016; Holbert & Wilensky, 2019) and learn better (Hughes & Morrison, 2018). Further, through making, makers and educators question the power dynamics inherent in multi-stakeholder learning situations (DiGiacomo & Gutiérrez, 2016; Vossoughi et al., 2020). In light of the above strands of maker education research and research on youth's engineering and design processes in loosely or unstructured, informal settings (Parekh et al., 2023; Simpson et al., 2017) which illuminates the convoluted path of the decision-making, problem identification, and solution process, we see value in studying making as a trajectory. Emphasizing the importance of the complex processes through which youth negotiate ideas when designing for a close more-than-human (i.e., a pet companion), we extend the lines of inquiry in maker education into the domain of learning while making for those whose lives and needs humans can understand only through a commitment to care and relationality. To this effect, we draw from the following constructionist ideas.

Maker education in STEM values learning through building complexity from simpler parts, particularly in difficult-to-learn and complex contexts such as Agent-Based Models (Wilensky & Rand, 2015) and video games (Holbert & Wilensky, 2019). Learning artifacts such as interactive models and games exist at the intersection of cultural presence, embedded knowledge, and the possibility for personal identification. They are a part of youth's material environment and disciplinary domains, inviting the exploration of complex ideas. Objects-to-think-with are transitional objects that bridge the abstract and the concrete, the physical and the psychological (Turkle, 1990). We explore a new dimension in maker education research by examining youth's positioning in their recognition of relationality within their everyday pet-care and pet-related maker-project work at a summer workshop. We define relationality as connections to peoples, creatures, lands, and objects.

Relationality is mutually affecting and reinforcing (Bateson, 1972); in relationships with others, we "become with" them and are defined by the relationship within a shared ecosystem rather than being othered. A relational perspective on learning entails attention to the relationship between the learner and the world. Specifically, we study how learners understand themselves as a part of the ecosystem they share with their pets or will share with future pets. By adopting this perspective, we argue that in this specific learning context, many factors, such as understanding pets' behavior associated with sensory experiences, pets' and humans' interests, learners' existing relationships with pets, and the setting of the human home are simultaneously present and shape learning.

A relational perspective has deep roots in theories of learning. In a departure from the cognitive theories of learning concerning information processing and sensory data in the learners' brain (for example, Gardner, 1987), the many traditions of constructivist learning consider the learner a social being. The individual constructivist perspective is concerned with the internal construction of knowledge followed by testing the knowledge in the outside world (von Glasersfeld, 1995) in a continuously interacting and iterative three-part system (Biggs, 1993). A social constructivist perspective proposed that learners construct knowledge through interactions with the social world (Vygotsky, 1978; Wertsch, 1985). Situated learning theories emphasize the importance of learners' active participation in the context of learning, constructing meaning through their participation in activities within communities of practices (Lave & Wenger, 1991; Brown, Collins, & Duguid, 1989). For many who subscribe to these perspectives on learning, the separation between the individual learner and the world is clear – knowledge is constructed through learners' interactions with material, social, and semiotic elements in the outside world. When one takes on a fully relational perspective, the learner is seen as a part of the world, becoming increasingly aware of the complex ecosystem and its connections through interaction with it over time. However, it is challenging to support learners to consider themselves in relational ties, co-becoming with the world.

Our response to this challenge is two-pronged. First, we emphasize the importance of youth's relationships with animals that live in the same home and yet experience the world differently. By including pets in the workshop, we harvest a complex yet accessible setting that might foster a relational approach to learning. Second, we introduce to the learning environment an Augmented Reality (AR) tool to facilitate youth's understanding of the relational ties with pets through perspective-taking (Parekh et al., 2023), supporting a sense of what it means to be an animal in a shared ecological setting. To this end, we designed a summer workshop where youth learned about pets' sensory experiences and related behavior and worked on maker projects to enhance aspects of the pets' lives at home. Below, we describe our orientation to learning while making, especially in our case, where youth make things for use by more-than-humans.

We consider youth's maker projects meant for their more-than-human pets to be objects that bridge youth's understanding of humans' and more-than-human's experiences in the ecology of the human home. In an ecosystem where youth feel compelled to recognize the effect of their maker projects and ideas, we highlight youth's awareness of how the process and outcomes of knowledge production make a difference in being ethically accountable to ongoing relationships. We ask the following research question: *How do the social positioning of makers and making objects for more-than-human pets contribute to opportunities for ecological learning?*

Theoretical framework

Positioning refers to the ways individuals locate themselves and others in a social context and along a storyline (Harré, 2012; McVee, 2011). Broadly, positioning is based on the implicit understanding that rights, responsibilities, obligations, and duties to perform and react to meaningful actions, and actors in an interaction, are reserved for only certain individuals (Harré 2012, p. 4). Hence, it is vital to highlight practices that support and detract from individuals' location of themselves and others while performing discursive acts (Harré 2012). Storylines, metaphors for individuals' discursive interactions within different activity systems, are recreated in conversations and link the past, present, and future. Studying changing storylines helps us interpret changing interactions in episodes of activity as positioning moves to change existing storylines and give rise to new ones. Positions within storylines can be dynamic and open to interpretation, those who are not the key players in a situation are able to interpret positions in different ways. Importantly, initial positioning moves are often subconscious, and individuals resist others' reading of one's positioning (Harré 2012, p. 6).

Although positioning is discursive and dynamic, individuals cannot freely position themselves. Through reflexive positioning, individuals position themselves (Davies & Harré, 1990) to match their worldviews and how they live, act, and think. Hence, this is a way of indexing events with actors' points of view. Through interactive positioning, individuals position others, giving us an opportunity to study how the position of specific individuals can differ in different contexts, thereby limiting how those people can act, perform, and think. Finally, roles are a subset of positions and are scripted, static, formal, and ritualistic (Davies & Harré, 1990, p. 43), while positioning concerns individuals' taking up specific locations in dynamic, temporal ways (McVee, 2011).

Foucault (1979) argued that power is everywhere because it comes from everywhere, thus opposing the view of power as a function of privilege. As a privilege enjoyed only by certain members of a social group, the division of power would present a binary worldview of the oppressor and the oppressed, the ruler and the ruled, and the dominant and the subservient. The scholars mentioned above question such binary divisions and emphasize instead the multiplicity and connectedness of human experiences. Others studying human-nature interactions are similarly intrigued by replacing the perceived binary of human-non-human existence with an intricate, complex, interweaving human-nature coexistence conceptualized as natureculture (Fuentes, 2010; Haraway, 2008). Challenging notions of human exceptionalism and speciesism, natureculture emphasizes entanglements. We are interested in the entanglement of human learners with their canine and feline companions and the learners' relative positioning of and with regard to more-than-human companions at home. Our study takes place in a pet sciences-focused maker workshop. Specifically, after introducing the hidden world of pets' sensory perceptions to middle school-aged learners, we study the learners' positioning of themselves and their pets as they construct their understanding of their pets' lives while working on maker projects meant for the pets. Following Donna Haraway (2008), we believe our entangled relationships with domestic animals are especially revealing because the human-pet co-evolution redefines humans and their more-than-human companions. In the following section, we detail our study design details and analytical strategy.

Methods

Workshop details

In the Summer of 2022, we conducted a week-long summer workshop for middle-school-age youth in partnership with a university outreach program. The outreach program recruited middle school age learners through their partnership with local schools and from contacts with previous participating families. All participants traveled to the university campus for the workshop. We began with eleven participants, and other than one participant who suffered a COVID infection, all participants completed the workshop. We collected whole-group video recordings and small-group audio recordings for each of four groups of participants. We also conducted semi-structured interviews with each participant once during the workshop, on the fourth day, once immediately following the workshop, and finally a month later. The semi-structured interview included questions about participants' project work, their motivations for the projects, how the projects improve their pets' lives, how they think the pet might use the project and what they expect to learn from their observation of the pets, some changes that they would like to make to the project, and how working on the project has helped them think about pets at home. In the post-workshop interviews, we sought participants' responses to questions such as the following: On the days of the workshop, did you do anything differently with your pet? What were the activities you would say you did with your pet? What role did your pet play in your projects/project ideas/testing projects? What did you learn from working with your pet? What science topics did you learn at the workshop? How did you use science to learn about pets? How was this program similar or different from other science classes you have taken? What do you think it would be like to have a career as a scientist? What would you like, what would you dislike? How would you describe your identity as a scientist, an animal scientist, and a designer? We asked participants without a current pet at home to talk about a pet they knew.

The workshop plan was as follows: Day 1: Exploration of pets' senses through Augmented Reality filter applications and enhanced hearing applications, mapping of pets' activities at home and around; Day 2: Discussion of findings and experiences with pets, sharing pet stories about sensory experiences, identifying pets' experiences to understand better, planning investigations; Day 3: Best practices and examples of investigation of pets' senses, sharing outcomes of investigations conducted at home with pets; Day 4: Discussion of individual projects with peers and project work; Day 5: Presentation of learning to peers and families.

We analyzed data collected from two participants working at two different tables. We chose these two participants because of the following reasons. These two participants talked enough at the workshop, giving us enough data to analyze, maintained unique and contrasting relationships with the pets (one had pets at home, and the other hoped to be a pet companion in the future), and participated in the workshop in different ways as well. These factors help us inquire into different possibilities for learning.

Participants

Stella and Mabel (both pseudonyms) are female and twelve. Stella is of Hispanic descent, and Mabel is White. The two participants were seated at separate tables with two other participants and a teaching assistant. For this paper, we analyzed only Stella and Mabel's talk and not the other members of the group. We paid attention to participants' talk following moments of recognition of pets' sensory abilities, specifically, vision, smell, and hearing. We specifically planned to inquire into these senses at the workshop.

Data analysis

Our analysis is based on the following assumptions about positioning. First, an individuals' positioning in a situation is complex and shaped by multiple factors. Second, positioning is fluid and can be read differently. Third, just as individuals can position themselves, others can position them as well; these positionings might not align. Fourth, individuals with similar positioning in one context can position and be positioned differently in a new context because individuals respond to cultural resources differently.

We present our findings in the qualitative research tradition of a case study (Stake, 1995) meant to capture the complexity of the human experience. Each case- individual participant in the setting of the workshop (with activities, facilitators and peers) and the backdrop of the relationship between the participants and pets at home. We chose two workshop participants for our analysis because of the contrasting nature of their participation that would help us answer the research question, and the quality of the audio data we collected. We transcribed Stella and Mabel's talk throughout the workshop and during the interviews. We began our analysis by inductively coding for participants' positioning within the initial goal of identifying as many intelligible positionings as possible. Next, for each of these positionings, we categorized events in the group (For example, open sharing, answering workshop prompts, etc.), along with the specific details about Stella and Mabel's participation. For example, what are Mabel and Stella acting as, what they are doing, possible reasons for them acting in a certain way, the outcome of the interaction between these participants, how the participants relate to pets, projects, and ideas and materials for the project, etc. Parallelly, we coded for the participants' projected role through positioning including 9 inductive categories: pet expert, pet novice, pet knowledge seeker, pet-related problem solver, pet empathizer, pet advocate, pet companion, aspiring pet companion, advocate for pets and humans. Following this, we wrote analytical memos about the nuances of Stella and Mabel's positioning with respect to the roles they chose in specific moments and aspects of the interaction that spoke to the interaction between individual's positioning and assumed role. We were especially attentive to situations where Mabel and Stella appeared to position themselves in different ways and in different roles.

In a parallel round of predetermined deductive coding, we analyzed the participants' maker motivations in response to the general question, why does the participant work on the project? Codes included the following: investigating with the intent to find something out, entertaining and fun to make something, making something nice and attractive, because my friends are making something similar, problem-solving for pet, problem-solving for humans, wanting to use an attractive material, wanting to look busy. We wrote memos to clarify how the participants' positioning and assumed roles in specific moments related to their project motivations. Finally, we created a critical participant narrative account (VanMaanen, 1990; Polkinghorne, 2005) for each of the two participants with attention to their positioning at various moments at the workshop and its implications. We would like to draw attention to the importance of our analytical scheme. We do not compare each participant's general talk (off-topic talk, friendly banter) to their pet-related talk; hence, we do not know if Stella and Mabel's pet-related talk is unique to their positioning in the workshop. Rather, we say that they are different as learners, and in the backdrop of a particular kind of difference, i.e., their positioning and social interactions at the workshop, they took part in particular ways and achieved certain outcomes.

Findings

Below we detail Stella and Mabel's positionings at the workshop along the general storyline of the importance of pets and pet care to humans who desire the company of pets. Later, we summarize the importance of their positioning while making objects for their pets to opportunities for ecological learning.

Stella's positioning as an aspiring pet companion

On the first day of the workshop, Stella quietly declared that if she ever had a pet, it had to be a cat. She had known her friend's pet cat, Toasty, for years, and Toasty was Stella's frame of reference for understanding all cats. However, although Stella cherished memories of being Toasty's play companion, she knew that Toasty was not *her* pet. Among those at her table, when others shared stories of their pets, Stella's stories of Toasty always followed with questions. "Does your cat jump into the air like that?" "I think Toasty rubs his head on my calf when he needs pets. Do other cats do this as well?"

On the second day of the workshop, Stella continued to ask if her understanding of cats was accurate, but at the same time, after using the KittyVision filter tool to investigate how the world must appear to cats, she began sharing her observations. "Well, I see that they don't really see red, so (Toasty) must have jumped because it (a toy) was moving." At the same time, she began refining others' understanding of their pets when they shared stories. Daphne, the facilitator at her table, too, began supporting and appreciating Stella's observations. "That's a very good question!" Stella also started seeking details about Daphne's cat Willow. What does Willow like? Why does Willow like certain things? Would Willow like this or that? Was Willow a box or blanket-loving cat?

Stella was stumped when the workshop moved on to making artifacts for the pets on the third day. She was aware of her peers' relationships with pets at home, and how they were confident about their pets' reactions to their projects for them, so Stella wondered if she "knew how to love a pet." She knew it was impossible to care for a cat without knowing the animal closely. For example, Stella wondered how she could make specific aspects of a cat's life better. When another participant began working on a project, Stella closely observed him and asked how his cat might play with the toy, a catnip-stuffed felt food item, a catnip stuffy. Stella made a similar toy for Willow while discussing the cat's possible reaction to the toy with the facilitator. She hoped that Daphne would have the answers to her questions. She found out that Willow might cuddle the catnip stuffy and sniff it lying down in a cozy corner. Also, finding out Willow loved cozy nooks and boxes, Stella decided to venture into another project – a cardboard Shrek-style outhouse for Willow. She also sent home with Daphne several catnip stuffies and two outhouses, asking her to introduce these to Willow and observe the cat's behavior. Daphne's reports back provided Stella with a new awareness of the cats' preferences, sensory experiences, and specific information about Willow's play with her projects. Stella used this information to choose her final project's materials, colors, smells, and dimensions carefully. She designed these specifically for Willow and hoped the cat would like her projects.

Throughout the workshop, Stella positioned herself as a pet novice and aspiring pet companion. She actively sought knowledge of pets, sought to take on the perspective of cats, but not dogs, and tried to understand and solve problems faced by cats she knew. Although lacking confidence in her understanding of cats and acutely aware of existing relationships with pets as her peers' source of knowledge of pets, Stella sought to understand cats more than her peers. Once she thought of an explanation of cat behaviors or a potential solution to problems faced by and created by cats, she sought confirmation of the accuracy and relevance of her ideas from peers and the facilitator. To Stella, it was not enough to know of other cats to take care of a future feline pet; every cat is different and needs to be understood as a unique member of the species.

Mabel's positioning as a pet expert

Mabel began the workshop by declaring her love for her pets; she had three pets in her family. Her primary family unit had a dog, a hamster, and her grandparents were companions to a cat. Mabel enjoyed close relationships with all three but had a special attachment to the hamster, Puffpuff: "well, the dog is everyone's pet, but the hamster is mine. He lives in a cage in my room." From the beginning of the workshop, Mabel demonstrated deep care about the specific animals and refrained from collecting general trivia about the species. Mabel shared rich details of her pets' behaviors, especially her hamster. "Puffpuff isn't really picky about taste, kind of eats whatever. It's hard to know a favorite because it seems like they would eat, like, a lot of things they don't like. The others (the dog and the cat) don't eat everything."

On the second day of the workshop, after investigating the pets' visual experiences, Mabel began connecting details of her dog and hamster's behavior to their sensory experiences. In response to stories of pets shared in the group, Mabel asked clarifying questions about the pets' surroundings and considered alternate explanations for pets' behavior. For example, when discussing dogs' sniffing behavior, Mabel asked a peer, "Are they really intent on like staying there, and they, like, pull away from you so that they can sniff at it?" Mabel wanted to learn about the possible environmental elements that were causing the pets' behavior. Her questions implied that she was thinking about what the pets could be seeing, hearing, and smelling something different than the humans, causing them to behave peculiarly. She considered as many available details as she could gather. For details that were not shared but Mabel considered necessary, she asked probing questions.

On the third day, when the workshop progressed to making artifacts to improve the pets' lives, Mabel was motivated to solve specific problems in her pets' lives. For example, the dog needed help communicating its needs, the cat needed to play freely with its ball-like rattle toys without losing them underneath furniture, and the hamster, who liked soft materials, needed a cozy shelter inside its cage. Mabel quickly generated potential solutions to all these problems and made multiple projects for the pets. In addition to solving problems faced by the pets, Mabel hoped to find a few things about the pets' needs through their use of the projects. She was careful not to conclude she could predict *these* pets' behaviors from others' descriptions of their pets. For example, she expected Puffpuff to have preferences similar to but not precisely matching her friend's hamsters, who liked mattresses and pushed the mattress around inside the crate. Instead, Mabel relied on her friend's stories of their hamsters as a data point, collected more information about hamsters through research, and combined these with her knowledge of her hamster to predict what Puffpuff would be like. For example, she conjectured that her hamster, who liked to burrow, and dark but cozy corners, would probably like a sleeping bag. To this, Mabel added her own preference for swings and made a felt sleeping bag that could hang from the crate's ceiling. While sharing her plan, Mabel speculated, "There's a possibility that it could work. I don't know if it's gonna work with *her*."

On the final day of the workshop, the realization struck Mabel that the pets might need some training to get accustomed to the projects. She needed to show the cats the right way to play with the toy, train the dog to use the need detector to match his needs with a pattern to communicate the needs to the humans, and train and convince the hamster to use the sleeping bag enclosure. Mabel actively sought to understand the nuances of the pet's behavior and was careful not to harm the pets. However, simultaneously, she was motivated by the understanding that pets lived with humans and humans' preferred ways of caring for pets.

While Mabel described her projects' features in great detail, details concerning how the pets stood to gain from the projects were largely missing. Considering that when seeking knowledge of and describing the pets' behavior, Mabel sought depth and nuance, this omission is a critical contrast. Overall, Mabel positioned herself as a pet expert and a knowledge seeker. Her care for the pets was situated in the knowledge that she was responsible for their well-being, her curiosity about animals' senses and behavior, her love for the pets, as well as her and other humans' interests and preferences.

Stella and Mabel's positioning while making for pets

Both Stella and Mabel positioned themselves favorably in relation to pets at home and as learners at the workshop. Building on the tools and topics of the workshop facilitators, each girl spoke at length about their pets' unique sensory abilities - vision, smell, and hearing, and associated the pets' senses with everyday behaviors such as sniffing under rocks while out on walks (territorial action), rubbing their heads against human legs (transferring pheromones to claim human). Hence, both girls valued an understanding of pets, that pet behaviors meant specific things and sought to interpret pet behavior accurately.

In their conversations, while working on projects, Stella, for example, repeatedly asked her peers who had cats as pets if the boxes were big enough. "I heard that cats, in general, like boxes, but one of the boxes might be a bit small for bigger cats. I don't want the cat to feel stuffy inside" "I was thinking like a tube or like a box thing. I could put treats in it, open the bottom, just a tiny bit on it, once you open it, the cat could jump onto it and grab it, some of the treats that shot up. So, like, how big should the box be, I mean, how far will the cat jump?" While some of Stella's questions correlated to her not knowing a cat closely and hence, not knowing enough about cats, other questions pointed to her concern for the cat's well-being. She wanted the cat to find her project useful; the cat had to feel loved and cared for in the cat's preferred ways. Stella's positioning was of a human who desired the company of a cat, cared for cats, and valued in-depth and specific information about individual cats. Most importantly, Stella knew that cats could reject her company.

Mabel, on the other hand, having known several pets as close companions, asked different questions. While working on the projects, she repeatedly considered the training as a requirement for pets to be able to use her projects. "I think having him go inside the sleeping bag is going to be hard, but I am going to try. Like leave it (the sleeping bag) in her crate and leave the room, or leave it overnight in the crate and come back next morning." Later, she worried, "I just hope he does not eat it up; he is a big chewer." Mabel's idea of hanging the sleeping bag from the crate's ceiling may have helped with this problem, but Mabel did not consider this affordance. Instead, she used multiple felt fabric layers for the project to prevent the hamster from chewing it. Mabel recalled that the hamster "only chewed food and cardboard, not the crate and toys," and concluded that Puffpuff might not eat the project. She felt the need to train the hamster to use the sleeping bag but pointed to the difficulty of humans wanting to train an animal that slept all day and stayed up all night. Mabel's positioning was of a human who enjoyed the company of several pets, cared for each of the pets, and was confident in her skills as a pet carer and pet-related knowledge seeker. Like Stella, Mabel, too, sought in-depth knowledge of pets' behavior but reserved the final decision for herself. Mabel knew what was good for her pets; she was confident the pets would agree with Mabel's choices.

Stella and Mabel's work on the maker projects demonstrates that both girls were attentive to aspects of pet behavior and taking care of pets that are difficult to notice, indicating their attention to pets' and humans' unique interactions with social and material environments. Notably, the two participants noticed different aspects of the pets' behavior, and their noticings correlated with their positioning at the workshop. Stella positioned herself as a novice regarding knowledge and care of pets and repeatedly sought information and confirmation of her developing understanding. She considered the cat's and other humans' preferences above hers and wanted to avoid failure. On the other hand, Mabel positioned herself as a pet expert. She actively sought details clarifying pets' behavior. Still, while making the projects for her pets, she considered her attention to future training as more consequential to the pets appropriating her maker projects than further observations of their empirical preferences and responses.

Discussion

Against the backdrop of research in maker education and relationally and ecologically informed science learning, we set out to understand how the social positioning of makers and making objects for more-than-human companions contributed to learning opportunities at a pet sciences summer workshop. Analyzing two youth participants' actions and talk at the workshop as well as their reflections on it in interviews, we found that their positioning of themselves as pet companions and aspiring pet companions coincided with their noticing different aspects of their pet's lives and the affordances of maker projects. We conclude that making for more-than-human companions opens up new opportunities for science learning. Specifically, depending on individual positioning, youth in our study became aware of pets' unique sensory experiences and related behavior and its implications for their life with human companions. Based on our findings, we identify the following two directions to extend this line of research.

First, our findings reaffirm the importance of maker projects as transitional objects (Turkle, 1990), but we found Stella and Mabel's making to be unique because of how they needed to think while making these. Beyond the focus on detail and process-oriented thinking while making, the emphasis on the artifacts' functionality, the learners' design and process skills, content learned, and humans as the intended users is noteworthy in this research body. We highlight that Stella and Mabel's projects, as artifacts made especially for more-than-humans by their human companions, bridged the learner to the ecosystem through relational ties. Although Stella and Mabel are yet to position themselves as embedded in a unified natureculture, they are clearly aware of the pets' and their relational connections. As evident in their talk during the making process, the girls' attention to several aspects of the ecosystem, how these aspects affected them and the pets differently, and some of the resulting differences in their and the pets' experiences in the ecosystem, were critical departures from existing research on making and learning. We see this as a step forward in valuing making and maker projects as processes and artifacts that highlight what and how we become with others.

Second, broadly, we have thought of thinking and learning while designing and making as approaching scientific thinking through reflection. Schön (1983) compared reflective practitioners to scientists engaged in impromptu experimentation and careful examination of situations where the "situation talks back" (p. 131). When the boundaries between thinking and acting collapse, reflective practice becomes an ongoing, cyclical process. Despite the obvious importance of reflection in practice, scholars (van Maanen, 1999) have questioned what we leave unexplored by focusing solely on reflection. Parallelly, sensing the need for criticality, we ask, what do we fail to understand about learning in human-more-than-human relationships when considering reflection as the only way of thinking about the relationship? How should we think when just thinking about our actions and their consequences fall short? Our participants, for example, had to venture beyond thinking about pets as animals living with them to considering the animals' distinct species-based and personal needs. Only with this understand could the participants hope to make artifacts for their more-than-human companions, artifacts that might make life better for them. Feminist and new materialist scholars propose the metaphor of diffraction as a means of sense-making, understanding what constitutes experiences, and critically studying similarities and differences in situated and relational contexts, indicating the need for "marking a place where change occurs" (Haraway, 1997). We see promise in studying learning contexts that draw attention to expected patterns and deviation from patterns, where learners create something ontologically new rather than the repeated, objective mirroring of perceived reality (Barad, 2007). Such a critical examination of how different meanings are made and lived would indeed help us value ecologically and relationally-informed science learning for a multispecies coexistence. As we rely on different ways of knowing to know others, we can illuminate similarities and differences in epistemologies, and consider why they exist, and how they come to matter.

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Middle Schoolers' Trajectories of Identification and Wayfaring Through a Pet Science Workshop

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Abstract: Based on the widely recognized situated nature of identity and youth as social producers and products, this qualitative case study reports findings from a week-long informal pet-sciences workshop for middle schoolers who have existing relationships with pets or a strong interest in future pet companionship. Mindful of the structure-agency dialectic, we analyze youth's wayfaring and trajectories of identification as they learn about their pets at the workshop, accounting for how youth see themselves and their pets and are seen by others. In contrast to a commonly assumed analytic directionality seeing people as moving towards or away from STEM, we find that there were different ways for youth to meaningfully engage themselves in learning about their pets at the workshop. We conclude that attention to fluidity in youth's identifications can inform us, the adults in the community, of the need to affirm the many possible trajectories that youth may follow.

Introduction and background: Youth science identity

This paper details two young learners' science identity work in a pet sciences summer workshop. We examine science identity in a personal-historical and practice context (Holland & Lave, 2009). Particularly, we illuminate the entanglement of multiple contexts, practices, and feelings in shaping youth's science identity. We define identity as being recognized as a certain "kind of person" in a given context (e.g., Gee, 2001; Carlone & Johnson, 2007), in relation to individuals' performances in society. Understanding the performance of whom individuals are becoming, in tandem with whom they are obligated to be and what it means to be them, with attention to what settings demand and prohibit, is key to understanding identity in practice. Identity work is an agentic understanding and performance of oneself that individuals develop over time and across settings (Barton et al., 2013).

Valuing the notion of identity as changing and shaped across contexts and activities rather than static, we study identity with two motivations. First, objecting to the metaphor of a STEM pipeline which alludes to a few predetermined ways of engaging in science, we adopt the view that there are many ways of engaging in science. Second, we draw attention to the personal attributes of people engaged in learning science and science practice across many locations. Together, these help us understand learners' situated aspirations, motives, perceived benefits, and future hopes of continuing in science. We construct two case studies sampled from data collected at an out-of-school pet sciences summer workshop conducted at a university campus. Middle-school-aged youth participated in the workshop designed for current and aspiring pet-companions to learn about and explore canine and feline pets' sensory experiences and related behavior in and around human homes. We used simple phone applications to introduce participants to the pets' hidden senses, generally unnoticed and unperceivable by human beings. Later, we asked participants to identify problems their pets likely face at home and make an artifact or design an experience to address the problem. After participants planned, prototyped, and completed their projects, they tested the prototype with a pet, and presented their findings to the group, we interviewed them about their learnings and their interest in science and their science identity. We craft a theoretical framework to study identity in practice, fluid and interactive, and shaped by individuals, others, and activities, and ask one research question: *What insights into science learning as wayfaring informed by trajectories of identification can we gain from two teen boys' participation at a pet sciences workshop?*

Theoretical framework

Dorothy Holland and colleagues (1998) described identity as the ongoing and dynamic "imaginings of self in worlds of action" (p. 5). Identities, as social products, are means through which individuals "care about and care for what is going on around them," (p. 5) and find out ways of being— "persons taking form in the flow of historically, socially, culturally, and materially shaped lives." Lave (2012) asked how lives, persons, and practices are produced in ongoing everyday practice. Understanding youth's science identities requires an understanding of the structure-agency dialectic, the view that identities are in flux, forming and re-forming in relation to historically specific and structured contexts. Individuals shape their identities constrained and facilitated by the social context of activity. Individuals' agency functions within, through, and against social structural constraints (Varelas et al., 2015; Verhoeven et al., 2021). Understanding youth's ongoing relations within, across, and beyond contexts and how this contributes to their figuring of and identities in science requires recognition of what scholars have described as "intimate and social landscapes through time" (Holland et al., 1998, p. 285) and meshworking (Ingold, 2011; Rahm et al., 2022). This view of science identity as agentic and unfolding across time and contexts is relational and attends to learning and becoming as life-long emergence, paths of wayfaring, and the threading of ways through the inhabited world (Ingold, 2011). Therefore, what we know and who we are becoming, in addition to being in flux, is meshworked. Scholars studying youth's science identities agree. For example, scholars (Avraamidou, 2020; Carlone et al., 2015; Polman & Miller, 2010; Rahm et al., 2022) have advocated for plurality of science identities along complex trajectories within a web of meanings and practices, and other identities such as gender, ethnic, and language identities. Correspondingly, our framework moves beyond identifying factors influencing youth's science identity to understanding the meshwork and wayfaring as informed by the intersecting trajectories shaping their science identity work. We focus on the movement undertaken by the learners.

Research on science identities across time and space

Polman and Miller (2010) found that in the sheltered borderlands of a science outreach apprenticeship program, African American youth developed professional work and career aspirations through "trajectories of identification" (see also Lemke, 2000; Wortham, 2006). The program designed to utilize participants' cultural capital successfully engaged some youth, developing positive trajectories. Some participants were initially hesitant to engage, but later found reasons and ways to engage in the program, yet others found no reason to participate and did not develop positive STEM trajectories through the program. Gonsalves et al. (2013) studied how youth relied on immediately accessible and relatable cultural resources to position themselves as insiders in science while reimagining science as a readily accessible domain of exploration. Across time and space, participants remained determined to stay true to their school-aligned definitions of science and science identities, indicating the lack of connections between their discursive practices and the world of formal science learning. Wade-Jaimes and Schwartz (2019) demonstrated how African American girls tread complex, multilayered discourses only to be positioned outside of science. Rahm et al. (2022) studied young women of color's STEM pathways through the lens of personal histories and local practice. Highlighting movement and the multiple ways of becoming in science, they found multiple ways of becoming, including the girls' transnational identities, to be relevant to their STEM identities. Finally, Page-Reeves et al. (2022) described the transformed identities of Native American learners in predominantly White institutions of higher education. They found that the learners were motivated to repurpose STEM content knowledge and connect to their communities. They described learners as "wayfinding" through different institutional and cultural contexts, thereby gathering experiential wisdom.

Relationally and ecologically informed science learning

Our study concerns a unique kind of learning – about pets at home with whom human youth are known to have deeply cherished relationships (Parekh et al., in review). We know from science education research that in close association with nature, youth practice attentive, caring learning of science (Bang et al., 2007; Koda, 2013). Several empirical studies on youth-pet relationships (for example, Simeonsdotter Svensson, 2014; Zimmerman, 2012) support Donna Haraway's (2003) observation that human-pet relationships are about "significant others." Haraway noted— "Dogs matter. . . They are not just surrogates for theory; they are not just here to think with... They are here to live with" (p. 5). Haraway's conceptualization suggests that learning about pets involves more than learning about their biology and how their senses can be helpful to humans.

Human-pet relationships represent multispecies knots of reciprocal action, enmeshed in ecosystems and generally addressed as natureculture (Fuentes, 2010; Haraway, 2003). In our work, we are most directly concerned with natureculture in the human home; in this particular multispecies interface, humans and pets are both actors and acted on as they mutually shape the ecology. Specifically, we study youth's relational science identities as trajectories, enmeshed in places and activities, and as they learn science in a context that requires attention to relationality with pets at home. In doing so, we respond to recent calls for a science education attentive to ecosystems and the relationships within them (Hecht & Crowley, 2020).

Methods

Workshop details

In the summer of 2022, we organized a summer workshop for middle-school-age learners on a public university campus in the western United States. A science outreach program within the university recruited participants for the workshop through alliances with local school districts and a mailing list of previous participants in programs offered through the program. Eleven middle schoolers signed up for the workshop, and other than one participant who tested positive for COVID on the first day of the workshop, ten participated until the end.

The workshop plan was as follows: Day 1: Exploration of pets' senses through Augmented Reality filter applications and enhanced hearing applications, mapping of pets' activities at home and around; Day 2: Discussion of findings and experiences with pets, sharing pet stories about sensory experiences, identifying pets' experiences to understand better, planning investigations; Day 3: Best practices and examples of investigation of pets' senses, sharing outcomes of investigations conducted at home with pets; Day 4: Discussion of individual projects with peers and project work; Day 5: Presentation of learning to peers and families.

Data collected

We collected session video data for the workshop using one camera and audio-recorded conversations at each table. We had asked participants to partner with two other participants to work with throughout the workshop. On the fourth day of the workshop, we conducted brief, semi-structured interviews with each participant to record their inquiry into their pets' senses in relation to their projects. The participants responded to questions such as the following: Describe your project and your reason for working on this project. How does this project improve or solve a problem in your pet's life? What are some problems that you think your pet might have when using this project? What are some changes that you would like to make to the project? How has the workshop helped you think about pets at home? We conducted two rounds of interviews with each of the participants two and eight weeks after the workshop, respectively. The following are some questions we asked the participants: On the days of the workshop, did you do anything differently with your pet? What were the activities you would say you did with your pet? What role did your pet play in your projects/project ideas/testing projects? What did you learn from working with your pet? What science topics did you learn at the workshop? How did you use science to learn about pets? How was this program similar to or different than other science classes you have taken? What would it be like to have a career as a scientist? What would you like, what would you dislike? How would you describe your identity as a scientist, an animal scientist, and a designer? Eight participants completed the first interview, and seven completed the second interview.

Data analysis

We identified two participants whose talk we analyzed for this paper. Our choice of participants was dictated by the nature of their participation and the contrasting nature of their personal experiences and orientation. Both Mateo and Yan (both pseudonyms) identified as male and attended local middle schools. Mateo's family is of Hispanic origin and immigrated to the U.S. from Mexico, while Yan's family immigrated to the U.S. from East Asia. Both boys are fluent in their native tongue and English, participated in all workshop sessions, and interacted enough with their peers through talk for us to gather enough of their talk for the analysis. After the workshop and the interviews, we transcribed both participants' talk at the workshop in their small groups and during the post-workshop interviews. The talk recorded in the small groups was a mixture of responses to facilitator prompts and conversations with peers. At the interview, we asked them questions concerning their experience of learning at the workshop, how the workshop affected their pet-care practices, and how the workshop possibly affected if and how they can see themselves pursuing science as a career. In the second interview, we asked them questions about their science identities in relation to school and the workshop and asked them to scientifically analyze an incident involving a pet and a human companion. For this analysis, we focused on Mateo and Yan's talk on the first two days of the workshop and post-workshop interviews. The first two days of the workshop were structured to allow participants to share freely about their pets and themselves.

Our analytical strategy is based on the following theoretical assumptions about identity. First, as individuals, we exist in and navigate multiple worlds, each with its own rules and ways of figuring worlds. Second, positioning and locating ourselves and others, by choice and inadvertently, makes us appear as certain individuals. Third, degrees of freedom exist within each participation domain relevant to our study. At home, in school, and informal spaces, youth exercise agency to transform themselves in specific ways and decide if they want to blend in or stand out. Fourth, who youth have been in the past and across spaces and time shape who they are becoming. Mindful of these four assumptions, we analyzed Mateo and Yan's trajectories concerning pet-care practices and science learning. The following paragraphs detail our analytical strategy in detail.

After transcribing Mateo and Yan's talk at the sessions and the interviews, we had a general sense of the big areas of talk we wanted to explore through thorough analysis. For example, the boys' stories of their pets' life at home, the many ways in which they established themselves as trusted and beloved pet companions, and their descriptions of the attributes of projects and why these were desirable were promising categories of talk at the workshop. Noting the similar domains of participation for both participants (pet-care at home, school, talk about pets at the workshop, and personal interests), we set out to understand the finer aspects of their trajectories through pet-care at homes, pet-sciences work at the workshop, and science learning at school and other places. Specifically, we coded for (1) the activities they engaged in, (2) how they engaged in these, (3) how they spoke about these, and (4) their overall observations and comments about how they are able to position themselves in each of these domains. To analyze Mateo and Yan's identities in each of these domains, we coded for (1) the attributes they assigned to the activities in each of the domains, (2) how they saw themselves as they engaged in these, (3) how they thought others saw them, and (4) the alignments and conflict with any other identities these indicated. Simultaneously, we were attentive to how they spoke and when, and what the timing of their talk implied for the purpose. This gave us an understanding of their concerns, doubts, confidence, etc., and what these might indicate for their identities. Combining our analyses following these strands, we wrote analytical memos about the boys' figuring across domains of practice, along with the negotiation of identities and location of themselves and others.

In a parallel analytical strand, we analyzed the participants' talk for their descriptions of their pets and what they considered to be valuable about pet biology and pets' experiences at home. This constituted evidence of learning about pets. After identifying the aspects of the pets' lives they talked about, how, in their view, these aspects were connected, and how these mattered to pets' lives, we understood their attention to ecologically and relationally-informed science. Unifying the two strands of analysis, we created a critical narrative for each of the two participants with attention to their practice of an ecologically and relationally-informed science and their identities in each of the domains of participation, the relationality of their identities across these domains, and what this meant for their science identity. Finally, we created a critical participant narrative account (VanMaanen, 1990; Polkinghorne, 2005) for each of the two participants with attention to their practice of an ecologically and relationally-informed science and their identities in each of the domains of participation, the relationality of their identities across these domains, and what this meant for their science identity. We present our findings in the qualitative research tradition of a case study (Stake, 1995) meant to capture the complexity of the human experience.

Findings

We briefly describe Mateo and Yan's trajectories through their homes and the workshop as pet companions and as science learners through the workshop and school. Following this, we summarize our findings with attention to the insights we gain from studying Mateo and Yan's wayfaring and trajectories of identification.

Mateo and Pepe

Mateo is thirteen years old. He is close to his younger sister, and they are each companion to one of two dogs in their home. Mateo loves caring for the dogs, walks, and plays energetically with both dogs. Mateo, an amateur boxer and wrestler, also likes fixing and making things at home. When the vet suggested that his sister's dog lose weight, Mateo described the dog as "muscular and strong, not fat," but planned to make him exercise in the yard by chasing the dog and throwing sticks far away. At the workshop, Mateo's project ideas were meant to engage his dog, Pepe, in active and energetic play at home and in the yard. Taking into account Pepe's high level of energy and tenacity, Mateo's plans involved tying "strong knots with ropes" and securing poles in the yard, things he thought he was good at. Initially, Mateo wondered if he could make a harness and a leash that could be attached to a treadmill to help Pepe exercise when Mateo exercised. Or, Mateo could attach a thin, flexible rod to Pepe's harness with a treat dangling from it over Pepe's head so the dog could smell the treat and be motivated to walk long distances. This way, he could use his skills in making things and exercise and fitness to solve a problem in the dog's life.

When Mateo considered his final project idea, he decided to carefully install a multi-purpose entertainment system for Pepe in the yard. He built a sturdy but flexible tug-and-squeak toy that hung from a pole firmly planted in the yard. He also added a treat to the toy as a reward for Pepe. He was mindful of the dog's need to "vent excess energy," "stay out of trouble with the other dog," and wanted to "reward him for good behavior, but not by harming him." Pepe played with the installation for a long time, making Mateo deem his project successful. Pepe's interaction with the toy provided evidence that Mateo understood the dog's needs and preferences and what constituted a desirable playtime for the dog. However, despite Mateo's obvious understanding of Pepe's nature and needs and his ability to find suitable solutions to the problems the dog faced at home, he considered himself just "okay" as a learner. Expressing difficulty articulating his ideas with words, Mateo said that he could "never explain the details and outright say it because then they'll get confused."

Mateo considered learning facts about pets' senses and systematically investigating pets' lives to be scientific. In his words, at school, he learned facts, but at the workshop, he found out why and how these facts mattered. For example, he knew that the sense of smell was essential to dogs, but at the workshop, he learned why smell was crucial for dogs' behavior and how smells affected dogs, specifically how smell affected Pepe. Mateo valued such learning but considered it to be different from learning science at school which constituted "mixing liquids with chemicals and stuff, calculating stuff," "building things to see if they work," and "testing things repeatedly to see if they worked well." Per this school-aligned understanding of science, only some aspects of his pet care experience, i.e., learning how pet senses worked and experiments about pets' senses, were scientific. Mateo considered other aspects of his pet-care practice at home and at the workshop, such as understanding the nature of the problems Pepe faced, thinking of solutions to these problems, designing and creating toys for Pepe, and testing it repeatedly to check if they worked for Pepe, to be everyday pet care and not scientific. Further, Mateo felt that using science to solve pets' problems under challenging circumstances, such as concerning a sick or dying pet, would be too difficult. Overall, Mateo's experiences at home, school, and the workshop, the different domains of activity such as chores at home, pet-care, making, and school coincided with him feeling like a certain kind of learner. Along with his predominantly school-aligned perception of science, Mateo's awareness of his strengths and limitations had a bearing on his perception of himself as a science learner.

Yan and Bear

Yan is eleven years old, lives with his family, and is a proud companion to a cat, Bear. Yan described Bear as a former stray adopted by his family as a tiny kitten. Among all four humans at home, Bear preferred Yan's company. The cat, eighteen months old at the time of the workshop, napped on Yan's bed and refused to follow the instructions offered by Yan's father, who wanted to keep Bear off the furniture.

Yan practiced playing a musical instrument at home, read his favorite book series, studied hard, and stayed out of trouble with his younger sibling. As a science learner, details mattered to Yan. His stories of cats, including those about Bear's life in their home, were rich with observations of feline behavior. Yan closely observed cats and tried to identify problems in their lives with humans. For example, why did the cat like specific locations inside the house and not others? Why would the cat spend time with some members of the household at certain times of the day? Upon finding out about cats' senses at the workshop, Yan could make sense of some of the problems he had previously identified. Then, he methodically talked through some problems and their potential explanations with his peers.

Later, Yan worked on many projects at the workshop to find out about the cat. Through most of these projects, Yan investigated Bear's preference for catnip. Yan wondered if Bear liked the smell, the taste, or just the feeling and experience of being near catnip. So, he made fish-shaped dangling prey toys filled with synthetic stuffing and catnip and introduced these two to Bear. Once he saw that Bear was not interested in using the toy as prey, he made a collection of food item-shaped toys stuffed with catnip to understand the cats' preferences. Yan concluded that Bear definitely liked the toys stuffed with catnip but did not prefer the toy's shape and nature (prey toy versus a cuddly toy). Although Yan could not understand why Bear liked catnip, he concluded that the cat liked a certain kind of catnip toys.

In his descriptions of Bear, Yan's language was noteworthy. Rich in details of feline behavior, Yan consistently referred to Bear as "his" cat. In his stories, Bear always preferred Yan to other humans, and Yan, in turn, understood the cat the most and was duly rewarded with attention and cuddles. Through his description of cat behavior in relation to senses, Yan demonstrated his ability to solve all of Bear's and other cats' problems and narrated these problems and their solutions in exquisite detail. After the workshop, Yan shared that he aspired to be a scientist. Having spent many hours after school and during breaks at his father's laboratory, he was quite fascinated with lab coats, safety goggles, and intense scientific investigations. Yan knew a lot about the investigations in this laboratory and similarly imagined himself – "I do feel like I am pretty strong in that area." However, he could foresee some challenges as well. For example, what would happen if something went wrong? What if he got impatient when experiments took too long to yield the expected results? Overall, Yan was confident that taking care of a pet required him to use scientific knowledge and that he would like to be a scientist in the future.

Yan's experiences at home, his parent's lab, and the workshop, the different domains of activity such as pet-care, finding out about events and phenomena as a hobby, and making, coincided with him feeling like a certain kind of learner. Confident of his ability to learn science and having access to scientific practice through his parent, Yan looked forward to a career in science, expressing only slight concerns about his personal limitations.

Summary of findings

Mateo and Yan were both exceptional in their abilities as learners. Both learners saw the animals in relation to themselves and were attentive to the pets' interests while working on their projects. However, their trajectories, as evident in their talk, are distinct. We highlight three aspects of their trajectories that are important to ecologically and relationally informed science learning.

First, Mateo treated Pepe as an animal living with his family. He referred to Pepe and the family's other dog as individual animals who occasionally got into trouble with each other at home and to whose distinct needs he had to be attentive. Yan perceived Bear as *his* pet, who sometimes spent time with his sibling but was most loyal to him. Yan also showered the most attention on Bear within the family and cared for him the most. Mateo was attentive to Pepe's habits and interactions with the surroundings because these were important to the dog's wellbeing, while Yan was attentive to Bear's habits and life at home because he felt rewarded by the cat's affection. Mateo and Yan's different relationships with the pets illuminate different ways in which the boys were attentive to relationality within the ecosystem. Mateo's attention was directed at the relational aspects of Pepe's existence within the home ecosystem because he knew that such attention was vital to the dog's wellbeing. On the other hand, Yan's attention, although directed to the relational aspects of Bear's life at home, was meant to find out more about the cat and to make him feel good as a pet companion and a learner.

Second, despite Mateo's ability to be attentive to Pepe's unique canine needs and his ability to successfully investigate the dog's behavior and design projects for him, he felt only moderately successful as a science learner. He perceived himself to have a lack of communication skills, academic vocabulary, and fluency, and saw these as significant setbacks. Yan, too, was an expert investigator of Bear's experiences in a human home, but he saw a future for himself in science. Yan felt that his extensive communication skills and precision, along with his assertiveness and outgoing nature, would help him do well in science. Research on learners' discourse development in science classrooms (Lemke, 1990) shows that through their participation in social situations, learners become habitual in their use of certain discourses in use in these social situations. In a setting such as an out-of-school pet science workshop, science talk was a valued discourse that Yan could engage in; this, in turn, affected how Yan self-identified as a successful science learner. Unfortunately, Mateo's interpretation of the science talk at the workshop was informed by his experiences of science talk norms at school, and made him feel less successful as a science learner, despite the goals of ourselves as the program designers to disrupt those school norms. Relatedly, Mateo perceived a divide between school science and everyday science such as pet-care. In fact, Mateo held school science in high esteem, while workshop and everyday activities that required investigations, problem-identification, and solutions did not qualify for him as scientific, even though he valued them as pet care. Yan readily accepted everyday pet-care-related practices, investigations, and problems as scientific. It is possible that regular conversations between Yan and his parent included everyday science topics or the structure of scientific inquiry, and this helped him immediately identify the workshop as a place for learning science and himself as a science learner. Nevertheless, the divide, and lack thereof, between school and everyday science in Mateo and Yan's perception points to the importance of learners' ability to relate to science practice as having certain features, including certain benefits for themselves (e.g., Martin, 2019; Rahm et al., 2022; Sengupta-Irving, 2021).

Third, Mateo and Yan reflected differently on their future in science. Initially hesitant about identifying himself as a science learner and the workshop as a place for science learning, Mateo finally expressed that the workshop had made him feel that he could pursue science, especially animal science, and "building things, constructing things that solve problems." Still, in the absence of a clear sense of the path ahead, Mateo was doubtful of such a possibility. On the other hand, Yan thought he knew what lay ahead and was confident in his ability to pursue a career in science, but was afraid that he might not know how to deal with failures and mistakes. Mateo and Yan's confidence and doubts in their own strengths and the path ahead are evidence of their awareness of navigation - following a path others have laid out and traveled before (Page-Reeves et al., 2018). However, wayfaring in science, using contextual cues to agentively weave the fabric of one's own life in the traditional system of science education might be easier for only one of the two middle-school-age learners.

Discussion

We set out to examine two male middle-school-age workshop participants' science learning as wayfaring and trajectories of identification at a pet sciences workshop. Analyzing their talk at the workshop and during interviews, we found that their trajectories were unique. Both participants spent considerable time taking care of their pets at home, understood the science of pet-care, and were good science learners, but only one participant had appropriated a strong science identity. This learner was supported by his successful science talk and knowledge of science facts and processes, while the other was doubtful of his presence and future in science. Our dual focus on learners' trajectories and wayfaring, relational identities in movement across space and time, and relationally-informed science learning, draws attention to the following two points.

First, one of the two participants saw himself as an invested member of communities, a learner, and a pet companion. His attention to relationality, both as a learner and in his learning about pets, was noteworthy.

However, his understanding of relationality also posed challenges for him when, at times, he felt overwhelmed by emotions and the recognition of the challenges that lay ahead. The other participant was attentive to relationality, mostly as factors affecting his pet's life. He did not consider the relationality pertaining to his movement across the different domains of participation in his life and found wayfaring to be minimally relevant. In fact, as someone who saw himself and who others saw as a successful science learner who liked to learn alone, he sometimes doubted his ability to foresee mistakes and prevent them and considered failures as impediments that might lead him off-track. He saw his trajectory as passing through a few predetermined domains of activity that were fixed and predictable. Despite this relative inattention to his trajectory, his experiences in science learning were rewarding. This contrast in the two participants' trajectories through the workshop raises an important question: How might we help learners become aware of their relational trajectories as well as relational learning of science? This is a pressing question because institutions of learning often reward learners' "intelligible identities" (Günter et al., 2020) rather than attention to relationality and relational identities. Second, our findings indicate learners with already strong science identities established elsewhere felt more comfortable at the workshop, while those with an emerging or questioning science identity hesitated. We were unable to make all learners inquire into their participation and identities along trajectories to identify their strengths and weaknesses as science learners. Drawing attention to multiple practitioners across settings and communities might communicate to youth the many possible trajectories, thereby making them confident in their own trajectories and relational identities. Brayboy, 2004; Rahm et al., 2022, Gonsalves, 2020, Page-Reeves et al., 2019, make similar recommendations based on similar observations.

In relation to the above two points, questions of access and opportunities beyond the inclusion of learners become important. That students should have access and opportunities to participate in science discourses is widely acknowledged and endorsed (e.g., Barton & Tan, 2020; Martin, 2019). However, key aspects of the participation of students lacking a strong science identity remain challenging and warrant continued research. Knowing learners' sociocultural locations, identities, and choices emerging from these locations are vital to their recognizing their identities. This, however, requires a deep understanding of learners and their contexts, leading to altering the status quo. We see promise in drawing attention to learners' political struggles across settings, and promoting acts of justice (de Royston et al., 2017). The struggles are key sites of identity work, particularly in middle-school-age learners who are acutely aware of stereotypes (racial and ethnic, and gender stereotypes in our case) and negotiate what it means for themselves and others (Nasir et al., 2017).

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The Promise of Sketching in Biological Problem Solving for Self-Directed Learning From Online Resources

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Abstract: This study brings together two research traditions. The first, investigates the ways in which learners' representational practices influence learning. The second, investigates the ways in which we can support learners in self-directed learning using online resources. We examined whether learner generated sketches that accompany self-study from a video and written text result in a better understanding of a novel biological mechanism than such study without sketching. We found a significant advantage to sketching. To reflect a real-world need for incidental learning, our study was couched in a scenario of running an online discussion group. Our findings suggest that fostering sketching as a habitual tool for sense-making is a promising way to prepare learners for the new realities of ubiquitous self-directed learning.

Introduction

The learning sciences have a rich history of investigating the ways in which learners' representational practices influence learning (e.g., Cooper et al., 2017; diSessa et al., 1991; Halverson, 2013; Kindfield, 1994; Medina & Suthers, 2013; Pierroux et al., 2022; Ramey & Uttal, 2017). Learner created representations serve multiple goals: they reify disciplinary practices, they make thinking visible, and they facilitate reasoning. We were especially interested in the ways in which sketching can facilitate reasoning and comprehension, because we are interested in understanding how to support learners who use online resources for self-directed informal learning—a form of learning that is becoming increasingly prevalent in the lives of both youths and adults (Esteban-Guitart et al., 2018). In this paper, we report on a study in which participants were asked to learn about a biological mechanism as part of a fictional scenario reflecting an everyday need for learning (running an online discussion group). The study compared understanding between those that learned with sketching and those that learned without sketching. Our study focused on learning through sketching in the life sciences, which has received less attention than design, engineering, and physical sciences. Thus, we both contribute to a broader understanding of learning through sketching and consider implications for supporting self-directed informal learning.

Literature review

Sketching as an external representation

Sketching, creating an external visual representation portraying any type of content (Quillin & Thomas, 2015), is a ubiquitous practice for artists, designers (Fish & Scrivener, 1990), architects, and engineers (Landay & Myers, 2001; Sangiorgi et al., 2012; Verstijnen et al., 1998; Zurita et al., 2007). By using lines as well as numbers and letters as symbols (e.g., H2O for water) sketches can depict structures, relationships, or processes (Haddawy et al., 2006; Zhang & Linn, 2011). Sketching can actively involve learners in the cognitive process of selecting, organizing, and integrating learned information (Ainsworth & Scheiter, 2021; Cooper et al., 2017; Schmeck, Mayer, Opfermann, Pfeiffer & Leutner, 2014), in other words, in creating a mental model (Mayer, 2009). According to Van Meter and Garner's (2005) generative theory of drawing construction, the sketch of a model might occur after the creation of a mental model or in parallel to the three cognitive processes listed above. Creating such external representations can facilitate comprehension and learning (Quillin & Thomas, 2015).

The process of drawing or using abstract graphic representations, as part of the development of a visual idea, is identified with content worlds such as design and engineering (Zhang & Linn, 2011). The necessity of using graphic representations arises from the need to construct or manipulate several objects without creating the product itself; thus, the verbal language and other tools used by the sketcher contribute to the development of visualization and self-expression abilities (Fish & Scrivener, 1990). Sangiorgi et al. (1990) and Kavakli et al. (2006) suggest that drawing in the early stages of visual design is an important part of the process because designers engage in a form of dialogue with their drawings that enable them to examine, critique and tweak their own and others' ideas.

The merits of sketching in problem-solving and knowledge construction

Spontaneous sketching of images that emerge in the designer's head during pencil-and-paper drawing is often observed during a creative design process. Designers sketch ideas in various ways, allowing themselves to look at a problem from different angles (Sangiorgi et al., 2012). One explanation for this phenomenon is that the drawing helps in translating creative thought discovery into dynamic visual ideas one can work with and return to during the work process; when eventually, a review of the visual image that comes to mind and a new structural and graphic interpretation for it will occur on the solution page (Forbus & Ainsworth, 2017; Verstijnen et al., 1998). Observing problem-solvers using pencil-and-paper drawings as part of the problem-solving process suggests that free use of these drawings when expressing a novel idea gives rise to additional thoughts and concepts that help them solve the given problem (Casakin, 2012; Landay & Myers, 2001).

Drawings, which result from the thinking process of users and therefore contain user-selective information, have multiple roles in the problem-solving process. Drawing and sketching by learners were found to be effective in facilitating memory and generating visual models as part of higher-order thinking skills (Ainsworth & Scheiter, 2021; Heideman, Flores, Sevier & Trouton, 2017). Studies have shown that by using graphic representations during problem-solving, not only can solvers develop the skills required to obtain the final solution, but they can also incorporate ideas and concepts from the content field in which the problem is addressed (Jitendra, 2002). In addition, studies of learning through representations indicate a relationship between high student performance and the use of appropriate representations (Ainsworth, 2006; Schmeck et al., 2014).

Sketching in problem-solving in the life sciences

Learning a biological principle, e.g. energy in the human body, may be challenging due to different organization levels: from the mitochondrion organelle to the intercellular energy production process. Thus, students practice proficiency related to scientific understanding, from a cellular organization level to a systematic organization level (Rea-Ramirez, 2008). According to Schmeck et al. (2014), students' sense-making of scientific texts improves when they are asked to draw illustrations or sketches that represent the content they read; this allows them to select, organize, and integrate information, which are a set of actions that contribute to comprehension.

Complex problems in fields such as technology and design involve objects and visual elements. Consequently, most of the research that deals with drawing for problem-solving focused on these fields (Verstijnen et al., 1998; Sangiorgi et al., 2012). Nevertheless, based on the connections found between drawing and problem solving across disciplines (Ainsworth, 2006; Ainsworth & Scheiter, 2021) and in biology (Kindfield, 1994a; Quillin & Thomas, 2015), there is much potential in the use of sketching in the life sciences (Schmeck et al., 2014).

In this study, we wanted to further understand whether sketching can help learners grapple with some of the inherent difficulties of understanding biological processes. We were interested in whether sketching could be used as a tool for understanding when people try to learn new topics when the need arises in their everyday lives. Therefore, we examined how people understood the mechanism through which Aspirin affects the human body by reading an expository text and viewing a video. We compared participants who augmented their reading and viewing with sketching to participants who did not sketch.

Methods

Participants

The group comprised sixty students from the undergraduate subject pool of the Department of Education. The participants included 58 females and 2 males (this reflects the gender composition of the student body) whose high school background was in the Humanities and Social Sciences. I.e., we tried to ensure that participants did not have much prior knowledge in biology.

Materials

Task scenario

To reflect the types of everyday situations in which a person may need to learn a new topic, or understand a biological mechanism, we set the learning within a fictional scenario. Participants were instructed that they run an online discussion group concerning health and nutrition. A discussion thread came up considering whether it was possible to develop a natural alternative to Aspirin. Specifically, whether salicin extracted from the bark of the white willow tree could be used for such a purpose. Following this thread, several users asked for an explanation of how these medications work to evaluate whether the natural remedy could be an adequate alternative to Aspirin. Participants were asked to learn about how Aspirin works and to compose a detailed post responding to these queries, and to include a description of the mechanism of each of the medications in the response.

YouTube video

All participants were shown a two-minute YouTube video describing the primary uses and chemical mechanism of action of Aspirin. We included this video in the experiment for several reasons: (1) to reflect the type of resources people encounter and use in everyday life (Dubovi & Tabak, 2020; Liu et al., 2018; Shoufan, 2019); (2) we wanted all participants to benefit from viewing dynamic visualizations of a biological process as a way to focus on the unique contribution of sketching above and beyond exposure to visual information; (3) we wanted to examine whether visual information influences the content of participant sketches.

Biological reasoning task

Participants received an identical, two-page explanation that provided basic background knowledge in plain language as well as context for the problem. It described two similar medicines— Aspirin and Salicylic Acid— and their chemical mechanisms of action. The text consisted of approximately 538 words (in Hebrew) and was divided into seven paragraphs. The two versions of these informational pages varied between "sketchers" (experimental) and "non-sketchers" (control) in two ways: (1) the inclusion of an implicit sketching prompt in the form of a sketch embedded in the informative description (see Figure 1); and (2) an explicit sketching prompt in the instructions.

The sketchers' informational background included a sketch (drawn by the experimenter) depicting a schematic drawing of the chemical structure of Aspirin (Figure 1). This author-generated sketch was intended to serve as a prompt to encourage sketching, and as a model of how one might approach the task of sketching the biological mechanism depicted in the problem.

Figure 1
Chemical Structure of Aspirin Sketch Included in Sketchers' Instructions

Following Schmeck et al. (2014), we took measures to ensure that participants in the control group had the same amount of information as participants in the sketching group. For this reason, the author-generated sketch was also described verbally in the informational text that was the same for both groups. The informational background was followed by two versions of the problem statement:

"Non-sketchers" received the problem statement: "You must write a detailed answer comparing the two drugs, including a description of their mechanism of action."

"Sketchers" received the problem statement followed by a statement (translated from the original): "In order to help online readers understand the mechanism in depth, it is necessary to draw or sketch the method of action of both medicines, even if it means a simple/schematic drawing."

Procedure and analysis

To control for prior knowledge effects and ensure comparability between randomly allocated experimental and control groups, participants answered a short multiple-choice pretest. Participants with low (0–2/11) or high (10–11/11) scores were excluded.

All participants viewed the same YouTube video, then read an informational text that differed by condition as described in the Materials. They were asked to read the text carefully to answer an open-ended question on an online forum: "Could Salicylic Acid's mechanism of action function as an adequate alternative to Aspirin?" Participants were asked to compare the two mechanisms of action while including a detailed description of each.

Each written solution was segmented into distinct biological statements: (a) Aspirin's mechanism of action, (b) Salicylic Acid's mechanism of action, (c) comparison between the two medicines, and (d) scientific mistakes. 0.5–1 point was awarded for each correct statement, or deducted for each mistake, the sum was the total biological sense-making score. Repetitions did not add or deduct points. Following Schwamborn et al. (2010), ideas that were represented in sketches were counted and added to the total number of statements (in the sketching group alone), but only if they made a point different from those noted in the textual response.

12% of the solutions were coded collaboratively with a second independent coder who is an expert in biology. Afterwards, each coder independently coded 25% of the solutions blind to condition, and a Cronbach's alpha interrater reliability of 0.900 was achieved.

Results

A major goal of this task was to examine whether asking non-biologists to generate sketches as part of their reasoning solution is a more effective learning strategy than asking non-biologists to write a reasoning solution with biological text alone. An independent-samples t-test analysis indicated that the use of correct statements from criteria (a) and (b), mechanisms of action, was significantly different between the two groups, respectively [t(52)=-4.228, p<.001], [t(52)=-3.124, p<.01]. Mean proportion correct and SDs on the biological reasoning task for both condition groups are presented in Table 1 and Figure 2. The sketching group used a significantly higher number of scientific statements related to Aspirin's mechanism of action (M= 6.268, SD= 2.0206) and to Salicylic Acid's mechanism of action (M= 3.269, SD= 1.4121) than the control group (M= 4.000, SD= 1.9131), (M= 2.173, SD= 1.1397). The sketching group also made a significantly lower number of scientific mistakes (M= .286, SD=.7127), p<.01, than the control group (M= .962, SD=.9584). However, the number of scientific statements used for comparison was not significantly different between the two groups. Furthermore, the sketching group scored significantly better (M= 11.179, SD= 3.8205) than the control group (M= 7.115, SD= 3.6778), p=.000).

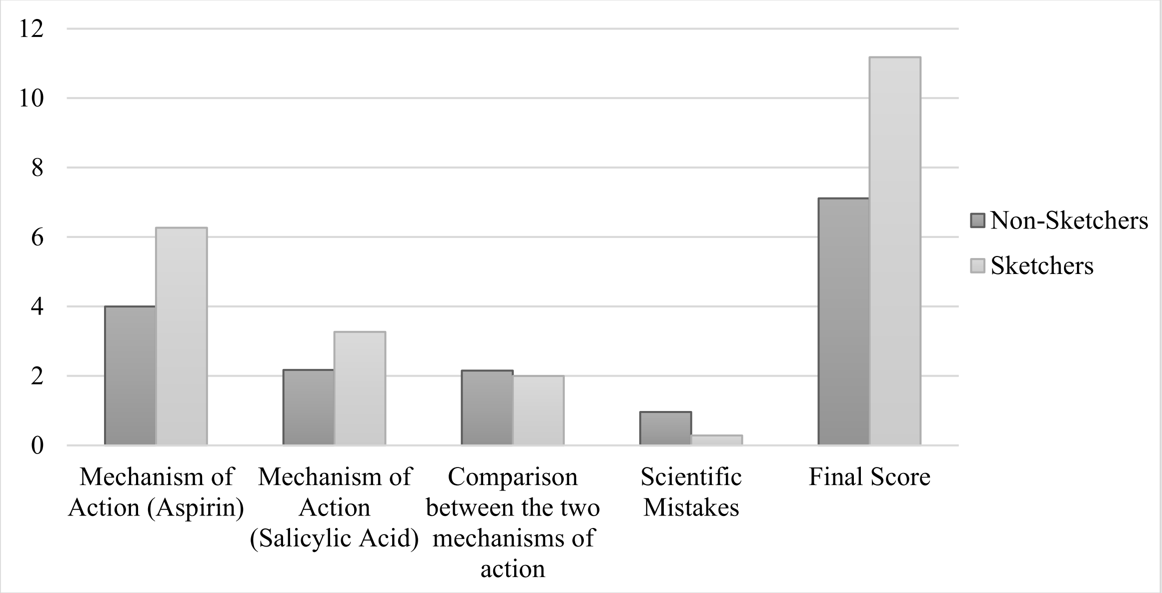
Table 1
Mean proportion correct on the biological reasoning task for two groups

	Condition			
	Non-Sketchers *n*=30		Sketchers *n*=30	
Criteria	*M*	*SD*	*M*	*SD*
Aspirin's mechanism of action	4.000	1.9131	6.268***	2.0206
Salicylic Acid's mechanism of action	2.173	1.1397	3.269**	1.4121
Comparison between the two mechanisms of action	2.154	1.0749	1.999	1.3792
Scientific Mistakes	.962	.9584	.286**	.7127
Final Score	7.115	3.6778	11.179***	3.8205

Note: Asterisks (*), (**), (***) indicate significant difference from control group at *p<.05, p<.01 and p<.001*, respectively.

Figure 2

Use of categorized scientific statements and scientific mistakes in the biological reasoning task.



The results show that the prompt to sketch had two significant effects on the quality of the biological reasoning task: (a) It improved the scientific knowledge of the given mechanisms; and (b) it reduced the amount of possible scientific mistakes made as part of describing an unknown biological mechanism. Accordingly, it improved the novices' biological thinking and scientific sense-making, as they selected information, organized, and integrated it in a verbal solution.

As part of the reasoning solution, participants were instructed to formulate subjective advice for their "online readers" on whether Salicylic Acid can constitute a natural alternative to Aspirin. A chi-square analysis indicated that there were no significant differences between the two groups in composing subjective advice as part of their reasoning solution [$\chi 2$ (6,N=60)=2.336, p=.31]. This result indicates that the prompt to sketch did not affect the integration of advice as part of the solution, therefore, it did not affect the quality of the solution in that sense.

Some participants used scrap paper to take notes and write down information from the text that they thought might be important or helpful. Most papers showed the participants were trying to understand the relationship between components mentioned in the text, such as acetyl and OH as functional groups, COX enzyme, prostaglandins, thromboxane, and platelets. There were no striking differences between the "draft notes" of the two groups, as the same amount of drafts were found in each group (n=7).

After writing their biological solution, the participants were asked if they felt that they were missing information and if so, what information might have helped them create a better solution or understand the scientific text. There was no significant difference between the groups in claiming they needed more information [$\chi 2$ (1,N=60)=.002, p=.965]. That the groups showed no difference in their need for additional information, may further support the conclusion that the differences in the quality of their understanding resulted from the condition of sketching.

Discussion

The main goal of this research was to explore whether sketching can serve as an intermediary factor that enables non-biologist learners to understand and reason about biological processes in biological problem-solving. We were interested in pursuing this question, because sketching is a practice that people could employ as they try to learn new complex information through self-directed learning from online resources. Results indicate that the prompt to sketch affected the quality of the biological reasoning task. In particular, it facilitated the understanding of given mechanisms as well as reduced scientific inaccuracies in describing the biological mechanism. Accordingly, it improved the novices' biological thinking and scientific sense-making, as exhibited in the way that they selected information and organized and integrated it in a verbal solution. So why is sketching as part of biological reasoning and problem-solving better for biological thinking than learning from scientific texts alone?

Biological processes and mechanisms are known to occur differently at different levels of organization as a result of multi-factor interactions (Rea-Ramirez, 2008). Therefore, biology, as a field of phenomena explained by mechanisms (Sheredos & Bechtel, 2017), includes complexities that challenge comprehension (Quillin & Thomas, 2015) and holds many inherent challenges for learning and understanding (Mayr, 1998). These challenges, such as lack of proficiency in biological terms and inter-level interaction and effects, are easier to handle during problem solving when aided by a self-drawn visualized model of a described mechanism, especially for those who do not have prior knowledge to rely on (Eick & King, 2012). This is due to some of its most prominent attributes:

a. Sketches function as part of a users' self-dialogue that occurs during work on a task, in order to visualize ideas (Fish & Scrivener, 1990), to represent a novel idea (Forbus & Ainsworth, 2017) and to promote thinking processes, making it easier to solve problems in different content areas (Landay & Myers, 2001; Jitendra, 2002; Ainsworth, 2006);

b. Sketches contain user-selective information, and by creating a two-dimensional set of visual-spatial symbol relationships in order to explain three-dimensional ideas, principles, processes, and models, these sketches play a focal role in the biological problem-solving process (Kindfield, 1994a; 1994b; Quillin & Thomas, 2015);

c. Sketches enable one to track the many factors involved in a biological process and make the hidden more visible and the complex simpler (Quillin & Thomas, 2015);

d. Sketching, as a modality of representations, assists learners who actively process a load of information (Ainsworth, 2006) in developing memory and generating visual models as part of higher-order thinking skills in biology (Heideman et al., 2017);

e. Sketching creates a mental model (Mayer, 2009), as it actively involves learners in the cognitive process of selecting, organizing, integrating learned information (Schmeck et al., 2014) and generates an external model (Quillin & Thomas, 2015).

Our findings suggest that sketching is not necessarily spontaneous, as we did not see a high incidence of sketching in the control group. The only subject that used sketches in the biological reasoning solution (and who, as a result, was analyzed as a "sketcher") used procedural sketches (e.g., chemical mechanisms of action—COX's irreversible deactivation by Aspirin or partial deactivation by Salicylic Acid and its effects) that were similar to other sketches found and analyzed in the sketching group. It is worth mentioning that the subject did not receive an author-generated text, while the other sketchers, who used similar sketches in their biological reasoning solution, did. Furthermore, 25% of sketchers indeed used an inspired form of the author-generated sketch in their biological reasoning solution. Following Schmeck et al. (2014), the present study encourages science instructors and educators to incorporate sketching practices as part of textual literacy, which they call the generative drawing effect. By providing an author-generated sketch augmenting the biological text, we provided a practical sketching strategy for the non-biologists "sketchers." An important implication is that non-biologists may need visual guidance for their sketching activity.

Some limitations and potential future directions of our study should be addressed. This study shows consistent evidence that after reading a scientific text, non-biologists who are asked to generate and combine sketches as part of their biological reasoning solution perform better than non-biologists who read without an embedded sketch and the prompt to sketch. However, two additional condition groups, such as "sketchers" without an embedded sketch in the text and "non-sketchers" with the author-generated sketch, might have extended the generative drawing effect according to Schmeck (2014) and Quillin and Thomas (2015). The added value of the aforementioned conditions could reveal the role of the embedded sketch in biological problem-solving and its effect on the quality of the biological solutions of the other condition groups.

Conclusion

This study aims to contribute to the understating of the promising role sketching plays in biological reasoning and problem-solving. We have found that a rudimentary use of sketches, without training or assistance, can improve biological thinking and reasoning among non-biologists. Participants who used sketches as part of their problem-solving performed better in biological reasoning than participants who did not sketch. These effects were present even after one-time, minimal exposure to such prompting. The results suggest the strong potential of using sketches in biology learning and understanding. Moreover, if learners are encouraged to develop sketching as a habit of mind for facilitating understanding, then this might prove as a useful tool to enhance self-directed learning from online resources.

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Catalyzing Teachers' Evidence-Based Responses to Students' Problem-Based Learning in STEM

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Abstract: This paper examines the processes middle school STEM teachers employ to interpret student learning and problem-solving activities during a problem-based learning unit and then design evidence-based lesson-plan customizations. Utilizing inductive and constant-comparative analysis of teachers' think-aloud data, we identify *catalyzing links* that support the transition from interpretation to enactment. We provide a contrasting case between an experienced and a novice teacher, and discuss how the results can inform STEM PBL professional development and teacher-support technology development.

Introduction

Prior research has demonstrated the importance of teacher engagement as students develop ideas and use of strategies to support their STEM learning in problem-based learning (PBL) environments that emphasize student-centered learning. This can pose challenges to classroom teachers, who have to interpret and respond to student progress in ways that target their learning and problem-solving needs while also adhering to the intent of the PBL learning design (e.g., not always addressing a specific knowledge gap through direct instruction) (Chen et al., 2021). Technology-enhanced approaches can assist in handling these challenges by logging student activities in a computer environment, and then using learning analytics to help teachers visualize student learning and problem-solving behaviors over time. This information can then be combined with orchestration technologies, such as teacher dashboards (Wiley et al., 2020) to develop subsequent instructional plans. However, more research is needed to target the complex task of translating our findings as researchers into a language that classroom teachers can interpret and convert to actionable information (Wiley et al., 2020).

Understanding how teachers use dashboards to develop and apply their evidence-based teaching practices in technology-enhanced curricula is critical for improving teacher support and preparation (Campos et al., 2021; Farrell and Marsh, 2016). This serves as the context for our research. In the study presented in this paper, a researcher (i.e., author 1 of this paper) interacted with eight teachers to understand how they used the Responsive Instruction for STEM Education (RISE) dashboard to assess and respond to students' learning and use of strategies as students worked on building computational models of water runoff in the C2STEM block-based coding environment. Teachers completed a series of five *Planning Period Simulations* that leveraged the co-designed dashboard to track students' learning progress and behaviors. We implemented think-aloud protocols using semi-structured interview questions enabling the teachers to verbalize their thought and evaluation processes (Charters, 2003). Our analyses targeted the following research question: *What processes do teachers use when making decisions by analyzing current student data for customizing subsequent lesson plans?* We conducted inductive analysis and constant-comparative analysis (Charmaz, 2006) to provide initial, exploratory patterns in the reasoning processes teachers used when transitioning from interpretations of student results to selecting evidence-based pedagogical responses, i.e., lesson plan customizations grounded in their domain-specific and pedagogical content knowledge and the student results visualized on RISE. A contrasting case between an experienced and a novice teacher explores and highlights these processes.

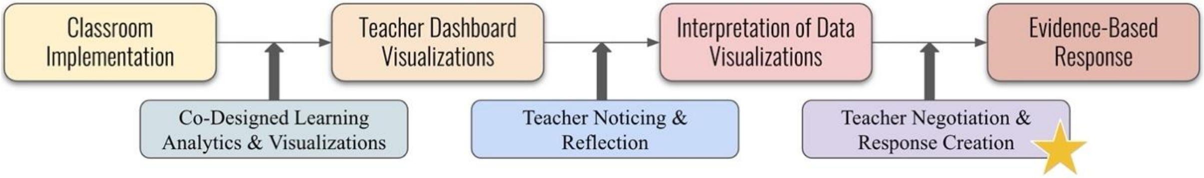
Background

A careful analysis of prior research models representing dashboard-supported responsive teaching identifies key research opportunities identified in Figure 1 (adapted from Campos et al., 2021). The first research area (Figure 1, in green) targets the impact of an educational event in the classroom by visualizing student data on a dashboard. Research in the area has targeted co-design methods for using teacher insights into developing and presenting such visualizations (Wiley et al., 2020), improving transparency in algorithm development (Holstein et al., 2019), and supporting teacher agency in the representations shown on the dashboards (Ahn et al., 2021). In our research, we have implemented a multi-step co-design process for the creation of RISE (Hutchins & Biswas, 2023).

Another research opportunity involves a deeper understanding of how teachers make sense of the information provided on dashboards and how we can support their interpretation processes (Figure 1, in blue). Campos et al. (2021) conducted a study with teachers and educational coaches to examine sensemaking processes and developed a typology of responses to different data visualizations. Others found sensemaking heuristics, which include comparing, monitoring, and exploring by teachers as they leveraged tools to support technology-supported collaborative learning (Voyiatzaki and Avouris, 2014). Molenaar et al. (2019) investigated how teachers make data visualizations actionable. Specific to our work, Chen et al. explored teacher dashboard use to support problem-based collaborative learning at the college level (Chen et al., 2021). Simultaneously, research on supporting teachers' interpretation process for improved decision making has recently received attention. For instance, researchers have evaluated the impact of different interpretive aids on teachers' sensemaking to support collaborative learning (van Leeuwen et al., 2019). Although we do not focus specifically on this research opportunity, we believe a deeper understanding of how teachers transition from learning analytics-based data visualizations to pedagogical decisions can aid in the future development of such tools and resources.

Finally, there is a need to understand how resulting teacher interpretations of dashboard visualization facilitate evidence-based pedagogical actions (Campos et al., 2021). To our knowledge, limited research exists that explores what teachers notice from classroom data and then generate evidence-based responses (identified with a star in Figure 1) to support students' learning and problem-solving strategies for K-12 science PBL curricula. As such, this research provides novel, exploratory findings on example pedagogical responses resulting from the noticing, interpretation, and reasoning about student data during a problem-based, middle school science curriculum.

Figure 1
A dashboard-supported responsive teaching process model



Instructional context

Science Projects Integrating Computing and Engineering (SPICE; spiceprojects.org) is a three- week, NGSS-aligned curriculum unit that challenges students to redesign their multi-functional schoolyard using different surface materials to minimize the amount of water runoff after a storm, while adhering to a set of design constraints (McElhaney et al., 2020). The problem-based learning curriculum consists of five core units. These units include: physical experiments, conceptual modeling, paper-based computational thinking tasks, computational modeling of the water runoff phenomenon, and engineering design, in which students use their computational models to design their schoolyard.

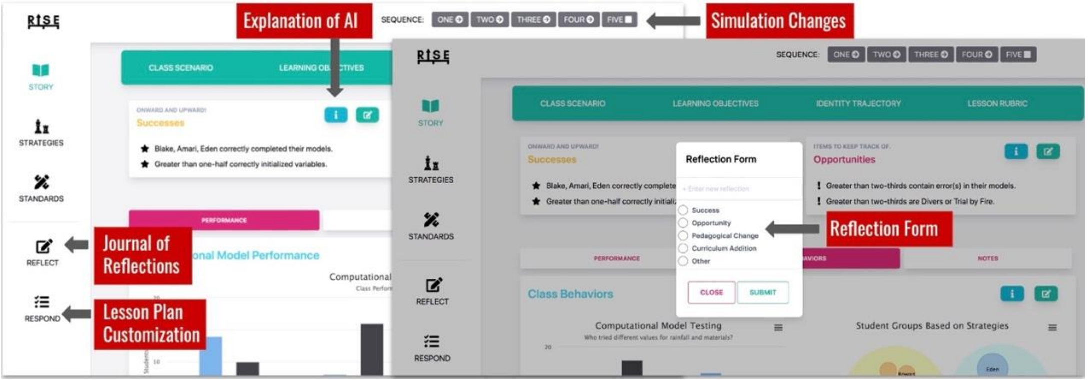
The dashboard simulations in this paper focused on supporting lesson plan customizations during the computational modeling task in SPICE, which were implemented in the C2STEM block-based coding environment (c2stem.org). In this task, students needed to initialize total rainfall and the absorption limit of the material they would test with their computational model. Students were required to construct their computational model with three conditional components corresponding to situations where the total runoff would be greater than, equal to, or less than the absorption limit of the selected material. Students tested their computational models as they built them by clicking on the green flag (similar to Scratch; scratch.mit.edu). Analysis of prior SPICE implementations highlighted the importance of (1) linking students' work during computational modeling to their prior science and unplugged CT work and (2) using productive computational modeling strategies (e.g., testing their models with different values of rainfall and materials) (Biswas & Hutchins, 2022). These findings were used to highlight relevant analytics during co-design of the RISE dashboard with teachers.

Co-designed dashboard components

The co-designed RISE dashboard (Hutchins & Biswas, 2023) consists of three core student result pages. The Story provides an overview of the class performance based on key immediate feedback needs recommended by teachers. This included text-based feedback highlighting class successes and opportunities for improvement based on performance measures (items scored by pre-defined rubrics) and strategies used (productive and unproductive strategies pre-defined based on the impact on student learning results). We included interactive data visualizations, such as the grouping of students based on strategy use with additional performance-based results (bottom right of Figure 2), based on teacher recommendations. The Strategies page provided a progression of student performance over the course of the curriculum (e.g., up to the "day" simulated in each planning period simulation) and their grouping by current strategy use. The strategy groups, e.g., Divers implemented unproductive, depth-first model construction strategies (c.f., Grover et al. 2016), were derived by previous analysis (Biswas & Hutchins, 2022). Finally, the Standards page provided a data table of all students with their scores on each completed curriculum task and identified strategy groups. All data visualizations based on artificial intelligence and machine learning methods include an explanation of the analysis approach to give teachers insight into the underlying mechanisms being visualized (e.g., a modal pops-up with the information when the blue button with an "i" is clicked).

The RISE dashboard is equipped with a Reflection Tool in which teachers can add reflections as they review the results (identified as the "Reflection Form" in Figure 2) and select categories for the type of reflection. Submitted forms were populated on the Reflection page based on the category selected (the page link is identified on the left-side menu bar in Figure 2). In the Reflection page, teachers can re-order and reorganize reflections as they see fit to support teacher engagement. Finally, teachers are also provided with a Response page. This page includes the current class plan for the next class day and tools to plan for any adjustments they deem necessary based on student performance. Teachers have access to a number of curriculum resources that include learning objectives and lesson plans relevant for the "day" to aid in their evaluation process.

Figure 2
Components of the RISE dashboard



★ Blake, Amari, Eden correctly completed their models.
★ Greater than one-half correctly initialized variables.

! Greater than two-thirds contain error(s) in their models.
! Greater than two-thirds are Divers or Trial by Fire.

Reflection Form
○ Success
○ Opportunity
○ Pedagogical Change
○ Curriculum Addition
○ Other

Who tried different values for rainfall and materials?

Methods

Eight middle school STEM teachers (5 female, 3 male) participated in the study. The teachers were from varying urban and rural locations in Tennessee, Illinois, Virginia, New York, Wyoming, and the US Virgin Islands. While all teachers had prior experience with teacher dashboards, four teachers also had prior training and experience in implementing a computational modeling curriculum in their science classrooms, so we labeled them as experienced teachers, and four teachers had no prior training or experience with computational modeling in science, therefore, we labeled them as novice teachers. All teachers consented to participate in the Vanderbilt University IRB-approved study.

Planning period simulations

We focus this paper on five Planning Period Simulations in which teachers enacted five 15 minute "planning periods" by utilizing the RISE dashboard to review and reflect on student, group, and class performance and then developed lesson plan customizations for the "next" class day. These simulations were inspired by the Teacher Moments research at MIT (Benoit et al., 2021). Student data used for each simulation was pulled from prior SPICE studies using an approach similar to the Replay Enactment protocol (Holstein et al., 2019). Student data from the prior implementations were de-identified and students were given gender-neutral names. The five simulations were selected based on class averages in summative assessment performances in science and CT (e.g., one simulation used data from a class that had an above average pre-test performance in science, but below average pre-test performance in CT).

Each teacher first completed a 90-minute professional development session led by the research team in which they learned about the SPICE curriculum. For each simulation, a research team member first described the class scenario, including the class performance on the pretest and other class results prior to the simulation "day" (e.g., performance on the science conceptual models). Using a think-aloud protocol, teachers reviewed student results and feedback provided on the RISE dashboard, interpreted what they saw, and customized class lesson plans for the next day (as they saw fit). Prior research has noted the benefits of think-aloud protocols on tasks involving building interpretations (Charters, 2003; Campos et al., 2021). To obtain verbalizations that accurately reflected the cognitive processes teachers implemented during responsive teaching, we refrained from providing detailed instructions or interpretation of results. Instead, we utilized prompts such as "what possible actions would you take with this group?" and answered questions about technology that did not impact class evaluations (e.g., describing how to use the reflection form). This helped minimize issues concerning bias in data if researcher support or feedback impact teachers' responses (Sherin and Russ, 2014).

Finally, researchers completed an observation sheet during the simulations. The observation sheet consisted of a table for researchers to identify the (1) discussed idea (e.g., computational model scores), (2) visualization targeted, when applicable (e.g., bar graph of class performance), and (3) keywords used or links made (e.g., poor initialization of science variables score during computational modeling relating to prior science performance). These observations were used to support our analysis approach, discussed below.

Data collection and analysis

All Planning Period Simulations were conducted virtually and recorded on a video conferencing platform. In total, we had approximately 12 hours of video data, which we transcribed with an online transcription service. For this paper, we formulated the base unit of analysis by segmenting the transcripts into episodes of pedagogical reasoning (Horn and Little, 2010). An episode of pedagogical reasoning started after the researcher's opening statement about the class scenario and ended when the teacher submitted their customized lesson plan.

We used methods of inductive coding and constant-comparative analysis (Charmaz, 2006) as opposed to theoretically developed codes due to the exploratory nature of the work and a dearth of prior research examining how the resulting interpretations facilitate pedagogical actions. This approach led us to identify catalyzing links that teachers used to transition from their interpretations of AI-generated data visualizations to evidence-based lesson customizations. We develop conjectures about these links and their implications on teacher responses. Team members met to discuss episodes and the links that teachers applied in these episodes. We created analytical memos (Hatch, 2002) to help us then compare teachers' catalyzing links. In the discussion of the links identified, we reviewed the literature on processes that support learning in integrated domains to refine our understanding of the links to help us define the emerging patterns. In the context of the full picture of all pedagogical episodes, we noticed the recurrence of similar patterns as catalyzing links (e.g., supporting learning through multiple, linked representations) and planning period simulations, which suggested patterns exist in the relationship between interpreted classroom needs and class performance distributions.

Results

Utilizing the exploratory analysis process described above on episodes of pedagogical reasoning from all eight teachers, the team identified five key catalyzing link patterns that combined students' learning performance and use of strategies. The teachers utilized these links to support the decision-making processes that transitioned from interpretation of AI-based analysis of students' results to evidence-based lesson plan customizations. These links include: **Supporting Student Understanding Across Multiple, Linked Representations** (MLR; implemented by 4 experienced and 1 novice teacher), **Leveraging Student Successes** (LSS; implemented by 3 experienced and 2 novice teachers), **Representing, Addressing, and Leveraging Productive Failure in PBL** (PF; implemented by 3 experienced and 3 novice teachers), **Weighing responses for different levels of social interactions** (LSI; implemented by 3 experienced and 4 novice teachers), and **Integrating real-world contexts** (RWC; implemented by 2 experienced and 2 novice teachers). We describe each and provide example teacher quotes in Table 1.

Table 1
Identified catalyzing links supporting teacher transitions from noticing to response creation

Link	Description	Example Quote
MLR	Supporting students' understanding across multiple, linked representations (e.g., science, computing, engineering) based on students' performance across multiple assessments and their use of strategies during the computational modeling task	[reviewing Strategy Grouping Figure] *"I'm still thinking about the materials. How to get them to transfer that original [engineering] grid you'd set up so that they have to have different values for the materials. Because it's still more than half [that aren't testing]. I think those overt connections between the lab experiment [in science] and the [computational] model. We make those [connections] implicitly as adults, but I think it needs to be more obvious for a younger brain to connect the model to the real thing."*
LSS	Planning lesson plans to promote future success and/or motivating and engaging students who were not known to be computing enthusiasts or were new to	[reviewing Domain-Specific Score Figure] *"Well, I think in two, you probably need to reflect on the success of the [initializing variables]. Because they did. They were successful for the majority, but I think it would be good to reflect [on that] because that may push them to do better on this, the equal*

	computing (leveraging the “Successes” dashboard feature)	*to condition. Does that make sense? So it’s important to have reflection on initializing variables as a class. Because if you focus on success, it drives success. Rather than say, Oh, y’all did a good job, let’s go on to the next one."*
PF	Understanding, addressing, and utilizing productive failure during PBL to motivate and engage students in the difficult problem-solving process	[reviewing “Opportunities” Text Feedback] *“The other thing that I look at a lot is normalizing mistakes. And so if I would, it becomes tricky. And it really you have to normalize it from the first day. We all make mistakes, but mistakes can help us get better at it and have someone share a mistake related to the materials where everybody looks at it together to figure out."*
LSI	Determining the optimal pedagogical response targeting different levels of social interactions (e.g., lecture, group activity, or individual support)	[reviewing Strategy Grouping Figure] *“When you look at the dashboard, and you see those bigger amounts of needs, that’s when you have to go triage time, and you got to think about okay, I’m gonna have to do something much different here. Because I’ve got a lot of misconceptions. Yeah, that’s where a bigger [class-level] action will occur."*
RWC	Connect the real-world context of the curriculum’s problem to create customizations that support collaborative work and allow for students to reinforce their knowledge	[reviewing Domain-Specific Score Figure] *“Because the whole framing of the problem is, you are a project manager and you’re designing a playground. So you’re gonna work with this team. And you’re, you know, it’s okay that you (a student that finished the computational model first) are a consultant. You are a part of the team that knows computing really well”*

The identified patterns in our exploratory analysis provide an initial framing to understand how teachers transitioned from their data interpretations to evidence-based pedagogical responses. In this section, we explore these transitions in more depth by comparing two episodes of pedagogical reasoning: one by an experienced teacher and the other by a novice teacher. Both cases involve an evaluation of a class that was low performing on the pretest in science, but high performing on the computing pretest.

This first example represents an experienced teacher. After the researcher provided the Simulation Scenario, the teacher began their think aloud process:

> TEACHER: *I always like looking at graphs first…I’m gonna go to that* [reviewing Domain-Specific Score Figure]. *So they had this same problem with initializing their variables. They did better at equal to, and then less than and greater than so not too bad. And this is probably reflecting that they were [science conceptual model group]…So yeah, knowing that, I would say because they did a not so great job here but they did a better job here. So they are getting some of this computing stuff. I would add in a quick physical demo showing the difference between absorption for a sponge and a paper. So they can just understand why they need to test more materials. So let me put in that.*

In this first segment, the teacher linked students’ prior performance in science with issues concerning the initialization of science variables in the computational model. The teacher then checked student behaviors to identify if any other data was available to explain this issue. They then clicked to add a Reflection (a technical issue arose) and the teacher then added a reflection noting they would need to conduct another science demonstration to show the difference between the absorption of different materials to help students understand why they would need the science variables in their computer models. As such, the teacher utilized the process of ***Supporting Student Understanding Across Multiple, Linked Representations*** to generate a possible evidence-based response. At this point, the teacher had only viewed bar graphs illustrating the number of students who got initial variables and the conditions correct and the number of students who tested more than 2 materials. The teacher continued.

> TEACHER: *TEACHER: Let me look at behaviors* [reviewing the Computational Model Testing Figure seen in Figure 2]. *So yeah, I think that I’m going to add [a reflection]. So this is an opportunity [for students[to see more physical examples. So I think that’s really important. Because they did a better job here. And yeah [reviewing the Student Groups Based on Strategy figure in Figure 2], we’ve got a lot of* [bad CT strategy group]. *So we need to fix that again. And I’m going to add an activity. Let’s do Palmer. So they’re gonna show and talk through their*

> *code. I think this is the nicest thing. I'm going to tell you why I like this…what I'm trying to do as a teacher is I am trying to get kids to be more* [good CT strategy group] *and getting comfortable with coding… So seeing who's doing those techniques is really going to help me and then seeing who changes because sometimes in the moment, I'm only picking on the kids that I know are strong in CT, to show examples. And I think that can be a bit demoralizing for other students. So like as this goes on, let's say Kendall, all of a sudden jumps* into [good CT strategy group] *or something like that, that's like a great thing. But if I'm able to see like, someone made the jump from here to here, I can then highlight them and hopefully give them as you know, some nice positive praise, reinforcement kind of thing that I think would be really helpful.*

In this segment, the teacher further acknowledged the need to understand why testing different materials, now from the perspective that a lot of students did not test their computational models. The teacher connected science practices and computational practices, and in addition to conducting the science activity, she elected to do a class presentation in which a student was selected to demonstrate their code and testing practices. Using the ***Leveraging Student Successes*** approach, the teacher selected a student who changed to a more productive strategy group to promote the students' good work and improvement. The teacher concluded with their customized lesson plan:

> TEACHER: *All right. So we still have the initializing variables, and the two thirds are [bad strategy group]. Okay, so I think let me go to reflect. Yeah, so I think having that physical example is really important for this class. And then maybe Palmer you know, maybe I bring in Palmer towards the end of class instead, for this group, and it because maybe the physical demo will help more. And then I can add Palmer in to wrap up.*

To address a conceptual issue regarding initializing variables and poor strategy performances by the class, this teacher used the processes of ***Supporting Student Understanding Across Multiple, Linked Representations*** and ***Leveraging Student Successes*** to determine and finalize an evidence-based lesson plan customization.

In the second example, we discuss a novice teacher presented with the same class simulation. The teacher utilized the links ***Weighing Responses at Multiple Social Levels*** and ***Integrating Real-World Contexts*** to create an evidence-based customized lesson plan for the class. The episode began with the teacher reviewing the Computational Model Testing Figure (seen in Figure 2) and identifying a class issue:

> TEACHER: *Would it help to have samples of those materials on display in the classroom? Are they already doing that?*
> RESEARCHER: [researcher describing that materials are available]
> TEACHER: *I mean, it looks to me that the biggest need for the next day is to address the materials portion. And I like that this makes it clear.*

The teacher began with a curriculum question about the availability of physical materials. The teacher identified that the lack of testing the computational model with different materials was a problem. The teacher continued:

> TEACHER: [reviewing the Student Groups Based on Strategy figure, Figure 2] *And I always worry about those students in the classroom who are done. Okay, now, what do you do now that you're done? I would be assigning them to work with someone who needed more support, so day Reese is going to be an expert. You can consult an expert with your work and bring in a consultant. And you can ask them three questions.*
> RESEARCHER: ... [researcher agreement]
> TEACHER: *You got to explain. But I would put a constraint on it. I think that's a challenge, that's why this could be really valuable to know that they're completed… But kind of put a constraint on it, like, you can only ask a consultant a question, they can't just tell you stuff. Yeah. And it can't be a question like, how do I write the code? Yeah.*

In this segment, the teacher applied Weighing Responses at Multiple Social Levels to reason about a potential lesson plan customization. The teacher also utilized pedagogical content knowledge (the consultant activity was described by the teacher in prior discussions during SPICE training) to determine a productive response. In discussing the idea further, the teacher said:

> TEACHER: *And this I think, I like also, because you can see who needs the most support. Yeah, you know, that they're kind of stalled … I like looking at the written feedback that you're pinpointing, you know, where there are opportunities, but that can also help you target the consultant. Yeah. I like that, because the whole framing of the problem is, you are a project manager and you're designing a playground. So you're gonna work with this team. And you're, you know, it's okay that you're a consultant. You are a part of the team that knows the computing really well.*

In this segment, the teacher described the opportunity presented by this pedagogical approach - being able to listen in on what consultants (students that finished the code) and project managers (in-progress students) were saying during this paired activity to identify students that may need additional support. The teacher reasoned about the choice of lesson activity by ***Integrating Real-World Contexts***. The teacher concluded:

> TEACHER: *Yeah, I think this is kind of invaluable. Alright, so the lesson plan is [coming together] I think the lesson plan for this is more, we'll have the consultants and the students that need work will create the three questions. And yeah, to have more complete testing behavior. Make sure everyone has like I also call them experts. calling you an expert. I do let them [talk to me] if they're stuck, I do become a spy but, don't do that often there.*

The teacher reiterated the response reasoning and acknowledged the underlying, student-centered design of the curriculum by noting that they should intervene when necessary but limit the number of interventions.

Comparison of the two teachers demonstrates key catalyzing links implemented by the experienced versus the novice teacher and highlights the differences in their approaches. For this simulation, the experienced teacher utilized the catalyzing links of ***Supporting Student Understanding Across Multiple, Linked Representations*** and ***Leveraging Student Successes*** to determine their lesson plan customizations, while the novice teacher utilized ***Weighing Responses at Multiple Social Levels*** and ***Integrating Real-World Contexts*** in their lesson plan customization. This seems to indicate that the experienced teachers leveraged their experience and comfort with the curriculum and technology (i.e., domain-specific knowledge) to notice and focus on multiple dimensions of student learning, while the novice teachers may have compensated for their lack of SPICE experience by leveraging their pedagogical content knowledge in PBL to discuss curriculum changes (e.g., discussing normalizing mistakes in Table 1, link PF), deciding on social level responses as gaps grow between groups of students, and leveraging the real-world context of the problem. We believe these results extend on Campos et al.'s (2021) findings by pointing to potential future research in (1) exploring how the provision of different types of teacher-created responses utilizing different catalyzing links post-simulation can help experienced and novice teachers critically reflect on their response choices and discuss how they might change, if at all, and (2) developing tools to aid in teachers' noticing by interpreting the complex learning analytics (e.g., van Leeuwen et al. 2019) that target their background and experience.

Results

This research presents a novel exploration into the processes teachers take from noticing and interpreting learning analytics from a co-designed dashboard to reasoning and enacting evidence-based pedagogical adjustments through lesson plan customizations. In particular, this exploratory work provides a preliminary framework for identifying and evaluating catalyzing links teachers implement to decide and create evidence-based pedagogical adjustments based on AI-based analyses of student learning and problem solving. Distinct from prior work in technology-enhanced responsive teaching (e.g., alerting teachers of individual student errors or disengagement) (Holstein et al., 2019; Van Lehn et al., 2021), these examples demonstrate that the dashboard supported teachers in implementing class activity that (1) increased class or group discussions and (2) supported the development of productive problem-solving strategies, both key for supporting PBL curricula.

We recognize limitations in our work. On the one hand, the low number of teacher participants in this study resulted in analyses focused on depth instead of breadth. Future work should increase the participant cohort to further validate our results and to ensure that teacher preparation is inclusive and supports equity in PBL applications. In addition, in terms of the selection of classes for each simulation, we recognize a limitation in the use of a high- vs low-performing dichotomy in the selection of classes as that approach may not fully represent the nuances of learning and problem-solving behaviors from a classroom context. Future work in selecting data for simulations (and co-design) can evolve more nuanced approaches to evaluating classes, groups within classes, and individual students. Finally, we aim to complete a full, iterative cycle in which the participating teachers will implement SPICE (supported by the RISE dashboard) in their classrooms to holistically examine the dashboard impact on lesson plan customizations and implementations.

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Epistemic Excursions as Agentive Meaning Making within a Digital Plate Tectonics Curriculum

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Abstract: Models and modeling are essential for mediating knowledge-building processes about geologic phenomena (Stillings, 2012). We draw on constructs of expansive learning (Engeström, 1987) and personal excursions (Azevedo, 2006) to analyze a case in which two secondary students develop geologic explanations using Seismic Explorer, a tool for visualizing information about earthquakes and volcanic eruptions. We present four episodes in which the focal students conjecture and test ideas through modeling plate tectonics phenomena. Using methods of interaction analysis (Jordan & Henderson, 1995) we describe how the students actively build and revise their moment-by-moment explanations. Our analysis contributes to a deeper understanding of how the design of geologic models and data visualizations for classroom contexts can support sensemaking as a kind of journeyed relationship-building with the phenomena, associated data, and with peers, through relational events that we term *epistemic excursions*.

Introduction

Making sense of geologic phenomena—including plate tectonics, global oceanic and atmospheric patterns, and other cycling of matter requires reasoning about systems that are distributed across vast spatial and temporal scales (Anderson, 2006; Herbert, 2006; Stillings, 2012). Developing understandings of earth science requires learners' competence in thinking about complex interrelated behaviors of Earth's systems. Earth science educators can use models and simulations to make phenomena accessible at more human scales, bringing the challenges of large spatial data sets and massive time scales into manageable forms, especially for learners in classrooms (e.g., LaDue & Clark, 2012; Stillings, 2012).

Expansive learning (Engeström, 1987; Engeström & Sannino, 2017) accounts for processes of human learning in which participants create new targets of learning as the interaction unfolds. As explained by Engeström and Sannino (2017), learners "construct a new object and concept for their collective activity, and implement this new object and concept in practice" (pp. 48 - 49). This is in contrast to vertical movement toward prescribed learning goals that characterizes many school learning environments. With the metaphor of expansion in mind, we investigate two high school earth science students' work in an online learning module about plate tectonics. We are interested in deeply describing how they came to engage in a spontaneous process of epistemically-rich activity using an interactive computer-based data visualization of geologic phenomena. We are especially interested in the ways that students use and relate to models, specifically data visualizations, to approximate legitimate professional geological practices. We draw on episodes in which students display epistemic agency (e.g., Miller et al., 2018) in conjecturing and testing ideas through modeling plate tectonics and actively revise their explanations based on information generated from their interactions with models of data. We describe the ways that they attempt to develop model-based explanations of geologic phenomena through four epistemically meaningful personal excursions (Azevedo, 2006). Our analysis seeks to answer the following research questions: *How do excursions with geologic modeling and visualization tools begin and unfold? In what ways are the excursions fruitful for students' agentive work to build, test, and refine geoscientific explanations through interaction with models and with one another?*

Theoretical background

Modeling is central to professional geoscientists' understanding of geologic phenomena (Stillings, 2012). For more than 30 years, learning environments have leveraged computing tools for students to engage in modeling (e.g., Wilensky & Resnick, 1999) and use of data visualization software (e.g., Lee & Wilkerson, 2018) as activities for learning in many scientific domains. Model-based reasoning, at its fullest, requires learners to engage with content through production of scientific knowledge, so that the ideas and explanations that the models represent are "testable, revisable, explanatory, conjectural, and generative" (Windschitl, et al, 2008). Explanation-building across multiple sources of evidence is at the core of the work of geoscience. However, orchestrating learning environments in which students enact epistemic agency in proposing, testing, and revising evidence-based explanations using modeling practices remains a central challenge in science education (Russ & Berland, 2019; Windschitl et al., 2008). As argued by Hall (1996), discursive theory-building exchanges can be especially generative for understanding how learners develop competencies for the production of knowledge, especially in discipline-specific contexts.

In geoscience especially, phenomena of study often occur at very large scales of time and space (Herbert, 2006). For instance, scientists have difficulty directly engaging with mountain building in real time as it occurs beyond the scope of a human's lifetime. As a result, plate movement and mountain building have traditionally been taught using historical second-hand data (data collected by others) over long periods of time. While many may argue that first-hand data collection is more meaningful for learners and representative of geoscience practice, Lee and colleagues (2021) have demonstrated that "students do engage data collected by others in deeply personal ways" (p. 664). Learners' work with second-hand data requires complex engagements on several layers: personal, cultural, and sociopolitical (Lee et al., 2021). On a personal level, learners relate to their direct experiences with data and measurement. On a cultural level, learners recognize routines of practice and technologies associated with a data set's collection and use. Finally, on a sociopolitical level, learners recognize political narratives that may influence how data is interpreted and used.

Learning scientists have demonstrated that data science education becomes more meaningful and equitable when students experience data science as relational work (Wilkerson & Polman, 2020; Rubin, 2020). Students build relationships with the data they are working with in order to locate themselves in relation to the data and to "see" the data from the perspective of others (e.g., other students). They make personal connections, ask questions, and generate their own ideas based on data. These relationships are embedded in the specific context of the data, knowledge about the larger domain (e.g., geology), and the concepts that exist in the interaction—which are often tentative and not fully worked out. A relational view of learning in activity gives way to contexts of expansive learning (Engeström, 1987). Relationships with and to the object of study forge pursuit of individual interests, what Azevedo (2006) has termed personal excursions. Personal excursions are diversions from the initially framed activity that generate a second activity—that is, an excursion. This second activity may bring forth meaningful connections to the original goals. It is through these personal excursions that many students develop and extend connections between the content of learning activities and their own identities and interests, often positively impacting learning along stated learning goals (Azevedo, 2006; Farris & Sengupta, 2016). Personal excursions allow students to build "pragmatic, conceptual, and question-generating resources so that more extended, coherent personal pursuits are possible and more likely to take place" (Azevedo, 2006, p. 93).

Methods

The context of this study concerns learning within an interactive Plate Tectonics curriculum (https://learn.concord.org/geo-platetectonics), part of the Geological Models for Explorations of the Dynamic Earth (GEODE) project. Approximately twenty 10th and 11th grade students, along with their teacher, engaged with the curriculum within their earth science class in a public school in the Southeastern U.S. The duration of this instructional unit was approximately ten class periods of forty minutes each. We analyze video and audio recordings from one focal teacher's classroom. Students worked in pairs on one laptop. The teacher selected three pairs for recording. The teacher's selection was based on consistency in attendance and the likelihood that the students would share their ideas with one another through talk. Recordings were generated using the embedded laptop camera and microphone. Students' screens were recorded using QuickTime Player.

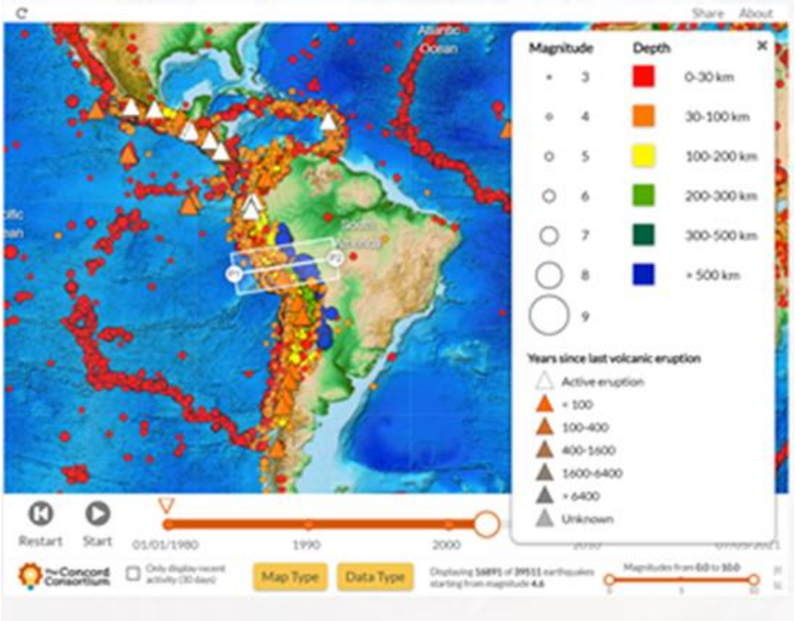
In this interaction analysis (Jordan & Henderson, 1995), we seek to understand how one pair of students––Noah and Zach—work beyond the curricular prompts to ask questions that are personally meaningful to them. We selected these students as focal students based on their talkativeness and consistent attendance. We first synchronized the screen capture and student video data to create multimodal transcripts of key moments of interaction. We describe the practices through which they share tentative sensemaking knowledge and engage in a spontaneous pattern of proposing, testing, and revising evidence-based explanations using the digital representations in the curriculum. We highlight four episodes of interaction, selected because they illuminate the ways in which Noah and Zach generate geoscience explanations as relational and sensemaking work. The episodes concern the students' conjecture relating mountain formation to volcanic activity (Episode 1), their emergent theory that seismic activity follows the leading edge of continent movement (Episode 2), their proposed mechanism of earthquake depth (Episode 3), and their explanation for the formation of the Andes Mountain range (Episode 4). These occurred on Days 2 and 3 of the 10-day curriculum.

The model: Seismic Explorer

The Plate Tectonics curriculum includes Seismic Explorer, an interactive data visualization tool. Seismic Explorer (Figure 1) is a time-oriented data visualization of earthquake epicenters, volcanic eruptions, and plate movements.

Students can view location, depth, magnitude, and frequency of earthquakes on a two-dimensional map of the world as well as in a three-dimensional cross-section. Other data included within Seismic Explorer is direction of tectonic plate movement and volcanic eruption data. We characterize Seismic Explorer as both a data visualization and a computer-based model of geologic information. The Plate Tectonics curriculum was intentionally designed to use the Seismic Explorer iteratively in support of student problem solving related to key driving questions.

Figure 1
Seismic Explorer representing volcanic eruptions and earthquake epicenters in the Andes Mountains. Students can create a cross-section as shown by the rectangular selection marked in white.



Analysis and findings

In this section, we follow four episodes that illustrate how Noah and Zach relate to models and data representations in order to sensemake within plate tectonics. In these episodes, they are at the point of the curriculum in which they are working to develop an understanding of plate interactions through historical data about plate tectonics. Each of these episodes constitutes an excursion from the prescribed activities in the curriculum, characterized by building relationship with the phenomena, associated data, and with peers. Drawing on existing work on students' epistemic agency (e.g., Miller et al., 2018) and personal excursion (Azevedo, 2006), we have termed these events *epistemic excursions*.

Epistemic excursion 1: Testing ideas of phenomena against local connections

In this episode, Noah and Zach are working with Seismic Explorer to describe the location of volcanic eruptions in the Andes Mountains, as prompted by a question in the online curriculum. Noah immediately notices that "they [the volcanoes] go along the Andes Mountain range," (see Figure 1) and Zach suggests manipulating the map to "go back up and see if any volcanoes are near the Appalachian Mountains and the Rocky Mountains." The students live within the Appalachian Mountain range. Zach recognizes that volcanoes and mountains are both located in the Andes, prompting the idea that volcanoes are associated with mountains.

Noah and Zach proceed to test the idea that volcanoes occur along mountain ranges. They use Seismic Explorer to examine volcanic history in the Appalachians and Rocky Mountains. They claim that the Appalachian Mountains are "clear [of volcanoes]" and the Rocky Mountains have "a little bit [of volcanoes]." We see this as a form of seeking coherence between curricular questions about the Andes and personal knowledge about other mountain ranges. Through this exploration of the data visualization, they conclude that there is no record of "active" volcanic activity in the Appalachian Mountains and minimal volcanic activity near the Rocky Mountains, contradicting Zach's initial theory that volcanoes are closely associated with mountain formation. This episode represents an excursion in which Noah and Zach seek to relate the correlation between mountain formation and volcanoes in the Andes Mountains to the Appalachian Mountains (where they live) as well as the Rocky

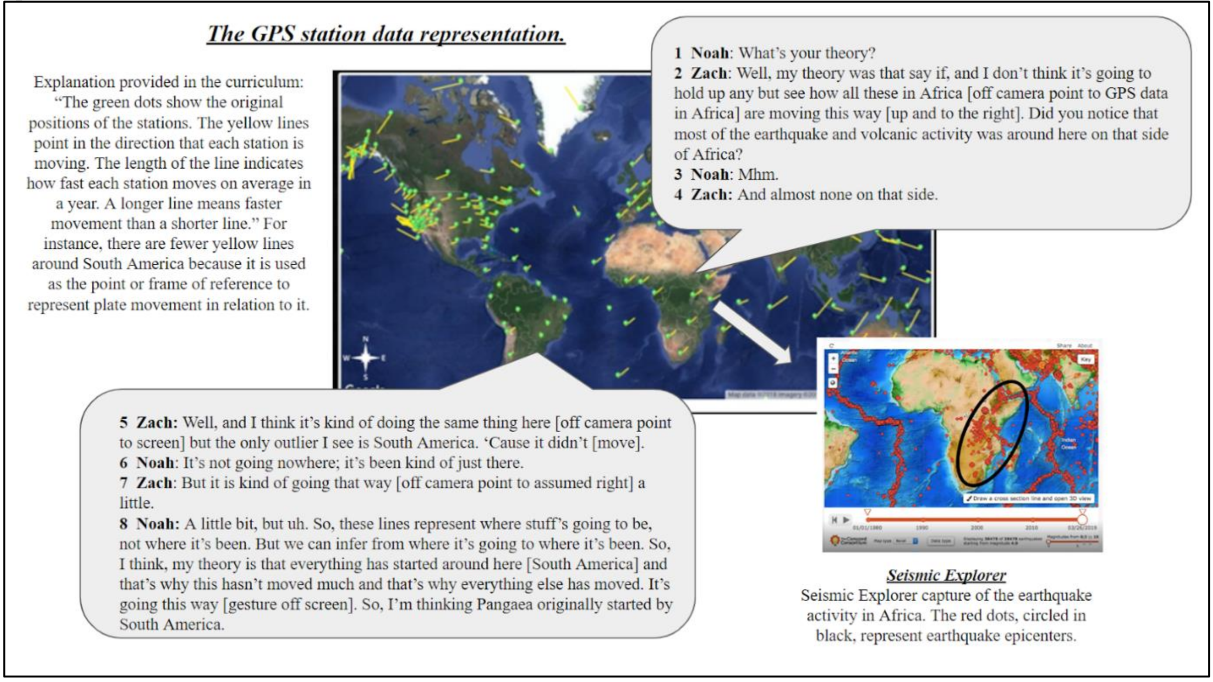
Mountains (which they have heard about). Noah and Zach begin to build a relationship to the data in which they test their emerging ideas in connection to geographies that are personally and contextually relevant to them.

Epistemic excursion 2: Presenting and refining personal theories across models

In this episode, we follow Noah and Zach's theory building talk across two days. Noah and Zach worked with Seismic Explorer to describe the patterns of earthquakes and volcanic eruptions in the Andes Mountains, as prompted by a question in the online module. Zach deviates from the exploration of the Andes Mountains and has Noah zoom in to only view the earthquake activity in Africa. After viewing this, Zach exclaims, "Ooh, I think my theory might be holding up." Noah prompts him to explain what he means. Zach says "okay, now my theory is…see Africa's going that way, right?" (see Figure 2). Zach points to the Southeast coast of Africa as he continues: "Look where all the volcanoes and earthquakes are. They're on this side." Zach has Noah then revisit South America and they compare the pattern in Southeastern Africa to South America. Noah asks "…so the way they are going determines where the earthquakes are?" to which Zach confirms "that's the theory so far." The class period ends, interrupting further discussion.

As soon as Noah and Zach begin working the next class day, they pick up the discussion of their "theories" (their word for initial claims). Zach decides he wants to test his theory developed from Seismic Explorer during the previous day against a model they saw earlier in the curriculum, the GPS station map (see Figure 2). Figure 2 shows how Noah and Zach built a "theory"—that is, a scientific claim—through talk and action as they revisit their initial ideas and this earlier representation of GPS motion data. Zach clarifies and justifies to Noah his claim that the direction and relative movement of the GPS station data suggests where volcanoes occur and adds earthquakes to his explanation. He points to the yellow traces of northeasterly station movement in Africa to convey his thinking. In Turns 2 – 7, Zach indicates that there is almost no movement in South America, highlighting the important information related to his unfinished ideas about mountain formation.

Figure 2
Epistemic Excursion 2



The GPS station data representation.

Explanation provided in the curriculum: "The green dots show the original positions of the stations. The yellow lines point in the direction that each station is moving. The length of the line indicates how fast each station moves on average in a year. A longer line means faster movement than a shorter line." For instance, there are fewer yellow lines around South America because it is used as the point or frame of reference to represent plate movement in relation to it.

1 **Noah**: What's your theory?
2 **Zach**: Well, my theory was that say if, and I don't think it's going to hold up any but see how all these in Africa [off camera point to GPS data in Africa] are moving this way [up and to the right]. Did you notice that most of the earthquake and volcanic activity was around here on that side of Africa?
3 **Noah**: Mhm.
4 **Zach:** And almost none on that side.

5 **Zach:** Well, and I think it's kind of doing the same thing here [off camera point to screen] but the only outlier I see is South America. 'Cause it didn't [move].
6 **Noah:** It's not going nowhere; it's been kind of just there.
7 **Zach**: But it is kind of going that way [off camera point to assumed right] a little.
8 **Noah:** A little bit, but uh. So, these lines represent where stuff's going to be, not where it's been. But we can infer from where it's going to where it's been. So, I think, my theory is that everything has started around here [South America] and that's why this hasn't moved much and that's why everything else has moved. It's going this way [gesture off screen]. So, I'm thinking Pangaea originally started by South America.

Seismic Explorer
Seismic Explorer capture of the earthquake activity in Africa. The red dots, circled in black, represent earthquake epicenters.

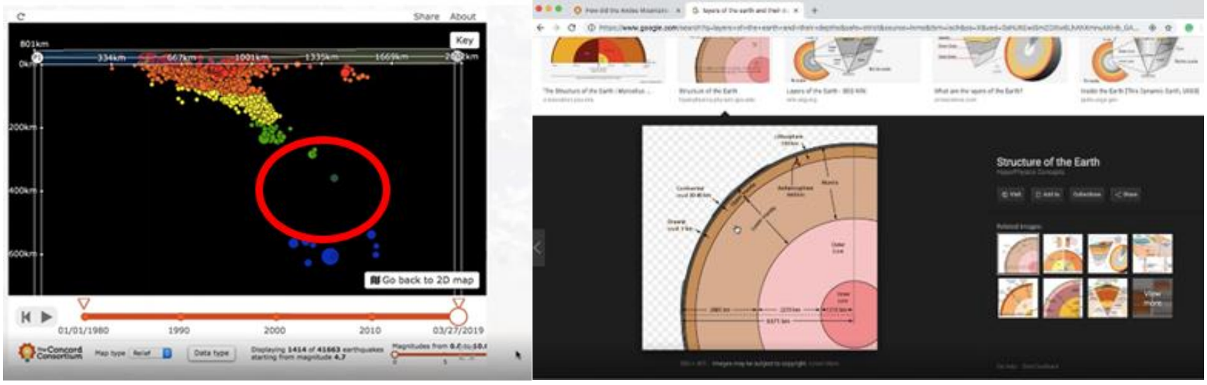
This explanation fuels Noah's own developing theory, arising from their return to the GPS station data. Referring to the relative movement and direction of continents, Noah proposes that the initial location of Pangaea (Turn 8) was around the current location of South America. However, we note that Noah and Zach's initial conceptions were based on their misinterpretation of the GPS station map as they did not consider that in order to identify movement, something needs to serve as a point of reference. The data points in South America indicate no movement because South America is the frame of reference. However, the students interpret the representation to mean that South America is stationary. However, this misinterpretation still promotes interesting theory-building conversation, even though it leads the students to an explanation that does not reflect the widely accepted perspectives of geoscientists. Our focus here is not that students develop normative explanations instantaneously while working with models, but that they iteratively test and refine their emergent theories as they move towards more sophisticated explanations and starting points for further development.

This episode highlights how Zach and Noah worked through two related instances of theory work: (1) the direction and relative movement of plates and (2), the spatial origin of Pangaea. In the first theory work, they relate their current thinking about the location of earthquakes and volcanic eruptions, which are represented in Seismic Explorer, to the relative direction and movement of tectonic plates using the GPS station representation. While the curricular questions are focused on the Andes Mountains, Noah and Zach explore other areas of the world through Seismic Explorer to gain insight on additional geologic data, such as earthquakes in Africa. This suggests that they understand that it may be useful to use information beyond the specific place-based phenomenon in the question. They choose the southeastern coast of Africa as a similar case and generate a comparison. This investigation allows the students to relate to their own personal ideas and examine a theory that Zach has regarding patterns of earthquakes and volcanic activity using Seismic Explorer. They then proceed to work on a related theory about the origin of Pangaea, against another visualization of geologic data that they had engaged with earlier in the curriculum. Noah and Zach refine their theories after discussing the GPS station map, in which the discussion leads to the development of a new theory, one initiated by Noah. Noah uses the GPS station map to "theory build" about the initial location of Pangaea, suggesting that it originated around South America due to its lack of movement. This connection to Pangaea is not part of the curriculum, suggesting that their interactions with these visualizations also prompt connections to prior knowledge. The pair iteratively relate to the personal questions that they have and to other sources of data in order to support their claims.

Epistemic excursion 3: Meaningful inquiry and connections, non-canonical ideas

In this episode, the pair return to the curriculum prompts. They use Seismic Explorer to create 3D cross sections, shown in Figure 3, in order to see the depths and magnitudes of earthquakes along the Andes Mountains as directed by the curriculum. However, Noah and Zach recognize a "gap" in the number of earthquakes at certain depths below the Andes (typically between 350-500 km below the surface). Unprompted by the curriculum materials, they question why there is a lack of earthquakes in this "gap" and wonder if this phenomenon can be explained by the layers of the Earth. Noah then seeks out a reference from outside the curriculum, using a new browser tab to search for images of the layers of the Earth. Noah asks, "what layer of the earth is that far below ground?" to which Zach responds, "you have the crust, the mantle, outer core, inner core or at least that's what I know." They continue as they investigate by clicking on several images of the layers of the Earth. Noah exclaims, "this [the gap of earthquakes] is all happening around the upper mantle." Zach then adds "that's magma, it's molten rock. What's the core supposed to be like? Nickel? Was it nickel?" The two students then debate whether the core is solid material or not, since "the core's really high pressure and heat," before returning again to the task directed by the curriculum.

Figure 3
The "gap" circled in red & a sample internet image that the pair reference.



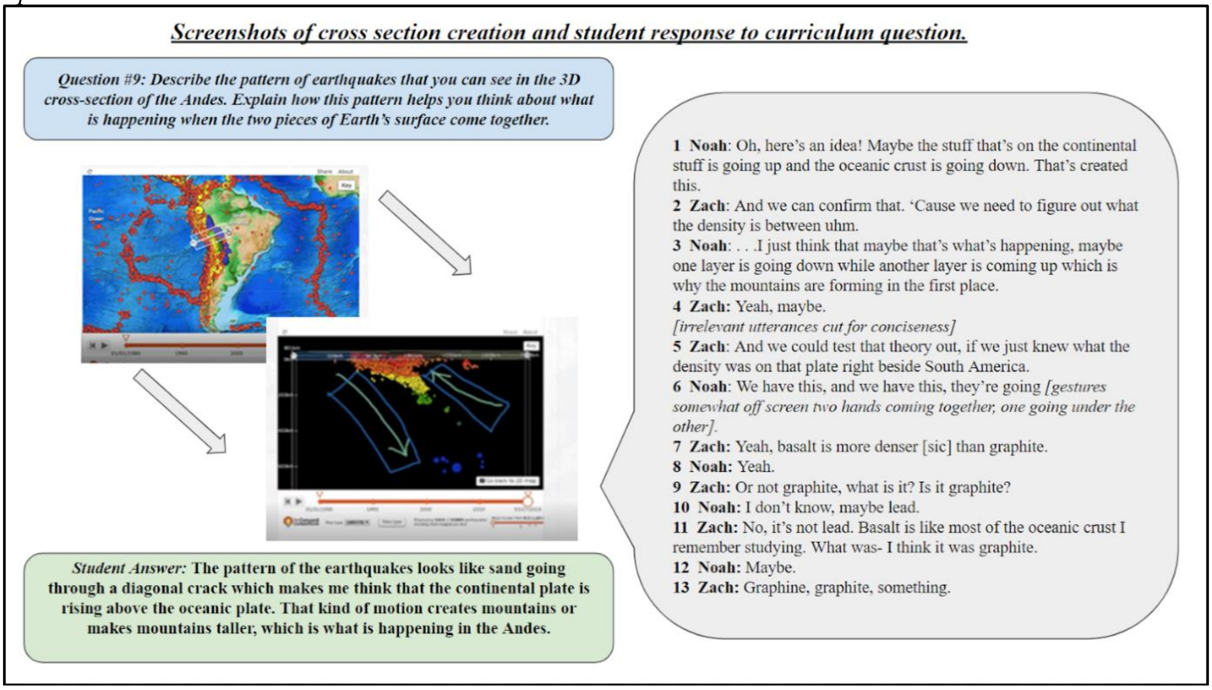
We see in this episode that Noah and Zach seek to investigate a question that is elicited by the earthquake data in Seismic Explorer. The two recognize a pattern within the cross section that there are relatively no earthquakes. They specifically relate this data-prompted investigation to their prior knowledge of the layers of the Earth. They iteratively seek to make sense of what they are seeing within the model by reaching out and referencing outside information found in their spontaneous internet search. They engage in talk about their knowledge of the layers and attempt to reach a shared understanding of the makeup of the upper mantle. This episode highlights Zach and Noah's attempts to connect existing knowledge resources about the layers of the Earth and their relative depth to earthquake activity as they work towards generating and refining shared explanations.

Epistemic excursion 4: Expansive learning full circle

The next task in the Plate Tectonics curriculum is to use Seismic Explorer to create a cross-section of earthquakes occurring underneath the Andes Mountains, prompting Noah and Zach to "describe the pattern of earthquakes that you can see in the three-dimensional cross-section of the Andes. Explain how this pattern helps you think about what is happening when the two pieces of Earth's surface come together." Figure 4 shows the selected area of the Andes Mountains using Seismic Explorer, a snapshot of Noah and Zach's cross-section, and their associated talk. The students call the two relevant tectonic plates "pieces," and specifically refer to them as the "continental stuff" and the "oceanic crust" [Turn 1] as the term "plate" is formally introduced after this task.

While looking at their cross-section, the students recognize that the trend line of the earthquake events likely corresponds with the boundary between the two plates. In cross-section view, the plates and their boundaries are invisible (see Figure 4). Noah verbalizes his idea that as the two tectonic plates converge, the continental layer (on the right side of the trend of earthquakes) is going "up" while the oceanic layer (on the left side of the trend of earthquakes) is going "down" (Turn 3). Zach then offers that they could test their theory about this relative movement if they knew the densities of the two plates to determine which plate is denser (Turn 5) and would subduct under the other. In Turn 6, Noah gestures with two hands to mimic how they expect these plates to interact, with one going under the other. In Turns 7-13, Zach and Noah discuss the geologic makeup of the oceanic plate in terms of density. As they continue to work out this idea, Noah inscribed two yellow arrows on their screen (See image of arrows on graph snapshot of cross-section in Figure 4) on each side of their earthquake depth model to represent this movement trend.

Figure 4
Epistemic Excursion 4



Screenshots of cross section creation and student response to curriculum question.

Question #9: Describe the pattern of earthquakes that you can see in the 3D cross-section of the Andes. Explain how this pattern helps you think about what is happening when the two pieces of Earth's surface come together.

Student Answer: **The pattern of the earthquakes looks like sand going through a diagonal crack which makes me think that the continental plate is rising above the oceanic plate. That kind of motion creates mountains or makes mountains taller, which is what is happening in the Andes.**

1 **Noah**: Oh, here's an idea! Maybe the stuff that's on the continental stuff is going up and the oceanic crust is going down. That's created this.
2 **Zach**: And we can confirm that. 'Cause we need to figure out what the density is between uhm.
3 **Noah**: . . .I just think that maybe that's what's happening, maybe one layer is going down while another layer is coming up which is why the mountains are forming in the first place.
4 **Zach:** Yeah, maybe.
[irrelevant utterances cut for conciseness]
5 **Zach**: And we could test that theory out, if we just knew what the density was on that plate right beside South America.
6 **Noah**: We have this, and we have this, they're going *[gestures somewhat off screen two hands coming together, one going under the other]*.
7 **Zach:** Yeah, basalt is more denser [sic] than graphite.
8 **Noah:** Yeah.
9 **Zach:** Or not graphite, what is it? Is it graphite?
10 **Noah:** I don't know, maybe lead.
11 **Zach:** No, it's not lead. Basalt is like most of the oceanic crust I remember studying. What was- I think it was graphite.
12 **Noah:** Maybe.
13 **Zach:** Graphine, graphite, something.

This episode illustrates how Zach and Noah draw on their experiences with Seismic Explorer to build a normative explanation of tectonic plate subduction in the Andes Mountains. But what makes this expansive? Similar to Episode 2, Noah and Zach draw upon shared terminology that is not introduced at this point within the curriculum, including scientific language related to plate composition and density. They garner one another's' support for the development of a theory of subduction, which, while normatively correct for this plate boundary, is beyond the intended curricular goal of this question, which was asking students to focus on the patterns evident in the depth of earthquakes that occur along the mountain range. They draw on knowledge from some experience that was not part of the Plate Tectonics curriculum concerning the ocean crust being made of basalt, which is going down (subducting) under the less dense continental plate. This episode illustrates students' use of the visualization tools within the modeling environment to examine patterns in the depth of earthquake events, and secondly, to begin to explain the phenomenon at the convergence. The match between the representational affordances of the environment and the prompt to guide what students were supposed to do with the environment supported the students to realize normative key concepts in a process of refining theories of geologic phenomena. We argue that each of these resources contribute to their decision to highlight the relative density of the plates as a key causal mechanism of plate subduction.

Discussion and conclusion

In order to craft geoscientific explanations, learners build relationships with the data they see and their sensemaking talk across representations. For Noah and Zach, using the interactive computer-based data visualization tools of Seismic Explorer and the GPS station map to think about complex geologic phenomena is a process of iteratively making, testing, critiquing, and refining explanations of what they notice. In each of the episodes, we have highlighted how Noah and Zach relate to the data directly or are prompted to relate based on their own personal excursions adjacent to or outside of the designed module. They often deviate from the curriculum to sensemake with their own emergent inquiries and curriculum-driven questions. Across these episodes, we have illustrated that Noah and Zach seek to relate to varied intertextual resources—including other models within and outside of the Plate Tectonics curriculum, their own personal geographical connections, and other existing knowledge resources—in order to sensemake around geologic data visualizations. They search to investigate their own questions as they relate to the data. In doing so, they establish their developing theories by drawing out naïve understandings and scientific language, exploring their emerging ideas within Seismic Explorer, and testing these ideas against additional interactions with the tools within the curriculum. The varied visualizations in which the students interact serve to drive forward their proposal of new explanations. Their shared theory building about geologic data transcended the given dataset and tools, yet approximates (Grossman, et al., 2009) ways that professional geoscientists leverage modeling environments (Bokulich & Oreskes, 2017; Stillings, 2012). In sum, Noah and Zach sensemake across data models, personal experiences, and their own ideas to form a disciplinarily acceptable explanation of a process of subduction near the Andes Mountains.

We argue that the fruitfulness of Noah and Zach's interaction in these episodes is largely driven by the freedom and sense of agency with which they tested tentative ideas against external sources. They demonstrate a high level of epistemic agency to draw upon additional sources and investigate their own questions. This process of relating to each other and relating the curriculum to other sources and experiences drives their sensemaking, which we argue, is instrumental in supporting their progress along disciplinary learning aims. Furthermore, we also note that many of the sources and experiences that Noah and Zach spontaneously relate to the curriculum were "conceptually risky," meaning that they were loosely connected to the phenomenon by analogy and or inference creating an indirect path toward canonical ideas.

Our focus here is not that students develop normative explanations instantaneously while working with models, but that they can iteratively test and refine their emergent theories as they move towards more sophisticated explanations. Epistemic excursions, as we have illustrated, were highly unpredictable. A real-time observer would have been unlikely to predict how these episodes were going to unfold. The "ends" of excursions were inconsistent in the degree that they led to disciplinarily key ideas about geologic phenomena. Excursions 1 and 3 contain sensemaking resources that are quickly and wisely abandoned. If analyzed in isolation, they could be deemed rabbit holes or even off-task work.

Our analysis contributes to a deeper understanding of how the design of geologic models and data visualizations for learning can support sensemaking as a kind of journeyed relationship building with the phenomena, associated data, and with peers. In these episodes, the supports of the curriculum and collaboration fostered generative epistemic practices in questioning and modeling geologic phenomena. The cases, furthermore, illustrate how excursions can be a key support for disciplinarily-relevant epistemic practices, especially within a digital learning environment. Epistemic excursions, including those that might be viewed as misaligned with canonical science, are important in a broader and more relational view of learners' sensemaking processes. Gaining insight into how students negotiate the excursion process is a step towards supporting all students with greater epistemic agency and ownership of their own processes of figuring things out in environments with extensive modeling and visualization tools.

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Revisions in Scientific Explanations Using Automated Feedback

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Abstract: Writing and revising scientific explanations helps students integrate disparate scientific ideas into a cohesive understanding of science. Natural language processing technologies can help assess students' writing and give corresponding feedback, which supports their writing and revision of their scientific ideas. However, the feedback is not always helpful to students. Our study investigated 241 middle school students' use of feedback as well as how the feedback affected their revisions and improvements in writing. We found that students made more content-related revisions when they used feedback and these revisions resulted in improvements in their writing. However, fewer students made integrated revisions. Finally, many students did not address the feedback in their revisions. Additional support to assist students to understand and use feedback, especially for students with limited science knowledge, is needed.

Introduction

Writing science explanations is an integral part of learning and doing science (NGSS, Lead States, 2013). Students need to explore, understand, and explain why scientific phenomena happen using scientific ideas. Writing scientific explanations provides opportunities for students to integrate their disparate scientific ideas into more cohesive and deeper understandings of science topics (Braaten & Windschitl, 2011; Linn, 2006). Though it is often challenging for students, making revisions of science writing can prompt them to connect their initial ideas to new ideas, see the connections between scientific ideas, and strengthen their understanding of science (Linn, 2006; Tansomboon et al., 2017). The development of skills in science writing and revisions of writing has been found to benefit students' long-term science learning (Rivard, 1994). Despite the importance of writing in science and making revisions, students usually get minimal support in writing and revising their science ideas in the classroom. This is likely because it is challenging for teachers to read and provide individualized, constructive feedback in a timely manner to students given limited class time and the number of students teachers have (Gerard et al., 2022). In recent times, Natural Language Processing (NLP) technologies are being used to provide timely and detailed feedback.

NLP tools can provide feedback to support students in understanding the gap between what they have written as well as what they have missed in their explanations (Hattie & Timperley, 2007; Roscoe et al., 2015). NLP tools can provide just in time feedback based on a student's progress, which is a key aspect of providing support within a Zone of Proximal Development (Vygotksky 1978). However, students often face difficulties in using automated feedback. Some students find it challenging to understand computer guidance and trust the feedback. Consequently, students ignore it (Zhu et al., 2017). Other students may struggle to make revisions based on automatic feedback because they do not understand the science well (Zhu et al., 2020). Further, students' revisions of science writing are influenced by writing practices in school, where revisions are most often viewed as accumulating ideas (Gerard et al., 2022). Students and teachers may have different understandings about what it means to engage in revisions of science writing and may take different approaches. As a result, automated feedback is not always helpful in supporting students to make in-depth revisions (Shute, 2008). This may, at least partially, explain why students tend to either simply add new, relevant ideas without integrating them into previous writing or elaborate on the existing ideas repeatedly without modifying their initial writing (Gerard et al., 2016). Further, some other students choose not to revise their ideas when they are supported with automatic feedback.

Prior studies have provided little information about how students use feedback based on automated assessments and if the use of feedback influences the types of revisions that students engage in. It is important for researchers to understand how students' revise their scientific explanations so they can enhance the effectiveness of automated assessment and feedback as well as better design supports that students need to engage meaningfully in writing and revising their science ideas (Tansomboon et al, 2017). Therefore, we need to understand how students actually engage in revisions after getting feedback, and whether students' revisions improve their writing (Lee et al., 2019, 2021). The goal of this study was to understand the ways in which students revised their scientific explanations in an essay based on automated feedback provided by a natural language processing software, called PyrEval (Gau et al. 2018; Singh et al., 2022). Our research questions were as follows: 1) How do students revise their explanations based on automated assessment and feedback? 2) To what extent do students use feedback in their revisions? and 3)What are the differences in the types of revisions students make?

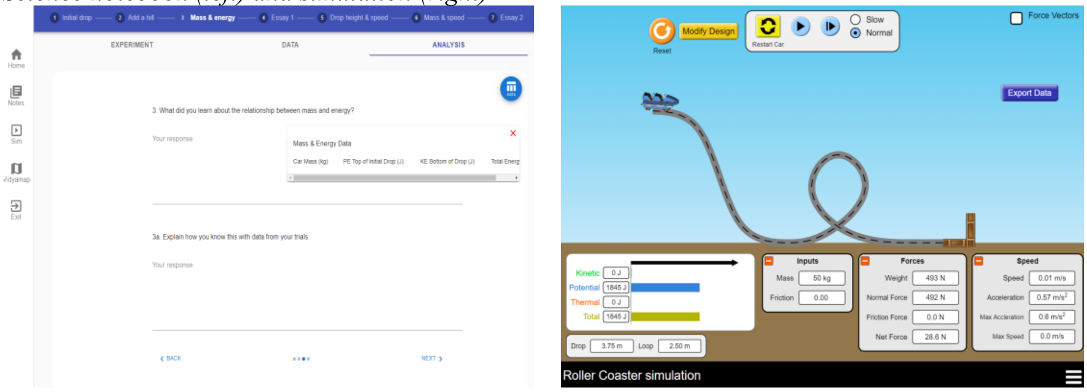
Methods

Participants and study context

Three 8th grade science teachers and their 262students (N_{T1}=95; N_{T2}=78; N_{T3}=89) from two semi-rural public-school districts in the midwestern United States participated in this study. The students for whom we did not have full data were excluded, resulting in data from 241 students (N_{T1}=90; N_{T2}=67; N_{T3}=84) for our analyses. Students from Teacher one's (T1) classes were in a different school district from Teachers two and three's (T2 and T3). All teachers received the same professional development before the implementation of a physics unit in their classes. The teachers' professional development was related to the physics unit and use of our NLP automatic assessment to provide students with feedback for their writing.

During the design-based physics unit, students designed a safe and fun roller coaster based on what they learned about physics during the unit. The unit was taught over approximately fifteen 45-minute class periods. Throughout the unit, students used a digital notebook and conducted virtual experiments using a roller coaster simulation (Figure 1), and recorded data based on their experiments in the simulation. Students learned crosscutting concepts about energy and energy transfer within a roller coaster system (i.e., The Law of Conservation of Energy, potential energy, and kinetic energy). Students wrote essays to explain their roller coaster design based on the science they learned during the unit and received feedback on their essays from our NLP system, PyrEval (described below). We provided students with prompts for their writing to help them understand which science ideas and relationships they should include in their essays, such as explanations about how height influences potential energy, or how energy transfers as the roller coaster car moves down the initial drop. The sequence of the unit was as follows: students a) were introduced to the roller coaster design challenge; b) conducted five virtual experiments to learn relationships between important science concepts that would help them to design a fun and safe roller coaster; c) wrote their roller coaster essays; e) received feedback from PyrEval the day after writing their essays; and e) revised essays.

Figure 1
Science notebook (left) and simulation (right)



3. What did you learn about the relationship between mass and energy?

Your response

3a. Explain how you know this with data from your trials.

Your response

○ Slow
● Normal
☐ Force Vectors

Kinetic 0 J
Potential 1845 J
Thermal 0 J
Total 1845 J

Drop 3.75 m
Loop 2.50 m

Mass 50 kg
Friction 0.00

Weight 493 N
Normal Force 492 N
Friction Force 0.0 N
Net Force 28.6 N

Speed 0.01 m/s
Acceleration 0.57 m/s²
Max Accleration 0.6 m/s²
Max Speed 0.0 m/s

The NLP software we used to assess and provide feedback on students' essays, PyrEval, was developed to identify weighted vectors of key content units (CUs), i.e., ideas and relationships that students should include in their essays using a wise-crowd method (Gau et al. 2018; Singh et al., 2022). PyrEval parsed students' writing into propositions and assessed whether each proposition was a fit with each of 15 key content units that we identified as important for students to include in their essays (See Table 1 for some of the important CUs). A binary score of 1 or 0 was provided in PyrEval logs, presence of an idea was marked as a 1 and an absence was marked as 0. Students got feedback based on whether PyrEval identified important CUs in their essay. If PyrEval did not find any one of these 4 most highly weighted CUs, that were grouped into themes from the original 15 CUs (See Table 1), it provided students with feedback for improvement. Students were also provided with positive feedback if any of these CUs were detected. The feedback consisted of high-level, general statements and questions aimed at getting students to reflect on which concepts they explained and where they could improve based on PyrEval's assessment of their writing. The feedback that students got was similar to this example:

> "*You did a great job explaining Law of conservation of energy! You also wrote that the initial drop height should be higher than the hill height. Now, can you explain how PE at the top and KE at the bottom are related? Also write about how mass affects PE and KE.*"

Table 1
Most Highly Weighted 4 CUs PyrEval Used to Generate Feedback

CU#	Science Idea / Relationship
CU0	Potential and kinetic energy transform back and forth as the car moves and changes height
CU1	Greater mass mean greater energy
CU2	Explaining the Law of Conservation of Energy
CU3	Initial drop must be higher than the hill to have enough energy to make it to the end of the ride

Data sources and measurement

Number of CUs per essay

Students' essays were analyzed automatically using PyrEval. As mentioned above, up to 15 CUs could be identified by PyrEval. We analyzed the total number of CUs that PyrEval identified in students' essays as the *initial CU score* (from the final essay) and *revised CU score* (from revised final essays) to understand if PyrEval detected more key CUs in students' revised essays. At the same time, we also generated a *CU change score,* which was calculated by subtracting the *initial CU score* by the *revised CU score*. The *CU change score* shows the improvement of content units. The change score could be either positive or negative, depending on whether more or fewer CUs were identified in the revised final essays.

Revised or not

Some students revised their essays while others did not revise their essays. We developed a binary code, *Revised or Not*, to capture if students revised their final essays.

Types of revisions

We analyzed the data using a coding scheme that was generated using both inductive and deductive approaches. We first used the categories of revisions identified in Gerard et al. (2016) and then inductively developed our coding scheme to fully capture the types of revisions found in our dataset. We developed a binary coding scheme that captured four types of revisions that students engaged in: (1) *surface-level revisions,* making changes in spelling or word choice; (2) *added similar content,* repeating an existing science ideas or relationship that was already in their essay; (3) *added new content*, including new science ideas or relationships that were not in their initial essay; and (4) *integrated revisions,* reformulating ideas to improve the science ideas and relationships that were already written in their essay (See Table 2). Students could engage in multiple forms of revisions and receive multiple codes.

Table 2
Examples of Types of Revisions

Revisions	Examples	Notes
Surface level revisions	**Feedback:** "You did a great job relating height with PE and KE! … can you explain how mass affects PE and KE?" **Final Essay**: "when the potential energy went up the kintetic would to affecting in the speed being higher" **Revised Final Essay**: "when the potential energy went up the **kinetic** would to affecting in the speed being higher"	Student corrected spelling of "kinetic" in the revised essays but did not address the feedback that suggested explaining how mass affects PE and KE.
Added similar content	**Feedback:** "…Can you explain how height affects PE and KE while explaining Law of conservation of energy? …" **Final Essay:** "I believe that the initial drop should be 3 because it's fun and safe, it also will give a higher amount of PE which helps it have enough energy to go up the hill." **Revised Final Essay:** "I believe that the initial drop should be 3 **meters** because it's fun and safe, it also will give a higher amount of PE which helps it have enough energy to go up the hill. **When**	Student explained height affects PE in the final essay without stating a direct relationship. Then the student added a sentence which explained a higher height means more PE in their revision,

	you have a higher hill height, you get more PE because there is more potential for energy because the hill is higher.”	which made the writing more precise.
Added new content	**Feedback:** “You did a great job explaining Law of conservation of energy! …Also write about how mass affects PE and KE.” **Final Essay:** NO writing about how mass affects PE and KE **Revised Final Essay:** “**On the other hand though, mass effects potential and kinetic energy. The heavier the mass is, the more potential and kinetic energy is created**.”	Student did not explain how mass affects PE and KE in the initial essay. Then added a sentence about it in their revision, based on the feedback.
Integrated revisions	**Feedback**: “… Can you explain how height affects PE and KE while explaining Law of conservation of energy? …” **Final Essay:** “When we have 4ft at the starting drop, it makes the KE at the bottom the same as the PE at the top because all the PE is transferred into the KE at the bottom because the law of conservation of energy states that energy can be transferred but not created nor destroyed” **Revised Final Essay:** “When we have a **4ft higher height** at the starting drop height, it makes the **PE at the top greater as well as the KE at the bottom** because all the PE is transferred into the KE at the bottom because the law of conservation of energy states that energy can be transferred but not created nor destroyed”	Based on the feedback, the students explained that height is directly related to potential energy by explaining “4 ft higher height…make the PE at the top greater as well the KE at the bottom” in the revised essays, thereby reformulating their previous writing.

*Students’ revisions have been bolded for emphasis.

Use of automated feedback

Though students received automated feedback to help them revise their writing, students did not always use or follow it. We developed a second coding scheme to capture whether students used the feedback they received from PyrEval. Students either: 1) used the feedback by writing about the science concepts that they were asked to address, or 2) did not use the feedback. This coding was binary as well, with students receiving a 1 for using feedback and 0 for not using it. Each student could only have one type of code. Interrater agreement was established for both sets of coding categories. For each set of codes two researchers independently coded 15% of all revised essays and achieved almost perfect agreement (Stemler, 2001) on the types of revisions and the use of automated feedback codes (Kappas of .826 and .817, respectively). All discrepancies were resolved through discussion and the two researchers coded the remainder of the data.

Data analyses

We identified how many students revised their final essay. Of the 241 students who wrote the final essay, 87 of them revised their essays in some way. From here, we generated two sets of data: 1) a full dataset containing 241 students, and 2) a subset of the full data containing the 87 students who revised the essays. These datasets were used in different analyses described next.

First, we wanted to compare the *initial CU scores*, the *revised CU scores* as well as *CU change scores* between students who revied and did not revise. To do this, we conducted an independent two-sample t-test using the full dataset. Second, for the eighty-seven students who revised their final essay, we wanted to understand how they used the feedback as well as the types of revisions they made. We calculated the percentage of students who engaged in each category of the types of revisions and whether they used the feedback. Beyond providing descriptions of students’ use of the feedback and types of revisions they made, we also wanted to understand how the types of revisions may have been related to students’ use of the automated feedback. We conducted four pairs of chi-squared tests of homogeneity for each type of revision and use of feedback: 1) surface-level revisions and the use of feedback, 2) added similar content and the use of feedback, 3) added new content and the use of feedback, and 4) integrated revisions and the use of feedback. Third, we wanted to more deeply explore if other factors along with the types of revisions and the use of feedback may have influenced the number of CUs that students mentioned in their revised final essays. To do this, we conducted a stepwise regression analysis, which included three fitted models.

Results

Comparison in the number of CUs in essays

We first conducted an independent t-test using students’ *initial CU scores* and *Revised CU scores* to compare any if there were any differences between students who did or did not revise their essay. This test was appropriate since the CU scores were normally distributed. Based on PyrEval's assessment of students' essays, we found that students who revised their essay included significantly more CUs in their initial essays ($t_{(239)} = 2.00$, $p = .05$). Similar results were found for the revised final essays; the 87 students who revised had significantly higher *revised CU scores* than students who did not revise, $t_{(239)} = 2.76$, $p = .005$ (see Table 3). Further, we conducted an ANOVA to examine the *CU change score* between students who revised or not. The results showed that students who made revisions had significantly higher *CU change scores* than students who did not revise their essays ($F_{(1, 239)} = 7.95$, $p < .001$).

Table 3
Mean of CU Scores and t Test

	N	*Initial CU scores*	*Revised CU scores*	*CU change scores*
Revised	87	4.93 (2.64)	5.26 (2.76)	.33 (0.81)
Did not revise	154	4.16 (3.00)	4.16 (3.00)	0 (0)
t-test sig.	241	$t_{(239)} = 2.00$ $p = .05$	$t_{(239)} = 2.76$ $p = .005$	$t_{(239)} = 5.07$ $p < .001$

Understanding students' revision behaviors

To understand how students revised their essay, we examined two dimensions: (1) the *types of revisions* that students engaged in (e.g., surface-level revisions, adding similar or different ideas etc.), and (2) *use of feedback* (e.g., used the feedback or not). For the types of revisions, we found that students most often revised by adding similar content (57.47%) or by making surface-level revisions (40.23%). However, fewer students added new content (26.44%) or made integrated revisions in their essays (21.84%) (See Figure 2a). For the use of feedback, we found that more students used the automated feedback (63.21%) than students who did not (36.78%) in making their revisions (Figure 2b).

Figure 2
Percentage of types of revisions ((a); left) and use of feedback ((b); right)

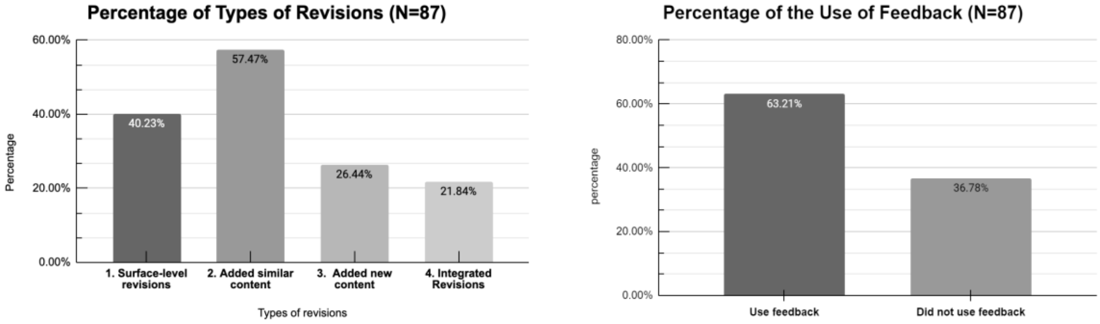


Table 4
Chi-square Omnibus Tests

	Surface-level revisions	Added similar content	Added new content	Integrated revisions
The use of feedback	$X^2_{(1, n=87)} = 11.96$ $p < .001$ **	$X^2_{(1, n=87)} = 15.99$ $p < .001$ **	$X^2_{(1, n=87)} = .98$ $p = .32$	$X^2_{(1, n=87)} = 1.79$ $p = .18$

Notes: ** is significant at .05 level and *** is significant at .01 level

Relationship between types of revisions and use of feedback

To examine if there was a relationship between whether students used the feedback from PyrEval and the types of revisions they made, we ran four pairs of chi-square tests (Table 4). We found that there were statistically significant differences for two of the four tests: surface-level revisions and the use of feedback ($X^2_{(1, n=87)} = 11.96$, $p < .001$), and adding similar content and the use of feedback ($X^2_{(1, n=87)} = 15.99$, $p < .001$). There were no significant differences for adding new content or making integrated revisions and the use of feedback. We found students who did *not* use feedback were significantly more likely to make surface-level revisions than students who used or followed the feedback. We also found that students who added similar ideas were significantly more likely to have used the feedback than students who did not use feedback to inform their revisions.

Exploring factors that influence students' science writing

As prior studies have shown, engaging students in revising their science writing is an important practice to help them improve their science writing and learning. To understand the factors that might have affected students' scientific writings (*CU change score* as the dependent variable), we conducted a stepwise regression analysis by using factors including (i) types of revisions (*surface-level revisions, added similar content, added new content, integrated revisions*), (ii) use of feedback, and (iii) teacher (see Table 5).

We first conducted a multiple linear regression to better understand to what extent the variation in students' increased CU scores could be explained by four types of revisions. A significant regression equation was found ($F_{(4, 82)} = 2.38$, $p = .05$), with an R^2 of .10. Students' predicted *CU change score* was equal to - .11 + .28*(*surface-level revisions*) +.54*(*Added similar content*) + .30*(*added new content*) -.29*(*integrated revisions*), where all the independent variables were coded as: 1 = presence of the type of revisions, 0 = absent. However, only one category of types of revisions, *added similar content,* was a statistically significant predictor. Students' *CU change score* increased .54 if students *added similar content* in the revisions.

Next, we examined whether the *use of feedback* was a predictor that explains CU scores in students' revised essays. For model 2, we excluded the non-significant predictors (*surface-level revisions, added new content, integrated revisions*) and added the *use of feedback* to predict the *CU change score*. But we did not find that model 2 was significant. Neither *added similar content* (one type of revisions) nor the *use of feedback* were significant predictors of *CU change score.* Based on the results from model 1 and model 2, we could see that only one type of revision, *added similar content,* was a predictor that explained students' CU change scores. In model 3, we further explore one more factor, teacher, and excluded non-significant predictor, use of feedback. Students' predicted *CU change score* were significantly predicted by this model 3 with an R^2 of .16. However, the factor of teacher is the only significant predictor.

Table 5
Regression Models to Predict Improvement in Scientific Explanations

	Outcome	Predictors	Regression Model results
Model 1	CU change scores	Surface-level revisions; Added similar content; ** Added new content; Integrated revisions	$F_{(4, 82)} = 2.38$; $p = .05$; ** $R^2 = .10$; Adjusted $R^2 = .06$
Model 2	CU change scores	Added similar content; Use of feedback	$F_{(2, 84)} = 2.74$; $p = .07$. $R^2 =. 06$; Adjusted $R^2 = .04$
Model 3	CU change scores	Added similar content; Teachers ***	$F_{(3, 83)} = 5.24$; $p = .002$. $R^2 =. 16$; Adjusted $R^2 = .13$

Notes: ** is significant at .05 level and *** is significant at .01 level

Discussion

While researchers have emphasized that writing scientific explanations and making revisions can help students integrate and connect scientific ideas (Braaten & Windschitl, 2011; Linn, 2006), these competencies are challenging to middle school students (Tansomboon et al., 2017). Students possess limited knowledge about how to revise their ideas to improve their writing (Hattie & Timperley, 2007). Further, teachers often do not have the time to provide students with detailed feedback to help them improve their writing (Gerard & Linn, 2022). To better support students and teachers, many researchers have developed technologies to automatically assess and provide feedback to students to help them improve their writing (Gernard et al., 2016). In this study, we wanted to know more about: 1) the types of revisions students made to their scientific explanations, 2) whether students used the feedback, 3) the relationship between these two aspects, and 4) how revisions may have led to improvements in writing to inform our work in better designing scaffolds to support their writing.

Our exploration of the revisions based on feedback and if the writing improvement showed that students were more likely to simply *add similar content* to their original writing and make surface-level revisions as opposed to making integrated revision. These results are aligned with prior studies that students find it challenging to: 1) see the gap between what they have written and what is missing and 2) connect scientific ideas, which means they tend to revise as if the science ideas are isolated or disconnected from what they wrote originally (Hattie & Timperley, 2007; Gerard & Linn, 2022). But we found that *added similar content* is an important type of revision that resulted in the detection of more content units by conducting multiple regression analyses. Even though students did not integrate these scientific ideas into their original writing, when they added similar content, they improved their writing by explaining ideas more specifically so that PyrEval could better detect the content units. Despite prior studies suggesting that integrated revisions aid in science learning (Gerard et al., 2016; Gerard & Linn, 2002), our findings demonstrated that reflecting on and revising scientific ideas by adding similar content can also lead to improvement in students' writing. Revisiting and revising explanations based on feedback likely helped students to better integrate their ideas, making them more cohesive (Braaten & Windschitl, 2011; Linn, 2006). Additional support is required to assist students in comprehending how to make integrated revisions, rather than simply concatenating similar ideas. Further, it could also be the case that since so few students made integrated revisions, there was not enough power to detect its effect on improvements in students' essays related to the number of content units detected by PyrEval.

We investigated feedback use and found that many students did not use it, which is aligned with prior studies showing challenges in understanding and addressing it (Zhu et al., 2020). Some students may have simply not followed the feedback because they didn't know what to do, there may have been too much to address, or they simply did not know how to improve their ideas. We further explored how the use of feedback may have been related to the types of revisions students made, which has not been widely studied thus far. Even though prior studies indicated that some students tended to have superficial revisions with the support of automated feedback (Gernard et al., 2016; Shute, 2008), our study showed that the use of feedback did help students to make more content-related (i.e., added similar or new content), instead of surface-level revisions (i.e., fixed spelling). But using the feedback to make revisions was less effective in making integrated revisions, as few students did so in our study. Additional support can be designed to help students to reflect on what they have written in reference to the automatic feedback and assess whether they have explained their science ideas and, if not, fix what they have written in an integrated way.

Our results showed that students improved their writing based on the assessment of CUs from PyrEval. It indicates that making revisions helped students to improve their writing. However, the fact that students who did not revise had lower initial CUs scores in their original final essays may indicate that they may have not addressed the automated feedback because they had limited prior knowledge, which was also a finding from Zhu et al. (2017). This may indicate that students struggled to clearly write about the science ideas in a way that could be detected by PyrEval, because perhaps they did not understand the ideas very well. In addition, we also found that the teacher was a significant factor that predicted students' improved writing. This indicates that helping teachers to better support students to understand the feedback and make revisions is essential (Shute, 2008). Support can be provided at a whole class, group, and individual level. For example, before students revise, teachers can discuss this process more deeply in a whole class discussion. This kind of scaffolding may be essential especially for students with lower prior knowledge (Gerard & Linn, 2022). Though it is challenging to write and revise scientific explanations, the use of automated feedback with teachers' facilitation provided students in our study with the opportunity to practice writing scientific explanations and making revisions in the classroom, which is rare (Gerard et al., 2019). Our findings show a potential for helping a large number of students to engage in this complex practice in science learning by using automated feedback.

Conclusions

Writing and revising scientific explanations helps students to strengthen their understanding of science. However, there are many factors that impede the implementation of this practice, such as the number of students that one teacher needs to give feedback in the classroom or the limited knowledge students may have about science and / or about how to revise their science writing. We provided students with the automated feedback by using a NLP software, PyrEval, to provide feedback to help students to revise their writing. Our investigation of the types of revisions students made demonstrated that automated feedback can positively shape students' approaches to revising their writing (i.e., focus more often on the scientific content and have less superficial level of revisions). However, the effectiveness of the tool still needs to be improved because it was less successful in getting students to make integrated revisions, which requires the students to reformulate their original writing. Based on our findings that improvements in students' scientific writing were associated with certain types of revisions (added similar content), we could focus more on helping students understand how to use the feedback to meaningfully revise and integrate their science ideas to further improve their scientific writing and learning.

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To Quilt Is to Math: Investigating the Breadth and Depth of Mathematics in Fiber Crafts

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Abstract: This study investigates connections between fabric crafts and the breadth and depth of mathematics involved in pursuing the crafts with a particular focus on quilting. The authors became participant observers in crafting circles, conducted 65 semi-structured interviews to investigate crafters' mathematical insights in their projects, and analyzed artifacts through close manual examination and photographs to deepen these insights. We ask the questions: (1) How do crafters observe the interplay between mathematics and the process of a craft? (2) How can crafters' products illuminate the breadth and depth of mathematics? The findings suggest that the different ways in which mathematics and craft intersect either bear the form of a craft-forward approach, as crafters produce patterns and explore it through changes in the patterns or in the form of a math-forward approach, in which crafting directly draws on mathematical concepts guiding the work toward the improved performance or modeling of math concepts.

Introduction

Girls report lower levels of interest and perceived ability in mathematics in secondary and higher education contexts (Fredricks and Eccles, 2002; Else-Quest et al., 2010; Guo et al., 2015; Ganley and Lubienski, 2016) due in large part to a lack of sense of belonging to the field (Cheryan, Drury, Vichayapai, 2012) even when they perform on par with men (Good, Rattan, & Dweck, 2012). As such, body of research focuses on the sociocultural context of learning and of doing mathematics outside of school contexts. However, it is rife with tensions and dilemmas (Boaler, 2007). These tensions culminate in colonized hegemonic ways of learning math through gendered and racialized categories. For example, fabric crafts are not usually included as a viable option for the study of math in informal and formal structures, despite research that demonstrates integrating mathematics with crafts and designs helps learners form a personal and meaningful connection with mathematical concepts (Shaffer, 1997; Elliott & Bruckman, 2002). Textile crafts have also contributed to generating new mathematical knowledge, including the modeling of hyperbolic planes using crochet (Taimina, 2009; Wertheim, 2005). Yet, in mathematics learning contexts, fiber crafts have largely been overlooked and their intellectual merit is still to be explored.

To pursue epistemic diversity of learning and being, it is necessary to recognize that crafting circles present opportunities to do mathematics within a diverse range of contexts (e.g., seeing domain concepts within fiber crafts) as well as recognizing and valuing action within these contexts as a form of mathematical doing that could lead to mathematical insights that are different from but not less important than traditional forms of mathematics. Our research interrogates the extent to which the culture of crafting can produce the learning conditions of Papert's (1980; 1993) Mathland to inform our understanding of the disconnect between mathematics as taught in school and everyday mathematics. The land metaphor within the term Mathland refers to the possibility of learning a language associated with a particular geographic region. Thinking of mathematics as a land where things are done in a particular way invites the possibility that there can be multiple languages and, by extension, multiple lands of mathematics. Additional Mathland-inspired principles have shaped efforts that seek to promote deep mathematical engagement. Earlier efforts to instill mathematics learning into craft have leaned heavily on technological interventions to make the mathematical principles of crafting salient to the learner. However, the larger work to which this paper contributes argues that crafting in itself is a technology that privileges patterned mathematical engagement and is supported by a social structure and broader crafting culture that rests on deep historical roots (Peppler, Keune, Thompson, 2020). In this paper, we analyze the mathematical concepts crafters use in their projects and how they form mathematical connections with their craft. To this end, we asked: (1) How do crafters observe the interplay of math and craft? (2) How can crafters' products illuminate the breadth and depth of mathematics?

To answer these questions, we draw on our ethnographic data that includes observational notes, semi-structured interviews with 65 crafters, and analysis of artifacts created by our participants. Crafters predominantly talked about mathematical engagement through craft terms (e.g., describing the pattern and arrangement of units into the overall pattern). They worked within an understanding of the process they were participating in and in pursuit of the project they wanted to create. For instance, while crafters may not have explicitly mentioned interlocking tessellations by name as part of their math/craft insights, they were able to intricate shapes which required the elegant application of the principles of translation, rotation, and mirroring while working on the structure of their pieces, including in the seam lines, sewing order, and assembly. This study provided us with an understanding that craft is a promising context for creating Mathland which can serve as initial starting points about the processes through which engagement with math could be supported through crafting.

Background

Giving learners powerful tools for creative expression by designing personally meaningful projects and sharing them with others is a central tenet of constructionist approaches to learning (Papert 1980;1992). Papert's constructionist approach draws on cognitivist and sociocultural perspectives by considering how a range of socio-material contexts support cognitive possibilities (e.g., domain learning) through ways of doing that are characteristic of the material context (Holbert, Berland, & Kafai, 2021). Crafting is a learning culture organized around the production of new artifacts and connecting with others in the process. Crafting promotes ties to one's cultural heritage, shaping learning and participation in ways specific to regional crafting traditions. Studies show that people engaging in fiber crafts apply mathematical ideas, but the nature of their engagement is distinct from traditional mathematics (Uttamchandani & Peppler, 2018.; Thompson, 2022; Keune, 2022; Peppler, Keune, Thompson, & Saxena, 2022). Mathlands within the constructionist tradition are learning environments in which rich doing of mathematics happens along the way of performing and practicing cultural practices that are deeply interconnected with mathematics. Papert (1980) describes Mathlands as microworlds where certain types of mathematical activities could develop with "particular ease" and the learner is involved in creative exploration of ideas. He compares children's learning of mathematics in a computer-based Mathland to learning their first language. This model acts against dissociated learning that takes place in schools that does not take into account activities such as mental and physical, resulting in epistemological alienation. Mathlands not only change the way we teach and learn mathematics, but also the way we situate learning in a cultural context.

Methodology

Our longitudinal, multi-year ethnography as learner-practitioners positioned us both relationally and cognitively into crafting communities. Observing and learning with and from skilled crafters provided a multitude of opportunities to draw deep connections between aesthetically, intrinsically woven patterns, and mathematics. Our intention was to adapt the practices of the crafters and grasp crafting as a research process that includes creativity and experimentation to coproduce knowledge (Puwar & Sharma, 2012). These helped us to envision crafting circles as Mathlands that initiated mathematical conversations similar to learning a language (Papert, 1980), and their intergenerational and sociocultural features that have the potential to decolonize ways of learning, knowing, and doing. Participating in communities of practice and care that created artifacts for their loved ones or for social causes (e.g., Keune, Yankova, & Peppler, 2022) allowed us to understand the social and relational aspects of artifacts. For example, knitting covers for trees to spread love and care for nature, crafting donation quilts to distribute to community members in need, or making sweaters for the unhoused. The work as embedded ethnographers resulted in audio notes, detailed, field notes, and crafting photographs and videos of crafting processes. Data sources also included interviews. Using snowball sampling and contacts provided by crafters in the guilds, we reached out to potential interviewees, the majority of whom (90%, n=59) lived in urban areas. Of the 65 crafters we interviewed, 57 were White, three were Asian, four were Black, and one did not disclose their race; 60 identified as women, four as men, and one as non-binary. Their ages ranged between 20 and 72-years-old. The average length of the interviews was 59 minutes (minimum 19 minutes and maximum 166 minutes).

Following Carspecken's (1996) approach for semi-structured interviews, we analyzed our data in two phases. The first phase included demographic information (length of the interviews, age and generation, gender, occupation). In the second phase, we conducted segment analysis to divide interview transcripts into emerging themes followed by iterative thematic analysis. In addition, we analyzed artifacts and observational notes from our work as embedded ethnographers. The artifact analysis included talking about the projects with crafters and asking them to highlight mathematical actions and patterning within their crafts. Further analysis of artifacts and their photographs demonstrated mathematical insights beyond those articulated by the crafters. The following section describes how the crafters see mathematics in their craft and how we analyzed mathematical content in their finished projects leading to ways of reconstructing and transferring knowledge in new contexts through Mathlands.

Findings

How crafters observe the interplay of math and craft

Through an emergent and iterative thematic analysis of the summaries related to the larger theme of math in the craft, we identified that some crafters describe the interplay as math forward and some as craft forward. Thus, two themes emerged around *math shaping the craft* and *craft shaping the math*. We saw crafters as meaning that crafts shape math when they talked about crafts as drivers of mathematical insight and as math shaping the way crafts are designed and conceptualized. We found that 22% (n=14) of the interviewees considered craft as shaping math, nearly a similar number of crafters considered math as shaping crafts (23%, n=15), and over half of the interviewed crafters (54%, n=35) talked about their engagement as both craft shaping math and math shaping craft.

Crafters talked about craft as shaping math in five distinct ways: (1) Repetitive action to produce a pattern, (2) craft as materializing math, (3) craft as producing math, (4) craft as giving math purpose, and (5) craft as containing math. Most frequently, crafters mentioned patterns that produced math through repeating material actions (32%, n=21). For example, Julie talked about quilting: "Math is about recognizing patterns and coming up with formulas to predict those patterns in the future." This example suggests that the crafting practice produces a pattern that could not have been foreseen without the craft. Following the production of the pattern through craft, the pattern can be translated into symbolisms (i.e., “formulas”) that help crafters reproduce the pattern.

Another way crafters articulated how crafts shaped math (15%, n=10) was in how craft materialized math and helped get a feeling for math by creating shapes. For example, Fiona (51 years old) spoke about sewing: “You can make changes (...) to make the fabric do something different. Individual stitches, that’s where I see mathematical thinking constantly at work.” It was the performance of the stitches that led to variations and changes in physical forms that supported Fiona and other crafters in getting a physical and material sense of a math concept. It was the production of the concepts and the possibility to vary through stitch combinations that clarified math through materialization. Others (12%, n=8) considered the way crafts shaped math as a longer-term production process in which crafting led to the slow discovery of math. Crafters (12%, n=8) also considered that crafts gave math a (personal) purpose, meaning that crafting gave them an opportunity to apply math in everyday life. Finally, 3% (n=2) said that craft contained math, meaning that math is always part of the craft but that crafters can choose whether and to what extent to actively engage with it. Across the board, for crafters who considered craft as shaping math, to engage with and know math with craft was neither tied to academic math understanding nor to an ability to point to academic math concepts in crafts. Math was part of crafts and lent itself to the discovery of math at their chosen speed.

Crafters talked about math as shaping craft in six ways: (1) math as improving craft, (2) math as externalized, (3) math as a prerequisite for craft, (4) absence of math hinders craft, (5) math as simplifying patterns, and (6) non-discrete math. These ways of math shaping craft are further explained below. Most commonly, crafters (35%, n=23) said that math improves their craft, meaning that applying math concepts enhances the quality and the range of the craft. For example, Veronica talked about sewing:

> There is nothing like really understanding on an incredibly deep level how bad you are at spatial relations because you realize you just sewed the pocket inside out because you just don't understand shapes in 3-dimensional space.

As Veronica grew in her understanding of the concept of spatial relationships while learning her craft, over time she would become able to iterate fewer times and produce the kind of artifacts that she wanted to see more rapidly. In other words, here, improving math skills leads to improving craft skills.

Next, eight crafters (12%) said that math was externalized through crafting. This meant that crafters could use tools for mathematics that were made by others, including specific calculators. In these cases, crafters described how math intersected with craft and was required for craft but can be facilitated and externalized through specialized tools, for example, online quilting or weaving calculators or even tools invented by the crafters themselves (see also Keune, Yankova, & Peppler, 2021). Just as frequently, eight crafters (12%) said that math was a prerequisite for crafting. With this, they meant that knowing math was vital and necessary for performing a craft. It was not possible to perform the craft without knowing math. For instance, 33-year-old Susan said that “I do a lot of circle skirts so you have to solve for X like in the circumference equation to figure out because you need the inner circle to match the diameter of your waist and then the outer circle is the edge of the circle.”

Less frequently, five crafters (8%) said that the absence of math hindered craft, five crafters (8%) said that math simplified patterns and made them more accessible, and one crafter (2%) said that math was non-discrete and that several concepts were in use at once. Interestingly, while crafters demonstrate several concepts at once in their craft and may name several mathematical insights as described above, here, they do not seem to often name the non-discrete nature of their work, suggesting an inherent fluidity between mathematical concepts when translated to a materialized form.

Where the examples above show how crafters considered craft as shaping math and math as shaping crafts, the majority of crafters (54%, n=35) did not exclusively consider either one of these perspectives in their practices. The perspectives most frequently came together and complemented one another. For instance, Phoebe (30 years old) sometimes led with math while sewing: "If you're trying to decide on the dimensions of an object that you're going to make and you look at an object that you like and then you measure the ratios of height to width."

To produce an object, Phoebe measured and calculated the ratios to aid in the production process. Yet, as with other crafters who shared both perspectives, she also discusses instances when starting with the craft led to math discoveries:

> I made the whole potholder but then I wanted to put quilting stitches in it in a rectangular array. I didn't really plan it. I just started putting them at a spacing that seemed relevant but then I realized that it was a 7 x 7 array. That would have been 49 stitches and I decided to do 48 stitches instead.

Phoebe started to craft and then realized that the physical performance of the pattern could be formalized. The craft led her to discover the math through the production of the craft. This was representative of the other crafters whom we coded as both craft shaping math and math shaping crafts. Fluctuation between perspectives, leading with craft and leading with math, happened frequently, indicating that both perspectives played an equal role for these crafters.

These different ways math and craft came together showcase different ways mathematics can be explored through craft. This can come in the form of a craft-forward approach as crafters produce a pattern, explore changes in shapes through changes in these patterns, or talk about the purpose of mathematics in relation to a personally meaningful project. These observations can also happen in the form of a math-forward approach, in which the process of crafting directly draws on mathematics concepts toward the improved performance or the modeling of math concepts. A Mathland needs to incorporate these multiple entry points to ensure accessibility. Practicing math through crafts can start with math as well as with craft and one approach does not exclude the other.

Illuminating the breadth and depth of the mathematics involved in craft projects

A breadth and depth of multiple mathematical concepts became visible in individual crafted projects. For example, Julia (56 years old) said "I've got to figure out the math ratio based on the 60-inch dimension of my fabric," illustrating the use of *ratios and proportional* relationships. In Julia's remark, she refers to the use of the size of the fabric to determine the proportional size of other design elements (see Figure 1). To create the quilt in the figure, the maker must determine the final desired length and width of the quilt (e.g., 60" x 60"). This square then is made up of an equal number of circles and half circles, with inwardly curved diamonds appearing within the circles. The shape formed between two adjacent diamonds is referred to as a leaf.

Figure 1
English Paper Piecing Quilt

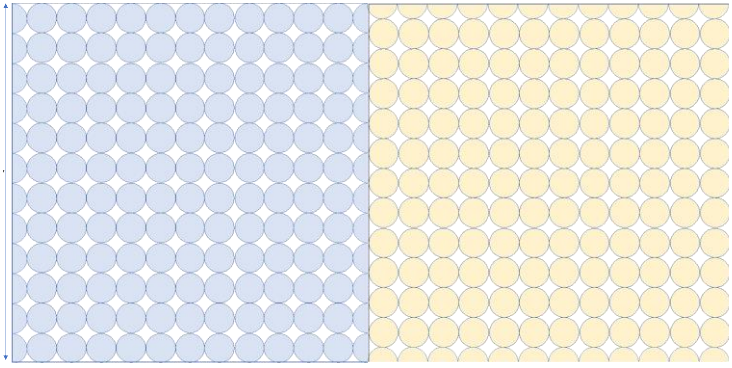
To determine how many of these shapes are necessary to complete a quilt, the maker must calculate the ratio of the diameter of one circle to the length of the full quilt. In Figure 1, it can be seen that 12 circles fit across the full length of the quilt. If the quilt is 60 inches long, the diameter of one of the circles must be 5 inches (i.e., 60” length/12 circles = 5” per circle). These circles are the primary units of the design. However, the mathematical task is not as simple as computing the size of the unit circles. The circles are made of two layers of fabric, and each has a different color or design, which leads to different designs on the two faces of the circle. The individual pieces of circular fabrics are then stitched together, while the display sides of both fabrics are in contact. Then, the stitched two-layered circles are turned inside out through a slit and are carefully cut along the edge of the inside square of one of the circular fabric layers. Turning them inside out results in a displayable circle of 5 inches in diameter. However, as the quilter cuts out the individual circular pieces, a seam allowance of 0.5 inches, which surrounds the circumference of each starting circular piece, must also be accounted for. Thus, without allowing for waste, the total starting fabric size needed is 66 inches by 66 inches, and the ratio of starting circle to the finished quilt edge is 0.092 (or 5.5” per circle /60” length = 0.092).

Note that the placement of the diamond shapes shown in Figure 1 also alternates, such that every other row ends with two half-circles at the quilt edge instead of twelve full circles all the way across. For the row that has 12 full circles, the dimension of the quilt is 60 inches due to the 12 full circles (12*5 = 60), while for the row that has 11 full circles and 2 half circles, so the quilt is still 60 inches (11*5 + 2*2.5 = 60) across (see Figure 2).

Further examination of the pattern shown in Figure 1 indicates that the mathematical insights used by Julia incorporate geometric translations as well. The pattern could be visualized through overlapping the two sets of circle configurations as shown in Figure 2. The first set of circles are configured so that they make up twelve columns and twelve rows, with one column split into two columns of half circles that make up the first and last column (see Figure 2a). The diameter of each circle is 5 inches, and the periphery of the circles in each column touches those in the adjacent columns. Thus, the dimension of the sheet of circles is 60” x 60”. The precision of these initial measurements has consequences for the quilt’s aesthetics, and its feasibility. Every error in measurement will compound over time. The size and dimensions of the quilt as a whole will be irreparably altered if a mistake is made anywhere.

Figure 2

Blue component with semicircles on the sides (a), yellow rotated component with semicircles on top and bottom

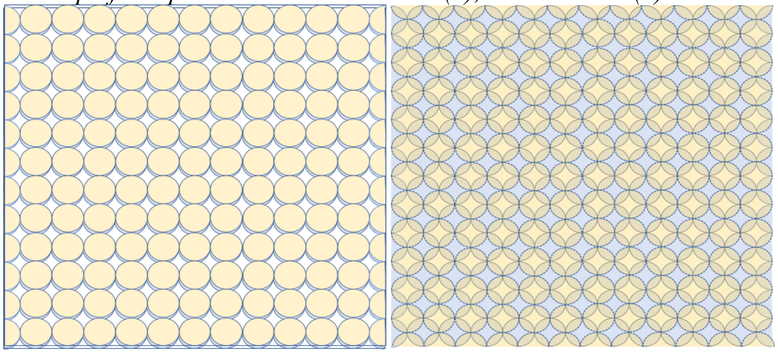


(a) *(b)*

To begin this pattern, Julia arranged twelve yellow circles with a diameter of 5 inches to a sheet of blue circles, but rotated by 90 degrees. The second configuration, while still producing aggregate dimensions of 60 inches by 60 inches, shows the half circle row at the top and the bottom, demonstrating a geometric rotation (see Figure 2b). The rotation of one of the sheets produces a pattern when the two sheets in Figure 2 are superimposed (see Figure 3a). The blue and yellow overlapping components form leaves within circles, and the area not covered by the leaves in each circle has a diamond shape with curved edges. Thus, a leaf and a diamond are created in each of the yellow and blue circles (see Figure 3b).

Figure 3

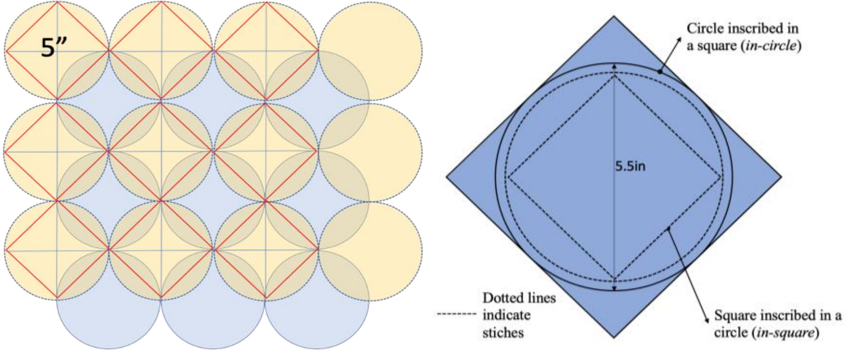
Overlap of two patterns without rotation (a), with rotation (b)



(a) *(b)*

Figure 4

Fabric planning for producing unit circles



(a) *(b)*

The circular fabric pieces seem to be inscribed in square pieces of fabric. The circles thus inscribed are called *in-circles*; in these, the edge of the square has the same length as the diameter of the circle (see Figure 4). There are 12 such adjacent circles along a 60-inch quilt edge, so that each circle is 5 inches in diameter. Each of the in-circles is cut out from a 5-inch by 5-inch square piece of fabric (5.5 inches square with an allowance of a 0.25 seam on each side to form a two-layered circle). The finished circles with a 5-inch diameter are then attached through a seam along the circle’s chord (the edge of the inner square) to produce leaves. Notably, the pre-planning calculations that go into the design of the quilt have deep ramifications for the crafter, in that the exacting manual tasks performed in each quadrant of the quilt are repeated several times and over a long duration of time. To understand the ramifications that inexactitude has for later labor on the quilt, crafters need to consider other aspects of the design, whether this be noticing interrelationships between shapes and space or planning ahead for other calculations (e.g., seam allowances and how they impact the overall dimensions of the quilt). As the crafter engages with the given product for a sustained period, the practice of iterative mathematical production allows deeper insights to emerge.

In sum, we observed crafters using proportional reasoning; properties of circles, incircles, and squares; spatial reasoning (mental rotation, spatial visualization, and spatial orientation); geometric translation; and aesthetic randomization of patterns. Producing quilt designs had the following salient components: First, the leaves in the quilt design are all of the same color, whereas the diamonds are of several colors. This requires choosing two fabric patterns in such a way that one side of the circles all have the same color/pattern (forming the leaves), whereas the reverse side has a diverse color and pattern (forming the diamonds). Second, the colors of the diamonds across the quilt, while they are to be nearly randomly distributed, should also be aesthetically pleasing. A mathematically random choice of arrangement must be supplemented by human judgment for aesthetics when selecting the placement of diamonds of different colors across the quilt. If all red diamonds are clustered together in one area of the quilt, even though this may be the output of a mathematically random algorithm, it may not be pleasing. How a crafter selects aesthetically pleasing but seemingly random distributions calls for further research.

Discussion

This work helped develop our understanding of crafters' relationship with mathematics, whether and how their relationship to academic mathematics compared to the mathematical insights that they reported using and experiencing in crafts, the types of mathematical concepts that crafters connected to crafting, how these intersect in action, and the breadth and depth of the mathematics involved in their finished projects. We gathered perspectives regarding whether and how craft is a promising context for mathematics learning. Crafters frequently fluctuated between explaining "math shapes craft" and "craft shapes math" demonstrating that both aspects play an equal and crucial role in their crafting practices. Our mathematical analysis of the English piecing quilt illuminates the impact of taking two-dimensional mathematics into three dimensions. Mathematical concepts of proportional reasoning, properties of circles, incircles, and squares, spatial reasoning (mental rotation, spatial visualization, and spatial orientation), geometrical translation, and aesthetic randomization of the patterns to include different colors were used in a variety of ways in various crafts and contexts. It is important to note that studies show that when trained on spatial skills, the subjects showed significant improvement in mathematics (Lowrie, Logan, & Ramful, 2017; Mix, Levine, Cheng, Stockton, & Bower, 2020). Crafts can be a context for training such skills. This line of inquiry resonates with what scholars have called for in "life-wide" STEM learning, in which attention is paid to learning experiences that connect to other areas of life, such as home and heritage, that transpire outside of the school day (Banks et al., 2007). A Mathland that is dedicated to pursuing crafts can provide a low floor for novices to enter with their mathematical skills and work their way through to make intricate quilts and reach a high elevation, disrupting mathematics learning as we see it in schools today. Such a Mathland can also provide wide walls to honor populations whose voices have been discounted and unheard in an effort to reify histories of knowledge hierarchies.

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“I’m Not Trying to Sell Anything”: Technology Tycoons’ Discourses of Urgency and Heroism in the Shaping of Education Policies and Utopias

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Abstract: This paper examines the narratives conveyed by three technology leaders of past and present: Steve Jobs, Bill Gates, and Salman Khan. Based on frameworks of technology discourse, we employ critical discourse analysis (CDA) to explore how such leaders communicate challenges and potentials of education, and what ideological markers can be discerned. We find and discuss four narrative genres that influence education policy and politics, and suggest key implications for the Learning Sciences.

Introduction

The relationship between technologies and education has become increasingly complex: while technologists try to dictate system-wide change through new products and practices, their discourses are often rife with faulty pedagogies and unwarranted claims (Blikstein & Blikstein, 2021). By force of repetition, and backed by mass media, ideologies about "good teaching" and the optimal locus of technology in schools – are being rapidly normalized. More importantly, such technocentric narratives set new expectations: the “classroom of the future” is one of many metaphors that suggest the revamping of teaching, learning, and education management by claiming that the centrality of technology is inevitable. This paper contributes to understanding which technology and schooling discourses are reinforced and disseminated by prominent technology leaders of past and present. To this end, this study treats discourses not just as acts of communication but also as capable of affecting social practices (Anderson & Cohen, 2018). Starting from Roderick’s (2016) idea of “Great Men” – embodiments of progress who move society towards betterment – this paper analyzes public talks of three influential technology leaders of the last decade: Bill Gates, Steve Jobs, and Salman Khan. Based on their manifested views about education, we employ critical discourse analysis (CDA) tools and well-studied technological narratives to create semiotic descriptions of an emerging EdTech ethos towards schooling. Gaining deeper insight into the discourses propagated by such technology leaders is not only key to understanding their influence over education practice and politics, but also an invitation for learning scientists to challenge such assumptions and propose new ideas about the politics, affordances, and limitations of technologies for teaching and learning.

Background

Discourses are conceptual systems that manifest through knowledge, language, and communication (Fairclough, 1992; Gee, 2010). While discourses are shaped by sociocultural practices, they are also *socially constitutive*, or capable of influencing practices and determining how individuals experience the world (Fairclough, 1992). Individuals, however, are not always aware of their own conceptual systems (Lakoff & Johnson, 2008), or the values and ideologies they might be reproducing through communicative acts (Freire & Macedo, 2005). In this sense, discourses need to be approached as silent communicators of “master narratives” (Brown & Gilligan, 1993), knowledge systems that convey culturally dominant, socially accepted norms, practices, and identities.

Power structures are often created, transmitted, and reinforced by discourses (Van Dijk, 2008). Foucault’s (2007) social semiotic approach foregrounds how discourses become accepted truths and exert control over individuals and institutions. Foucault also explains how discourses are internalized by individuals and develop into subtle forms of surveillance and control. In this context, knowledge is inseparable from power, with power being exercised through ways of understanding the world. The same phenomenon is seen in education technology discourses: ideologies and practices around learning with technology become naturalized and integrated into common sense views about education as inevitable.

Critical approaches to analyzing discourses

The language of everyday speech is complex and symbolic (Lakoff & Johnson, 2008; Morris, 1946). The fields of Linguistics and Semiotics traditionally break down discursive acts (e.g., spoken language, written text, nonverbal communication, etc.) in two dimensions: *signifier* (the material, or visible aspects of language) and *signified* (the underlying meanings) (Saussure, 2011). This layered approach finds echo in Gee (2010), who separates the observable elements of communication (e.g., word choice, tone of voice, syntactic construction, aspects of genre, etc.) from "Big D" discourses, or the ideologies and beliefs that are enacted through communication and social practices. Under such layered view, how should learning scientists approach the complexity of discourses to reveal underlying narratives and belief systems?

Gee (2010) proposes that discourse analysis should start with a reflection about Big D discourses and then descend into other discursive layers, such as text and meaning. Similarly, feminist theorists suggest that analysts should seek both master narratives and contrapuntal voices – divergent discourses that deviate from norms and conventions – when approaching a corpus of text (Brown & Gilligan, 1993). Both views are examples of Critical Discourse Analysis (CDA), a method that focuses on issues of ideology, power dynamics, and influences of one societal domain (e.g., technology) over another (e.g., public education). CDA takes into consideration not just bodies of written text but also considers the sociopolitical context in which messages are conveyed. As Fairclough (2013) proposes, acts of communication such as public talks or interviews should be examined as social practices through the lens of CDA. This study considers that analyzing the outer (i.e., written text) and inner (i.e., underlying meanings) layers of discourses are complementary parts of CDA and that, together, might reveal how speakers communicate and contribute to received views of technology and education.

Technology discourses

Technology cannot be merely understood as tools or industrial processes, but as a lens individuals use to make sense of the world (Heidegger, 1977). As with any other aspect of culture, individuals receive and reproduce discourses about what technology is and what purposes it serves. One of the most persistent of such discourses portrays technology as a neutral, pragmatic means to inevitable ends. The idea of **Technology as Progress** (Roderick, 2016; Slack & Wise, 2005) understands "progress" as tied to society's betterment and advancement towards the future. In this sense, humanity is seen as moving *forward* providing that technological innovation is achieved. This genre of technological discourse facilitates strong personality cults, with railroad tycoons and Big Tech CEOs being the *Great Men* of their respective ages (Roderick, 2016). Progress, however, demands *inevitable sacrifices* of resources, and people. It is widely documented how such narratives have been utilized and continuously recycled to justify colonialism, armed conflict, and negative impacts on the environment.

Common sense frequently attributes causative powers to technology. The idea of technology as an actor in society, capable of producing change alone, is an example of Technological Determinism (Roderick, 2016; Slack & Wise, 2005). This discourse gives rise to other ideas such as technological solutionism (i.e., "if there's a problem, there's an app for that") and technological revolution (i.e., social practices need to "start from scratch", be "disrupted", "transformed" and "fundamentally changed"). Individuals also tend to personify technology, attributing to it causative powers and capabilities that exceed their actual technical affordances (Lakoff & Johnson, 2008). Roderick (2016) describes this phenomenon as Technological Fetishism: ascribing an autonomous personality to the technological artifact and manifesting a desire for sublime and magical properties. Any similarities to the expectations towards generative AI (e.g., ChatGPT) in education are not a coincidence.

Why discourses matter in education

Discourses are not innocuous acts of communications but might have real impact on education practice and research. Several scholars have studied how discourses directly shape or construct frameworks for education policy (Anderson & Holloway, 2020), in matters that range from curricular choices, teacher training, district management, and technology adoption, to cite a few (for examples, see Levin, 1998; Priestley, 2002; Sam, 2019; and Selwyn, 2013). Even aspects of teacher identity might be influenced by such narratives about teaching, learning, and technology (Marsh, 2002). What is more, the effects of discourses over education policy are not bound to a school district, a state, or a nation, but may quickly spread internationally, much like an *epidemic* (Levin, 1998).

One key (but subtle) discursive practice identified by scholars is the establishment of schools and teachers as antagonists to progress. This is often achieved by disseminating stereotyped views of school systems, which are described as ineffective, "analogic," and anachronistic (Blikstein & Blikstein, 2021). Terms such as "transformation," and "the future of education", and the discourses they belong to, bear significant negative influences on public education by positioning innovative technologies over and above "traditional" school systems and "slipping into pejorative views of schools and teachers" (Vossoughi & Bevan, 2014, p. 38).

Discourses that antagonize public school systems are often accompanied by a slow and steady push to change established curricular practices. A general trend is to suggest educational technology (EdTech) products as the "medicine" to what is described as a malfunctioning and outdated education system, or to appeal to gaps in the nation's workforce in the future. This is precisely the case of Apple and Microsoft, which pushed coding into the US curricular standards by warning against an imminent blackout in computer science majors (Singer, 2017). Treating technological progress as the answer to a broken system echoes the idea of *necessitarianism* advanced by Munck (2003), or the notion that "there is no alternative" (TINA) to technocentric reforms. The mass media play a key part in giving rise to such manufactured crises by giving rise to personality cults and creating **Discourses of Derision**: narratives of moral panic that drive public opinion and shape the political agenda (Wallace, 1993).

Discourses about EdTech also amplify market-based views about schooling, with technology (or its lack thereof) being employed to justify attacks on the public sector. Williamson (2018) explains how Silicon Valley entrepreneurs often reinforce the need for "radical disruption" of schools. The new prototypical "smart school" is not only a fruit of a technocratic ethos but a reflection of "corporate education reforms that have sought to create 'shadow schools' as competitive alternative marketplaces to state schooling" (pg. 233). Similarly, Anderson and Cohen (2018) maintain that the widely accepted discourse of managerialism creates a need for a New Public Management (NPM), or the transfer of well-established market principles to the public sector. When thinking about schools, these views of the public sector as *in need* of the private sector echo Roderick's (2016) idea of inevitability: to pave the way for "schools of the future", sacrifices will need to be made.

Methods

Following Roderick's (2016) concept of Great Men, this article examines the discourses enacted by three of the most influential technology leaders of the last decade: Bill Gates, Steve Jobs, and Salman Khan. Two selection criteria guided the choice for these individuals: first, all of them have significant influence not only in the realm of technology but also in the public and private spheres. Second, each represents a particular segment: the private sector, venture philanthropy and foundations, and education startups (Table 1).

Table 1
Corpus of data used in this study

Data	Context / Length	Perspective
Steve Jobs: *Computerworld Awards Oral History Project* (1995)	Interview: 20min (excerpt), 3,214 words	Private sector
Bill Gates: *"Teachers Need Real Feedback"* (2013)	TED Talk: 10min, 1,518 words.	Venture philanthropy
Salman Khan: *"Let's use video to reinvent education"* (2011)	TED Talk: 20min. 3,608 words	Education Startup

Data sources

The corpus of data utilized in this study (Table 1) is composed by online videos, selected in accordance with their topic, availability, and potential influence. The first source – Steve Jobs' interview – is one of the first to reflect how technology leaders from Silicon Valley view the role of public education in contributing or hampering what they deem as progress or innovation. The interview was given in the context of the 1995 Computerworld Awards and covers topics that range from the voucher system, the role of teachers, and school competition in a free market. Despite being more than two decades old, this interview is still the most complete and extensive material containing Job's views on education available on public domain. Considering that video platforms did not exist at the time of the interview, it is unlikely that Jobs was aware of the potential reach of his words. Also, Jobs' interview was given in a time in which business leaders were much more "naïve" about what they said publicly, without more carefully-crafted language we see today in similar interviews, likely prepared with the help of PR departments and public image consultants.

Gates and Khan's videos are TED talks, where speakers have full control over their presentations and, with rare exceptions, do not take questions from the audience. In his 2013 talk, Bill Gates defends that American teachers should access video recording of their classes as a form of automated coaching and professional learning. Gates criticizes public schools for letting teachers drive blind, without a close support of video-coaching, such the one developed by his foundation. Similarly, Salman Khan's 2011 talk advocates for the use of free instructional videos to relieve the work of teachers and personalize learning. He explains the benefits of self-guided learning using web-based movies prior to formal classes, a practice that is introduced as "flipped classroom".

Data analysis

This study aimed to make underlying discourses visible by creating semiotic descriptions of how messages were built and conveyed, intentionally or unintentionally (Fairclough, 2013). The analysis of the videos adopted an intentional critical stance, based on Fairclough's (1992) and Gee's (2010) CDA. First, we adopted a deductive approach to identify "Big D" discourses (Gee, 2010), mainly those previously studied by Roderick (2016) and Slack and Wise (2005), and discussed in the previous section of this paper. For each discourse, we coded "DISC", plus a short memo describing the nature of that instance. The second movement was also deductive: we looked and coded for specific vocabulary choices that reflected those present in Selwyn's (2013) and Williamson' (2018) analyses. For example, words such as "traditional" or expressions such as "traditional classroom" were coded "TEXT/VOC" and connected to one of the macro narratives identified in phase 1 of the analysis. Third, we took an inductive, bottom-up open coding approach, where text-features such as additional vocabulary choices, allegories, and metaphors were identified and grouped (Gee, 2010) under parent codes such as "AL/MET" for allegories and metaphors and "GEN", for generalization language. One example is "all our students," which is repeated across all three sources and is indicative of a generalization. These codes were then recombined into four categories, which are presented in the following section. Finally, in step 4, we actively listened for *contrapuntal voices* (Brown & Gilligan, 1993), or discourses that deviated from the main narratives identified in step 1. One example is found in Jobs' interview: while defending solutions as a needed addition to traditional classrooms, he views humans – and not computers – as fundamental to mediate learning. In this step, both authors also discussed their own biases as learning scientists, creators of both knowledge and products. Although we acknowledge intentionally conducting the analysis from a critical standpoint — as proposed by the CDA tradition — we kept each other under check to avoid any conclusion that was not based on the data.

Emergent discourses

The textual and contextual analyses of the videos rendered four macro narratives, which we present below:

Discourses of antagonism: Schools are broken

Consistent with the literature, all three videos advanced a narrative that depicts the American public school system as broken, inefficient, and incapable of delivering what is needed in the Information Age. At the vocabulary level, employing CDA revealed several cases of synecdoche, a literary device typically employed by speakers to create generalization language (i.e., the part representing the whole). For instance, words such as "traditional" were combined with others such as "model" and "classroom" to represent entire pedagogical paradigms and school systems, respectively. The lines below, from the Khan talk, illuminate this case:

> "The traditional model penalizes you for experimentation and failure… In a traditional classroom, you have homework, lecture, homework, lecture". (Khan, 2011)

The commonplace discourse that vilifies schools and their communities is usually coupled with comparisons between the US and other countries in international assessment. Without contextualizing the nature, size and conditions of each school system, influential figures such as Bill Gates make all-encompassing assertions about the current situation of education in the country. Consider Gates' words about international rankings:

> "Consider the rankings for reading proficiency. The U.S. isn't number one. We're not even in the top 10. … So, there's really only one area where we're near the top, and that's in failing to give our teachers the help they need to develop their skills." (Gates, 2013)

Gates' message deviates from Khan's previous excerpt in one key aspect: it explicitly incorporates elements of moral panic by connecting "the system we have today" with a risk to the country in the global arena.

> "The system we have today isn't fair to them. It's not fair to students, and it's putting America's global leadership at risk." (Gates, 2013)

Similarly, Jobs suggests that, if teachers were as good as corporate workers, they could be earning higher salaries. Jobs also suggests that mid-career educators are not suitable for teaching anymore, as they "lost their spirits".

> "I'd like the people that are teaching my kids to be good enough that they could get a job at the company I work for, making a hundred thousand dollars a year. Why should they work at a school for 35/40 thousand dollars a year if they could get a job here at a hundred thousand dollars a year? … Unfortunately, the side effect of pushing out a lot of 46-year-old teachers that lost their spirit 15 years ago and shouldn't be teaching right now…" (Jobs, 1995)

Another textual feature present in Jobs' interview is the constant use of "they" (marked in bold), suggesting a conspiratorial school system focused on limiting creativity and controlling students.

> "School was pretty hard for me at the beginning…. And **they** almost got me, **they** really... almost... they came this close to really beating any curiosity out of me. … **They** tested me, and **they** decided… I could skip one grade." (Jobs, 1995)

Discourses of urgency: "Kids can't wait"

In all videos, discourses of broken schools converged to a single point: if rapid changes are not made, students will suffer. Similarly, if investments are not made to professional development, educators will suffer. The possibility of educators and pupils being at risk was reinforced by two textual features: *generalization language*, materialized by expressions such as "everyone" and "we all" (italicized below), and *conditional language*, as evidenced by the verb "need" and other expressions in past tenses, such as "wanted" and "could" (in bold):

> "*Everyone* **needs** a coach" (Gates)
> "No reason why it really **can't happen** in *every classroom in America*" (Khan)
> "And this **could happen** in *every classroom in America* tomorrow" (Khan)
> "We **wanted to donate** a computer to *every school in America*." (Jobs)
> "One day, we **would like** *every classroom in America* to look like that." (Gates)

The idea of a whole generation "in the dark" is intensified by a *sense of urgency* and *prospect of loss,* as seen in Jobs' and Gates' words below:

> We realized that a whole generation of kids was going to go through the school before they even got their first computer. So, we thought: The kids can't wait. (Jobs, 1995)
> But this system would have an even more important benefit for our country. It would put us on a path to making sure all our students get a great education, find a career that's fulfilling and rewarding, and have a chance to live out their dreams. (Gates, 2013)

Discourses of corporate heroism

The attacks on public management pave the way for multiple flavors of necessitarianism and reinforce cults of personalities. These discursive allegories resemble Roderick's (2016) Great Men, thus resonating with the American collective imaginary. Khan, for instance, uses the stage to recount his organization's foundational myth, or the story about how he left a career in a hedge fund to start Khan Academy. The archetype of the benevolent capitalist is evident when Khan explains his decision of offering instructional videos for free, as a means to achieve "*something of social value*". In what resembles an infomercial – which informs and advertises – he explains:

> I want to talk about how I started. … I saw no reason to make it private.… Here I was, an analyst at a hedge fund. It was very strange for me to do something of social value. You can go to the site right now, it's all free, not trying to sell anything. (Khan, 2011)

The use of *heroic language* is not exclusive to Khan. In his interview, Jobs recounts how he tried to change a federal law for the benefit of students, illustrating how public figures actively influence federal regulation. Jobs' refusal to hire a lobbyist adds to the narrative, reinforcing the idea of a powerful leader (Jobs himself), fighting the government ("*they*"), and willing to invest his own wealth in America's schools and students ("*the kids*").

> We could give a hundred thousand computers away, one to each school in America. (…) We literally drafted a bill to make these changes… We called it 'the kids can't wait bill.' (…) I refused to hire any lobbyists. I went back to Washington myself and actually walked the halls of Congress for about two weeks. (Jobs, 1995)

Jobs suggests that it takes entrepreneurship, capital, and good intentions to "transform" education, with no mention that pedagogical knowledge is necessary for such endeavor. Resonant with his views of young *versus* old professionals, he suggests that graduates from elite universities should found schools and outperform teachers:

> If you go to Stanford Business School, they have a public policy track. They could start a school administrator track (…). You could have twenty-five-year-old college kids, very idealistic, full of energy, instead of starting a Silicon Valley company, they start a school. And I believe they would do far better than many of our public-school teachers do. (Jobs, 1995)

Similarly, Gates incarnates another well-established archetype in the American imaginary: the activist. By using language commonly seen in civil rights marches and political campaigns (“fair”, “just”, “deserve”), Gates conveys a message in which he is the caregiver, one who advocates for the rights of educators:

> [teachers have] one of the most important jobs in the world. This wouldn't just make us a more successful country. It would also make us more fair and just too. I'm excited about the opportunity to give all our teachers the support they want and deserve. (Gates, 2013)

Gates' activist-like discourse mirrors Khan’s words when both declare teachers deserve more, but diverges from Jobs, who posits that teachers are fundamental but not good enough.

Discourses of disruption: Recreating the public school

In their approach and ideologies about education, technology leaders tend to overemphasize *curiosity*, *creativity, failure,* and *discovery* as opposed to what is seen as “*traditional schooling*”. The data, however, showed different variations of this type of narrative. Jobs, for instance, resists the view of technological determinism by positing that curiosity and discovery should be sparked by human agents, and not machines. Khan defends a balance between mastery, experimentation, and failure, in opposition to what he describes as traditional schooling.

> The most important thing is another person that guides and feeds your curiosity. Machines cannot do that ... The elements of discovery are around you. (Jobs, 1995)
> The traditional model penalizes you for experimentation and failure, but it does not expect mastery. We encourage you to experiment and fail. But we do expect mastery. (Khan, 2011)

Looking into the social practice of teacher preparation, Gates proposes one single technology – video feedback systems – as a remedy to gaps in teachers’ coaching and professional development. In his presentation, however, there is no indication about how teachers would interpret their own data, whether they would be coached by a human agent based on the images and, ultimately, what are the desired behaviors that could lead to the improvement of teaching practices. Gates’ propositions are inconsistent with the body of Teacher Noticing literature, which upholds that intentional, visible scaffolds need to be in place for teachers to benefit from video recording of their practices (see, for example, Sherin & Van Es, 2005).

Jobs' version of how to recreate the school system incorporates elements of the neoliberal reform agenda, namely competition and choice. He uses words such as “freedom” and “boring” and alludes to the tensions between “equal opportunity and equal outcomes” to communicate views about education policy and equity. The antagonism with unions is self-evident, and a reflex of the first genre of discourses identified in this study:

> I'm a big believer in equal opportunity as opposed to equal outcome. … I believe very strongly that if the country gave each parent a voucher, a check for forty-four hundred dollars they could only spend at any accredited school… But the problem of course is the unions. The unions are the worst thing that ever happened to education; because it's not a meritocracy. It turns into a bureaucracy, and teachers can't teach, and administrators run the place, and nobody can be fired. … We need to attack these things at the root, which is people and how much freedom we give people; the competition that will attract the best people. (Jobs, 1995)

Discussion

By employing Critical Discourse Analysis tools, this study found four macro narratives present in the speeches of influential technology leaders. Representing technology corporations, startups, and venture philanthropists, Steve Jobs, Salman Khan, and Bill Gates portrayed public schools as the establishment, inefficient, and in need of corporate support (Anderson and Cohen, 2018; Munck, 2003). In essence, **Discourses of Antagonism** use generalization language to paint a picture of a malfunctioning school system, governed by inefficient educators whose aim is to exert control by limiting students’ creativity. This type of discourse gains traction by establishing school systems as an adversary to progress-oriented reforms (Blikstein & Blikstein, 2021). With the antagonist identified, **Discourses of Urgency** establish an impending nefarious future for the country (e.g., “the kids can’t wait”) and urge society to *demand* change, immediately, or else something terrible will happen.

The **Antagonism-Urgency** discursive pair has been extensively described by linguists, philosophers of language and learning scientists. Bakhtin (1984), for example, while exploring the politics, aesthetics, and morality of deeds, saw *dialogism* as a fundamental characteristic of human communication: in everyday acts of speech or language use, speakers often position themselves in relation to another. This *I-for-the-other* serves not only to establish and reinforce the speaker's identity but, most importantly, to justify certain actions or urges to act. In the case of EdTech, the Antagonism-Urgency pair serves to justify the urge towards products and ideas without the need to describe current educational systems in more precise and accurate ways, nor to provide robust evidence of *how* these products will fulfill their goals (Blikstein et al., 2022).

What follows in the discursive sequence observed in our data are **Discourses of Corporate Heroism,** in which technology leaders establish themselves as Great Men. Represented as corporate heroes and activists, technology tycoons resort to language that establish education reform as a mission suitable only for young entrepreneurs, college graduates, or savvy technologists, who offer their skills to serve the public good. Finally, **Discourses of Disruption** establish how particular views of education – as well as products and partnerships – are fundamental to prevent the otherwise unavoidable tragedy in education. In essence, Corporate Heroism and Disruption are discourses that result in one single narrative, where the hero is typically not concerned with tranquil negotiations nor complex understanding of nuanced contexts. As in century-old stories, such archetypal heroes have a rebellious, outlaw side, who needs no permission to abruptly disrupt, "move fast and break things." In our data, we observed a common stance towards schooling models towards participation in a "market society." Interestingly, Mautner (2010) reminds us that even "The Market" is often discursively reified as an anthropomorphic entity and a cultural model used to regulate behavior — another entity that is inconsequentially authorized to "break things".

Beyond typifying narratives, this study identified several discursive mechanisms and moves employed by technology leaders to communicate technology-oriented education reform narratives. For example, discursive strategies such as comparing countries in international education rankings and the use of words such as "just", "fair" and "deserve" create the framework needed to establish technology leaders as key partners to policy makers (Anderson & Holloway, 2020). The analysis also revealed how technologists mimic the language typically associated with politicians (e.g., "everyone needs") and equity advocates (e.g., "education for all", "no child left behind".) to justify the urgent need for their proposed technologies, and policies (Singer, 2017).

The portrayal of public education systems as in need of *constant saving* can be decomposed into several elements. First, as seen repeatedly throughout the analysis, such narratives often imply that public schools should be modeled after private corporations (Anderson & Cohen, 2018; Levin, 1998; Munck, 2003; Priestley, 2002, Rudd, 2013). Unfortunately, these claims typically "displace other education stakeholders from setting the agenda" (Blikstein & Blikstein, 2021, p. 22), and silence nonconforming voices at schools and districts (e.g., "The unions are the worst thing that ever happened to education", as declared by Jobs). Second, as shown by several studies, advocates of "radical disruption" often seek to shape narratives about learning in ways that are disconnected from evidence-based claims (Anderson & Holloway, 2020). It is important to note that EdTech is not inherently wicked, nor every entrepreneur or technology leader a disseminator of the narratives identified by this study. However, the key challenge academics are faced with is to identify instances when learning technologies are appropriated to legitimize power and corporate interests (Rudd, 2013).

Implications for the learning sciences

While this study focused on three leading Silicon Valley technology leaders, their discourses reach far beyond the US. Anderson and Cohen (2018), Levin (1998), and Priestley (2002), have demonstrated how trends in education have assumed an international character, with policies – and their underlying discourses – migrating across the globe. As suggested by Levin (1998), discourses that propose the radical transformation of education systems have the power to spread fast, like an *epidemic*. So, what responsibility falls on us, members of a global Learning Sciences community? First, we have a duty to understand how such discourses shape our own practices, within the lab, across schools and in the many research-practice partnerships we engage in. More than understanding, the research community may contribute to "strengthening the public mind on education to increase 'resistance' to 'infection' by superficial but seemingly attractive policies." (p. 139). Much like in a pandemic, the response to the rapid spread of educational technology discourses – and their pervasive influence on policy, business, and management – lies on the idea of *prevention*, or opposing fictive narratives with evidence-based claims. Understanding that any new educational trend — from Automated Tutors to Personalized Learning — is "half technical and half a narrative" (Blikstein et al., 2022) is a consideration we invite our peers to make.

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Design and Evaluation of a Conversational Agent for Formative Assessment in Higher Education

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Abstract: In recent years, there have been attempts to design and use conversational agents for educational assessments (i.e., conversation-based assessments: CBA). To address the limited research on CBA, we designed a CBA to serve as a formative assessment of higher-education students' knowledge and scaffold their learning by providing support and feedback. CBA was designed using Rasa — an artificial intelligence-based tool — and shared with students via Google Chat. The conversation data showed that CBA produced high standard accuracy measures and confidence scores. The findings suggest that ensuring the accuracy of CBA with constructed-response items is more challenging than CBA with selected-response items. In addition, a cognitive walkthrough of CBA provided preliminary evidence for the use of CBA as an interactive assessment tool. According to survey responses, most of the participating students reported positive attitudes toward CBA and its use to improve their assessment experience and learning.

Formative assessments and interactivity

An assessment is formative if it allows teachers or students to gather, analyze, and apply information about students' learning to choose an instructional strategy that is likely to be more well-founded than those they would have made otherwise (Black & Wiliam, 2009). Teachers use formative assessments to periodically measure and monitor what their students know and are capable of doing and to provide feedback to better help students. The design, administration, and scoring of formative assessments have all been improved due to technological advances. Through their advanced and accelerated use at many levels of education, computers have digitized the conventional formative assessment format (i.e., paper-and-pencil testing). Research has found that students tend to be more motivated to take a computerized assessment than a paper-and-pencil assessment (e.g., Octavio, 2022). A computerized format does not, however, ensure that all students will be highly motivated and make a significant effort to do well on an assessment, in specific, formative assessments (Eklöf, 2010). As a result, researchers have started to seek alternative strategies to keep students motivated while completing a computerized formative assessment. Research studied gamification to promote interactivity in formative assessments and reported increases in student motivation (e.g., Zainuddin et al., 2020). In addition, timely interventions like sending students a proctor message to their computer screens can help keep students motivated during the administration of a formative assessment (e.g., Wise et al., 2019). A timely interaction is still required for sustaining or boosting student motivation, as opposed to repeatedly undertaking reactive interventions. The lack of interactivity in assessments can be addressed by using technologies including artificial intelligence and natural language processing. Giving students the chance to participate actively in the testing process can boost their engagement during the assessment process, leading to more diligent test-taking behavior and reliable test results that accurately reflect student ability levels (e.g., Wise et al., 2019; Zainuddin et al., 2020).

Conversational agents and assessment

The research into technology-based support in education has been motivated by the increasing demand for supporting diverse and personalized educational needs. The intelligent tutoring system (ITS) was one of the first attempts in this regard. In the late 1970s, ITSs were introduced as a computerized learning environment that could optimize each student's learning (D'Mello & Graesser, 2013). ITSs blend instruction and assessment for instructional purposes to adaptively respond and give immediate feedback to student responses and guide them on what to do next (Graesser et al., 2014). Although ITSs provided great potential for personalized education, they could provide deeper interaction. To address this limitation, researchers have attempted to integrate more advanced interaction methods.

Conversational agents are one of these techniques, and their use in ITSs has been shown to support learning processes (e.g., AutoTutor; Graesser et al., 2014). Because conversation is a channel through which nearly all students are accustomed to expressing themselves, the use of dialogue is a major component of conversational agents and thus can allow students to focus on the learning task better (Kerly et al., 2008). Previous research has shown that the interactive structure of conversations creates an ideal environment for information exchange and reveals student knowledge (Graesser et al., 2008). Consistent with these findings, conversational agents can provide tailored support to each student and improve engaged and independent learning by building on each student's strengths, interests, and abilities (Kerly et al., 2008).

Although conversational agents are mainly designed for instructional purposes — such as virtual teaching assistants, tutors, and peers (or learning companions) — they have a wide range of potential applications in education. There are now efforts underway to investigate and harness methods for modeling conversations for assessment purposes (i.e., conversation-based assessments: CBA). CBA creates an interactive assessment environment where assessment takes place between a student and a computer agent (Jackson et al., 2018). It can measure student learning and provide feedback through the computational agent's automated or adaptive moves. CBA combines assessment and feedback to improve student learning while assessing student knowledge and providing timely feedback (e.g., Jackson & Zapata-Rivera, 2015). Thus, the use of conversational agents advances computer-based assessment by integrating interactive feedback to enhance student learning.

Benefits of conversational agents

Student learning

Students can shoulder the responsibility for learning by participating in learning activities through active engagement and social interaction (Vacca et al., 2011). Previous studies reported that using conversational agents, as a means to improve student engagement and social interaction, could improve student average learning gains by nearly one letter grade compared to reading the textbook for an equivalent amount of time (Graesser et al., 2008). Interacting with a conversational agent also supports gains for deep levels of comprehension in comparison with reading nothing, starting at the pretest, or reading the textbook for an amount of time equivalent to that involved in interaction with a conversational agent (Graesser et al., 2014). In addition, a comparison of a conversational agent and novice human tutors showed that the student average learning gains were virtually equivalent on the same topic (VanLehn et al., 2007). In another project, Ruan et al. (2019) contrasted a conversational agent to a flashcard app and discovered that students gave more correct responses when they used the agent. In a similar study, researchers investigated the potential benefits of a conversational agent and found that interaction with an agent allowed 41% of students to submit a more complete response to constructed-response items (Jackson et al., 2018).

Student motivation

Human-like features, such as interactivity and natural conversation, are often perceived as social attributions and thus motivate students to prefer social responses and behavior (e.g., Ruan et al., 2019). In a recent study, students stated that the virtual agent was more beneficial for learning and chose to spend more time with the agent when given the option, although it was more time demanding (Ruan et al., 2019). Ruan et al. (2019) suggested that students may prefer conversational agents because they enhance learning and motivation. The motivating effects of conversation are supported through a prior study (Heffernan, 2003). This study also found a strong positive impact on learning and reported that students who used a conversational agent solved fewer problems but learned as well as or better than students who were simply given the solution. This finding has been characterized as "less is more". In other studies, students found conversational environments were an engaging and easy way to practice and learn English as a second language (e.g., Forsyth et al., 2019; Hong et al., 2014). Students who interacted with the digital agent were shown to be more actively engaged in learning activities and outperformed those who did not (Hong et al., 2014). Moreover, students expressed an interest in using digital agents in their other subjects. Going beyond motivation, the emotional states of students who were interacting with conversational agents have been investigated (D'Mello & Graesser, 2013). Among the emotional states observed, engagement (or flow) was the most frequent state followed by boredom and confusion.

Feedback

Even though instructors often assume that students can understand the feedback given (i.e., feedback literacy, Carless & Boud, 2018), students may not be able to understand that feedback. Researchers investigated the role of feedback in conversational agents and found that when students interact with an agent, they were under the impression that the agent cared what the student communicated, and thus they were more engaged with the feedback provided (Graesser et al., 2008). Previous research showed that most students appreciated how well the agents asked follow-up questions and provided guidance and feedback to help them comprehend the questions (Lopez et al., 2021). It has been suggested that feedback helps enhance the testing effect in CBA regardless of whether the attempted answers are correct or not (Ruan et al., 2019).

Current study

CBA advances conventional digital assessments by simulating human teachers to increase student learning and motivation through interactivity and assistance that are often missing in digital assessments. CBA can provide personalized help to each student while also assessing their learning. Furthermore, CBAs can build on each student's strengths, interests, and abilities to enhance learning and motivation. Through the natural flow of conversation, they can hold social interactions with students, ask questions, provide hints, direct students on what to do next, and provide feedback on the quality of responses (Jackson et al., 2018). Despite the aforementioned mounting evidence that conversational agents help students learn and enhance motivation, these systems have yet to become a standard feature of classrooms. In addition, most conversational agents are designed for tutoring purposes (e.g., AutoTutor which focused on the role of conversational agents in learning rather than assessment). Scientific evidence and knowledge of CBA are limited and incomplete. To address this gap and contribute to the literature on the utility of CBA in monitoring student learning and understanding student attitudes toward taking an assessment in an interactive environment, this study designed, implemented, and evaluated a new CBA in higher education. This study aimed to design a CBA that can measure student knowledge and provide support and feedback to scaffold their learning.

Methodology

Question 1: How was the performance of CBA in answering student responses?

A new CBA was designed for two sections of an undergraduate-level course at a Canadian university. The course content was educational assessment, where students in elementary and secondary education programs learn about concepts, issues, and instruments to assess learners' knowledge and skills. CBA consisted of two constructed-response and three selected-response tests following the previous research that designed conversational agents with both formats (e.g., Lopez et al., 2021; Ruan et al., 2019) and also the preference of the course instructors. CBA was offered to students as an additional and optional formative assessment tool by the course instructors in the 2021-2022 academic year, and participation in CBA was voluntary. Table 1 shows further details about each test including the availability as well as the number of items in each test.

Table 1
A Summary of the CBA Designs

	Availability	Number of items
Selected-response test 1	Sections 1 and 2	8
Selected-response test 2	Sections 1 and 2	7
Selected-response test 3	Sections 1 and 2	8
Constructed-response test 1	Section 2	3
Constructed-response test 2	Section 2	4

Selected-response tests combined assessment and feedback to measure student knowledge and provided timely feedback. The back-and-forth dialogue was intended to be a turn-taking conversation where the agent asked a question, the student responded, and the agent provided feedback and asked the next question. Constructed-response tests combined assessment, scaffolding, and feedback to measure student knowledge, give a second attempt for their initial incorrect or out-of-scope responses, and provide feedback. CBA with the selected-response tests was available for both sections of the course while CBA with the constructed-response tests was available for only the second section following course instructors' availability and preference to use CBA in their sections. The total number of students who took selected-response and constructed-response tests are 98 and 21, respectively. Table 2 shows the number of participating students in each test.

Table 2
Number of Students in CBA by Each Test and Section

	Total	Section 1	Section 2
Selected-response test 1	67	51	16
Selected-response test 2	77	61	16
Selected-response test 3	58	42	16
Constructed-response test 1	19	0	19
Constructed-response test 2	7	0	7

Conversation data from each test was used to calculate the intent classification and confidence score to investigate the functionality of CBA in interpreting student responses accurately. Considering the binary classification of student response to each item can be either positive (i.e., classification of student response as correct) or negative (i.e., classification of student response as incorrect), true positives (TP; the number of correctly classified correct responses), false positives (FP; the number of incorrectly classified correct responses), true negatives (TN; the number of correctly classified incorrect responses), and false negatives (FN; the number of incorrectly classified incorrect responses) were calculated. Using these indices, similar to previous work (e.g., Abdellatif et al., 2021), the standard classification measures — precision, recall, and F1-score — were calculated for intent classification to evaluate CBA performance. A human coder assessed the performance of CBA in classifying students' responses and calculated the corresponding performance measures.

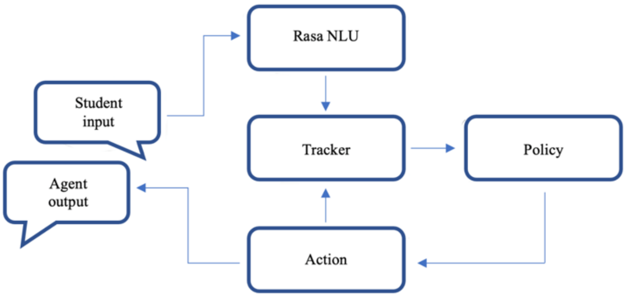
Standard classification accuracy measures and median confidence scores were calculated to understand the functionality of CBA in interpreting student responses, but with slightly different purposes for each CBA format (i.e., constructed-response and selected-response). In terms of constructed-response format, these measures were calculated to evaluate the performance of CBA in understanding and processing students' written responses. For the selected-response format, the goal was to evaluate how accurately the CBA design was implemented. Thus, even though there were no written responses, the aim was to check the accuracy between system design and system implementation in CBA with the selected-response format.

Rasa framework

Previous research examined the performance of the most commonly used natural language understanding (NLU) tools, namely IBM Watson, Google Dialogflow, Rasa, and Microsoft LUIS (Abdellatif et al., 2021). Among those, Rasa had the highest confidence scores for accurately classified intents. Rasa includes two separate modules: Rasa NLU and Rasa Core. Rasa NLU extracts structured information (i.e., the intent) from unstructured student responses using machine learning and NLP approaches (Abdellatif et al., 2021). Rasa Core handles dialogue management, which entails choosing what actions the CBA should take in response to student responses (Shahriar Khan et al., 2021). Rasa processes student responses in a series of phases, as shown in Figure 1 (Bocklisch et al., 2017). Rasa NLU performs only the first step while Rasa Core performs the rest. After CBA was written in Rasa, the trained NLU and Core modules were deployed to a hosted web server and connected to Google Chat. Conversations were stored in a password-protected computer using an SQL database.

Figure 1

Phases from Input to Output in Rasa; Note. Adapted from "Rasa: Open source language understanding and dialogue management", by Bocklisch et al. (2017), arXiv preprint, p. 3.



Question 2: How usable is the CBA?

CBA was shared with students (n = 106) enrolled in an undergraduate-level computing science course focusing on a user-centered approach to software design. This course requires students to conduct cognitive walkthroughs for different software designs. A cognitive walkthrough is an analytical inspection procedure for a user interface to test and evaluate usability issues (Atiyah et al., 2019). It shows if a first-time user can understand and use the tool without any training or background knowledge (e.g., Ren et al., 2019). Evaluators test different actions, and they can detect more potential problems than a user would come across in a single experience. Thus, this method helps to identify user experience issues so that they can be addressed (e.g., Shekhar & Marsden, 2018).

Students were grouped into 21 teams and performed the cognitive walkthrough method as a preliminary validation of the system by evaluating its usability for potential usage scenarios (i.e., actions). CBA with one selected-response test was shared with students because the other tests were not completed when teams conducted their cognitive walkthrough to reveal possible usability flaws. They were not trained on how to use CBA. Teams performed the cognitive walkthrough method: (1) try to produce a goal (e.g., answer a question), (2) search for actions available (e.g., click or type a response), (3) select a suitable action to progress (e.g., type a response), and (4) perform the selected action and evaluate if the progress has been made toward the initial goal (e.g., receive feedback) (Lewis & Rieman, 2011). Each team prepared a report including what they were able to do and not able to do for the actions they attempted. Reports were examined to determine which topics (i.e., usability indicators and issues) were discussed. They were analyzed inductively from a particular to a more general perspective: from codes to themes.

Question 3: What were student attitudes toward taking an assessment with CBA?

CBA invited participating students to complete an experience survey through a link it had provided. As indicated above, the unique total number of students was 98 for the selected-response and 21 for the constructed-response format. The unique total number of students who completed the survey is 61 — a response rate of 51% — with only three responses for CBA with the constructed-response format. The survey consisted of background questions related to demographic information (e.g., age, gender), technology use, and content knowledge. Students were asked a series of questions to better characterize their engagement and overall experience with CBA. For example, they were asked to score their level of agreement with statements concerning general engagement with the CBA. Ethical approval was obtained from the Research Ethics Office for the use of survey data and secondary use of conversation data. Participation in the study indicated participants' consent to use the conversation data and survey responses.

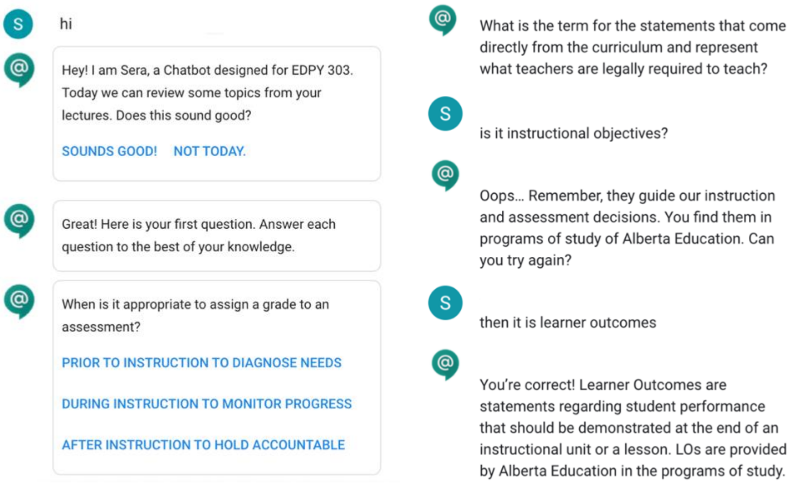
Findings

Performance of CBA

Figure 2 shows examples of selected-response and constructed-response items. For CBA with the selected-response format, the precision, recall, and F1-measure of CBA were all 100%. The median confidence scores for each intent were about 1, meaning that the NLU is entirely confident in classifying each input. For CBA with the constructed-response format, the recall for each item was 100%, meaning that CBA correctly identified correct responses as correct. However, the precision measures of constructed-response items ranged from 80% to 100%, and F1-measure values ranged from 89% to 100%. That is, there were misclassifications of incorrect responses by CBA. These misclassifications in the conversation paths occurred due to the overlapping responses between student responses and expected responses for a different item. In addition to intent classification, the median confidence scores for each correctly classified response ranged from 0.30 to 0.99 for correct responses and range from 0.59 to 0.98 for incorrect responses.

Figure 2

Examples of Selected (a) and Constructed-Response Items (b)



hi

Hey! I am Sera, a Chatbot designed for EDPY 303. Today we can review some topics from your lectures. Does this sound good?

Great! Here is your first question. Answer each question to the best of your knowledge.

When is it appropriate to assign a grade to an assessment?

What is the term for the statements that come directly from the curriculum and represent what teachers are legally required to teach?

is it instructional objectives?

Oops... Remember, they guide our instruction and assessment decisions. You find them in programs of study of Alberta Education. Can you try again?

then it is learner outcomes

You're correct! Learner Outcomes are statements regarding student performance that should be demonstrated at the end of an instructional unit or a lesson. LOs are provided by Alberta Education in the programs of study.

(a) (b)

Preliminary validation of CBA

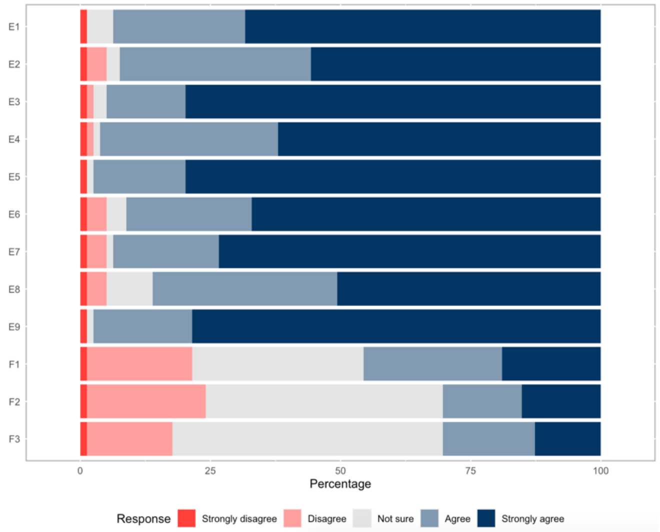
The cognitive walkthrough was performed by external evaluators and each team prepared a report that included what they were able to do and not able to do for the actions they attempted. The teams observed no major usability issues and reported some suggestions to improve the usability of CBA. Fortunately, participating students did not encounter any of the potential issues when they interacted with CBA. We still reported the possible usability problems from the preliminary validation of the system to inform researchers, designers, and practitioners so they can enhance students' assessment and learning experience with CBA.

Some teams attempted to perform actions that CBA was not designed for and thus the agent failed to follow these actions (i.e., default response or inaccurate conversation path). In terms of the usability problem for the action of *clicking an option from a previously answered question*, teams suggested making the options of the previous questions unclickable once a student chooses their answer. One team attempted to type "skip", "help" and "leave" the assessment and suggested adding buttons for these options. These suggestions should be considered for further improvement of CBA. However, even though a solution to these concerns could be more buttons, the solution also depends on the purpose of the assessment and the instructor. For example, the instructors did not suggest skipping a question while developing the questions.

In general, most teams found the action of *answering questions* is clear to users due to several reasons: (1) a common known format (i.e., selected-response items), (2) clickable options with blue color, larger font size, and full capitalized letters, (3) a red dot to indicate an unread message, (4) a loading animation once a student types or selects an answer (see Figure 2). They also reported that it is not clear how to respond to the questions: type or click. Their concern is important for the future use of CBA and thus the system should be updated following their suggestions: (1) explain how to respond to questions at the beginning; (2) make the text box unavailable for the selected-response items or (3) update the CBA script to make sure students will be directed to the correct conversation path if they type to answer a selected-response item. Another potential usability problem was the lack of information about the total number of items on the test and the question number they were answering. Even though the agent indicates "FIRST, NEXT or FINAL QUESTION" to direct students in the assessment, CBA should be updated by numbering the questions. The final concern was the lack of information about their performance, and the teams recommended a score bar showing their performance. Even though this concern is reasonable from the user perspective, the goal of CBA is to provide an interactive environment for students to assess their knowledge and also scaffold their learning.

Teams also reported valuable suggestions in general to improve user interaction with CBA. They suggested more social interaction at the beginning before the agent asks if students want to take an assessment or not. The decision regarding short social interaction was made based on the literature (e.g., the trade-off between engagement and efficiency; Ruan et al., 2019) and the discussions with the course instructors. In addition, one team suggested giving students more time to read the feedback or adding a follow-up question to confirm if users read and understood the feedback before sending the next question. This had not been done because a follow-up question for feedback can be judged as protracted by students and previous research has discussed the negative impact of excessive interaction (e.g., Katz et al., 2021). The other suggestion was to send a reminder message to users if they do not respond for some time without ending the assessment. This action of CBA would help make it more interactive and human-like. CBA could be updated by scheduling a reminder to be executed after a certain time if the user stops interaction without completing the assessment.

Figure 3
Distribution of Student Responses to Survey Items



Student attitudes toward CBA

To answer the third research question — student attitudes toward interacting with CBA, the student responses to 12 survey items were analyzed (see Figure 3). Nine of the items (E1 to E9) are experience-related, while the remaining three items (F1 to F3) focus on the comparison of CBA and more familiar assessments. Overall, students reported positive experiences with CBA and found CBA helpful and engaging.

Student responses to the experience-related items were high and at similar percentages (see Figure 3 for items E1 to E9). Most students found the feedback (94%; item E1) and summary answer (95%; item E3) helpful and indicated that the summary answer helped them to improve their understanding (97%; item E4). This positive trend regarding student experience with content feedback suggests the importance of real-time assessment and feedback to increase the impact of intended outcomes for formative assessments, considering their use for *assessment for learning* rather than *assessment of learning*. Most students indicated that they were engaged during the assessment (91%; item E6) and CBA was helpful for them to stay focused (86%; item E8). They also reported that they felt comfortable (98%; item E5) and found taking an assessment with the agent straightforward (98%; item E9). These results are aligned with the previous research regarding the impact of conversational agents on learning (e.g., Ruan et al., 2019), motivation (e.g., Forsyth et al., 2019), and feedback (e.g., Lopez et al., 2021).

Despite their positive reactions to CBA, their responses to comparing CBA with more familiar assessments (e.g., online quizzes) varied (see Figure 3 for items F1 to F3). Forty-six percent of the students said they would prefer CBA to a regular assessment (item F1). Only 30 percent of the students indicated that they would perform better (item F2) and would be more accurately evaluated using CBA compared to a regular assessment (31%; item F3). About half of the students showed neutral reactions to this comparison. This result could be interpreted as students viewing CBAs as not ready to replace regular formative assessments but to support their intended outcomes on student learning.

Conclusion

To date, conversational agents in education have been mainly used for instructional purposes and thus they blend assessment with instruction rather than focusing solely on assessment. This study designed, implemented, and evaluated a CBA that can provide both interactivity and assistance, which are missing in conventional digital assessments. By providing both interactivity and assistance, CBA can offer a more engaging and personalized approach to formative assessment, highlighting the potential for conversational agents to transform assessment practices and enhance the assessment experiences of students.

The results from this study suggest that CBA can be administered to motivate students to take assessments by holding conversations with an agent and thereby enhancing their assessment experiences. However, CBA was unable to handle all students' written responses and thus failed to direct students to the accurate conversation paths. Future research should address the technology-related limitations and focus on improving the performance of CBA. In addition, the aversion from some participants to CBA in comparison to regular assessment formats calls for research that comprehensively compares the two approaches (e.g., survey data collected for both CBA and regular assessments). At last, the cognitive walkthrough revealed several usability issues associated with CBA. Among these, the reports highlighted the need for a comprehensive introduction at the beginning. Future research should explore this suggestion to improve the performance of CBA. In conclusion, more conversational agents will be used in education going forward to support students during all learning phases, including teaching, assessment, and feedback. As technology develops, it is anticipated that CBA will become more widespread and more capable, playing an important role in the future of education and assessment.

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Teachers as Co-Designers: Forming Equitable Participation through the Lens of Relational Trust

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Abstract: Collaborative design is a research-practice partnership with partners having equal decision-making power. However, creating and sustaining equitable participation in codesign partnerships is a significant challenge for further research efforts. Thus, this exploratory research investigates a trajectory from imbalanced participation to an increasingly equitable and collaborative one in a three-year research-practice partnership that aimed to design and implement a STEM-integrated bioinformatics high-school curriculum through the lens of relational trust. We adapted a multidimensional relational trust framework and followed an inductive approach to analyze a corpus of interviews with two teachers who participated in the codesign sessions and three researchers who facilitated the curriculum implementation and codesign processes. Our results suggested the partners shared authority as they collaboratively redesigned the curriculum and, by further reframing the relational trust dimensions intersected with the shifts in partners' participation, offered a preliminary conceptualization of multidimensional and multifaceted relational trust for equitable participation in codesign partnerships.

Introduction and background

Collaborative design (codesign) is one way for teachers and researchers to act as design partners and share decision-making power to develop technologically-enhanced innovative learning experiences that promote transformational change in school and district practices (Penuel et al., 2007). Research has documented ways that sustainable and effective codesign can support teacher agency (Voogt et al., 2015) and pedagogic knowledge and practices (Penuel et al., 2011). However, it is challenging to develop and sustain a productive codesign partnership as its premise of bridging research and practice by creating equitable participation in decision-making processes depends on the extent to which such equitable participation is fostered through shared status and authority over decisions regarding the collaborative process and its outcomes (Farrell et al., 2019). At the same time, without having intentional efforts to cultivate equal positioning of the codesign partners in the design, implementation, and refinement of learning experiences, tensions can arise between the partners, leading to breaches in trust, even bringing the partnership to a halt (Denner et al., 2019; Ko, 2022).

A growing body of literature has been exploring codesign participation as a context of knowledge and capacity building for teachers and researchers (Goldman et al., 2022), examining the shifts towards more equitable relationships with the increasing agency of teachers over the course of collaborative partnerships (Gomoll et al., 2022; Ko, 2022). One pivotal element of supporting equitable relationships is developing and maintaining trust between stakeholders (Denner et al., 2019). However, even with its wide recognition, trust is predominantly described in general terms, leaving its multidimensionality and multifacetedness implicit (Lezotte et al., 2022). Thus, how partners develop and facilitate the conditions for enabling and sustaining trust in their relationships to foster equitable participation remains underexplored (Lezotte et al., 2022). In response, this exploratory study attempts to develop a preliminary understanding of relational trust, a multidimensional and multifaceted social process (Edwards-Groves et al., 2016; Edwards-Groves & Grootenboer, 2021), in a teacher-researcher partnership and its role in cultivating equitable participation of the partners. Here, equitable participation involves recognizing teachers and researchers as experts with different domain knowledge and skillset as well as learners who need to develop adaptive expertise to collaborate on equal footing (Ko et al., 2022).

This study builds on a longer study on developing a high-school STEM integrated biology curriculum on the topic of bioinformatics and professional development (PD) activities (e.g., Yoon et al., 2023). All participating teachers implemented the curriculum designed by researchers during the project's first three years. Following the third-year implementation, three teachers were selected to collaboratively re-design the curriculum with the researchers. Here, we aim to explore this shift in the role of teachers and researchers as they create a more equitable way of making design decisions about the curriculum and develop a preliminary understanding of the role of relational trust in this process. We followed an inductive approach to analyze a corpus of interviews with the teachers who participated in codesign sessions and the researchers that facilitated these processes. More specifically, this paper seeks to answer the following research questions: (RQ1) To what extent was equitable codesign participation achieved, as reflected in teachers' and researchers' experiences? (RQ2) How was relational trust cultivated to support equitable codesign participation? Building on the need for infrastructures to support equitable participation of codesign partners (e.g., Tabak, 2022), this work could help fine-tune our understanding of how relational trust can be developed over time in a research-practice partnership that fosters more equitable roles and participation in collaborative design partnership. This work could also offer a preliminary conceptualization of relational trust's multifaceted and multidimensional nature in research-practice partnerships.

Forming equitable participation and relational trust

Researcher-practitioner collaborative designs seek to involve teachers and researchers as partners with equal roles in design decisions. Previous work has examined how partners develop new ways of thinking about design, pedagogy, and research to assume equal roles (Coburn & Russell, 2008; Farrell et al., 2019). Lack of trust is a primary issue that substantially limits the equal positioning of codesign partners (Denner et al., 2019). However, even with the recognized value of trust, its intricacies and dynamics with the equal positioning of teacher and researcher roles in research-practice partnerships remain underexplored (Edwards-Groves et al., 2016). Our work is situated in this problem space, as it explores the cultivation of trust in the shifts of partners’ participation and roles.

Trust is a "psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another" (Rousseau et al., 1998, p. 395). Building on this definition, relational trust is trust situated in interpersonal relationships and develops through repeated social exchanges between different role groups (e.g., teachers and researchers) (Schneider et al., 2014). Here, we focused on relational trust by recognizing trust's interrelated and interdependent nature in social, political, and intellectual realms of codesign practices and relationships (Lezotte et al., 2022). Edwards-Groves and colleagues (2016, 2021) conceptualized relational trust as a multidimensional phenomenon situated at five dimensions of relationships: pragmatic (e.g., proposing practical, relevant, and achievable goals), interactional (e.g., sustaining safe spaces for collaboration), intersubjective (e.g., demonstrating collegiality through shared language), interpersonal (e.g., demonstrating empathy), and intellectual (e.g., conveying self-confidence and professional knowledge). However, their original framework focused on how middle leaders in school partnerships develop unileteral relational trust; thus, it was limited in offering a more comprehensive lens to examine mutuality or reciprocity in trust building. In this study, we adapted this multidimensional relational trust framework to guide our exploration by redefining the dimensions of relational trust to uncover how they interrelated with shifts in teachers' and researchers' roles towards a more equitable form of participation.

Methods

Context

This study is part of an ongoing NSF-funded research project that undertakes the design, implementation, and revisions of a STEM-integrated bioinformatics curriculum that is implemented in high school environmental science and biology courses. The curriculum had 20 lessons that aimed to guide students in a problem-based learning inquiry on the issues of air quality and asthma in urban environments. Throughout the curriculum unit, the students investigated problem scenarios by collecting local air quality data through a mobile app connected to carbon monoxide and particulate matter (PM 2.5) sensors, analyzing and visualizing these data, and they learned about bioinformatics research on asthma and air pollution as well as environmental and sociocultural factors impacting pollution level and asthma rates (e.g., Yoon et al., 2023). The curriculum was initially designed by researchers at a university and then implemented by three cohorts of teachers in three subsequent years. Professional development (PD) workshops for each teacher cohort were held in the summer prior to their classroom implementation during the school year. Researchers served as facilitators and supported the pre-implementation planning, classroom implementation, and after-implementation reflection phases. In the first year, five teachers implemented the curriculum; the year after, four new teachers and two cohort-1 teachers were involved in the project; and in the third year, six new teachers, four cohort-2 teachers, and one cohort-1 teacher taught the curriculum. At the end of the third year of implementation, one cohort-1 teacher with three years and two cohort-2 teachers with two years of curriculum implementation experience were invited to participate in the collaborative design sessions to redesign the curriculum. The initial purpose of the codesign sessions was to shorten the original curriculum since it was an issue posed by our participating teachers, particularly one of our codesigner-teacher, Will. Later, the scope of the sessions shifted as the codesigners redesigned most of the curriculum. Three codesign sessions were held in person with these three teachers and one research team member. Each lasted roughly three or three and a half hours.

Participants

We interviewed two teachers who participated in the codesign sessions and three research team members who facilitated teachers' pre-planning, implementation, and after-reflections. One of the researchers also participated in and facilitated the codesign sessions with teachers. Due to a schedule conflict, one codesigner-teacher, Cassie, did not participate in this research but will be interviewed at a later date. The participating teachers (both males), Jimmy and Will, taught biology and environmental science in two separate urban schools in PA and have 17 and 21 years of teaching experience, respectively. Will had a curriculum design certificate, while Jimmy did not have curriculum design experience.

The three researcher-participants (all females), Sarah, Jessica, and Jenny, designed the initial curriculum and coached the teachers throughout all the phases. Sarah, the PI of the project, is a learning science professor at a university in the Northeastern United States, and Jessica and Jenny were two learning sciences doctoral candidates in the same institution at the time. Even though all research team members interacted with and supported all participating teachers, Jessica worked more closely with Will, while Jenny worked more closely with Jimmy as their facilitator.

Data source and collection

We conducted five semi-structured interviews with the teachers (*n*=2) and researchers (*n*=3) four months after completing the codesign sessions. The interviews were conducted by the first author, who recently joined the research team and did not participate in the codesign sessions. Thus, she conducted the interviews as an external observer. The protocol included questions designed to elicit participants' experiences in the codesign sessions, shifts in their roles over the course of their partnership, their interrelational and interactional relationships, how and why they sustained their partnership over three years (e.g., why teachers came back for another year of implementation; why researchers wanted to work with them again), and what factors shaped teachers' decision to participate in codesign sessions and researchers' decisions of involving these three teachers. The interviews were held and recorded on Zoom, each of which took roughly 45 minutes. The zoom transcriptions were reviewed by the first author for accuracy and then used for the data analysis.

Analytical approach

We conducted a thematic analysis to discern the (1) participants' reflections on their codesign experiences and (2) relational trust behaviors they described as enacted in their interrelational and interactional relationships that shaped their roles and participation in the project. We adapted a multidimensional relational trust framework (Edwards-Groves et al., 2016; Edwards-Groves & Grootenboer, 2021) to guide our analysis in addressing RQ2. However, since the framework did not fully capture the meaning provided by the participants for this context, we used it as a measure of credibility, and following Saldaña's (2016) two-cycle coding, we redefined its dimensions and identified the associated behaviors. Moreover, unlike the original framework, we identified whether the behaviors were mutually exerted by teachers and researchers, i.e., teachers' trust in researchers and researchers' trust in teachers. For that, we open-coded the interview transcripts, followed by focused coding to determine what initial codes made more analytical sense based on our research goals and prior literature. Thematic analysis was conducted independently by the first author and one external researcher who was not involved in the researcher-teacher partnership for investigator triangulation (Patton, 2015), and through multiple short debriefings, the discrepancies were resolved between the two coders, and the findings were merged (Saldaña, 2016).

Findings

Here, we first describe to what extent equitable codesign participation was achieved, as reflected in teachers' and researchers' experiences in codesign sessions (RQ1). Then, we present the two main themes outlining how relational trust was cultivated over a three-year partnership of the teachers and researchers in a way that supports equitable codesign participation (RQ2).

RQ1. Shared power and authority through democratic and collaborative interactions

Throughout the collaborative design sessions, codesign partners came together in a dialogic space where they collectively re-designed the curriculum. Participants underlined three primary characteristics of these sessions: safe space for democratic dialogue, collaborative discussions, and shared authority and power. All participants described the sessions as a safe dialogic space where they felt comfortable sharing, discussing, and negotiating diverse challenges, needs, and practices and incorporating them into their collective design decisions. Reflecting on this aspect, Will, for example, noted that he expressed his concern about the previous curriculum comfortably, "I just said, there's so much in here… and it should be divided up into two different programs: the bio component and environmental component…". His concern was then taken as an action item in the codesign sessions as the redesigned curriculum was considerably shorter, with 12 lessons, compared to the previous curriculum, with 20 lessons. Jimmy further commented on how their diverse styles contributed to the design by saying, "I think it worked well…we maybe had different styles. And so, we got like an interesting diversity of types of lessons."

These collective decisions were also enacted through collaborative discussions, where codesign partners were "...all putting ideas forward…" (Jimmy), "...building off each other's thoughts and ideas about what would make the curriculum work" (Jessica), "...listening to each other." (Will), posing and negotiating alternative perspectives, and collectively making the decisions. Jessica further described these collaborative dynamics, saying:

> We collectively built this outline…we worked through the first lesson literally as a group. There'd be a conversation happening about the order, and then Cassie would briefly drop out of the conversation. And then she would come back in and be like, I just found a video… they each would do that…they totally took ownership of that…it was a really collaborative process.

Here, Cassie's behaviors suggest that the codesign team members were invested in producing a high-quality design, and they worked together to accomplish it. Jessica's description of this situation, i.e., "they totally took ownership of that," was interesting as it further suggested that team members shared authority and power in the decision-making processes. This was also reflected in the experiences of Jessica, Jimmy, and Will, as all of them repeatedly noted having an equal say on the decisions throughout the sessions. For example, Jessica referred to an instance where Jimmy shared a disagreement with Jessica by posing an alternative design idea:

> I had started writing stuff on sticky notes and sticking them to the wall, Jimmy got up and… started moving them around, adding sticky notes of his own as we were talking… he didn't ask permission or anything like that… He just like got up, and it was like, no, no, I think they should go in this order…which is exactly what we wanted to have happened.

This excerpt indicates that Jimmy was comfortable with posing a problem in Jessica's idea and taking action to fix it by adding his sticky notes. However, the fact that "he didn't ask permission…" suggests that this was not a normative behavior of teacher-partners, and there was a shift in their power dynamics toward a more equitable form. Jimmy also echoed this shift by saying, "I felt like there were four people in the room that were equals that just kind of through our ideas."

RQ2. Cultivation of relational trust

Here, we describe two main themes regarding how relational trust was cultivated over the three-year partnership that developed and facilitated the conditions for equitable participation in the codesign sessions described earlier.

Theme 1. Commitment to supporting partners' diverse needs and interests

All participants emphasized the critical role partners' commitment to supporting each other's diverse needs and interests played in the sustainability and evolution of their partnership. For example, Will pointed out the research team's, particularly his facilitator, Jessica's, commitment to support his needs and interests as his primary rationale to sustain the partnership over multiple years, "Jessica was just perfect… She listened. She understood. the whole team is great; that's why I'm still here." Two relational trust dimensions were prominent pertaining to this theme: interpersonal and pragmatic. While demonstrating their commitment to supporting diverse needs and interests, the partners attended to the interpersonal dimension of trust by reciprocal reliability, demonstration of genuine caring and mutual personal regard, and the pragmatic dimension of trust by targeted activities and professional support and investment in research efforts.

Participants described reciprocal reliability as teachers and researchers being responsive and timely in communicating with each other and fulfilling their obligations. This was an influential criterion for researchers in their selection of the codesign partners; e.g., "... teachers' commitment was critical [in their selection] ...whether they are timely responsive to us… Because we're working as a whole group and there are a lot of time pressing preparations…" (Jenny). In her sentiments, Jenny depicted their partnership with teachers as teamwork and emphasized teachers' timely responsiveness in ensuring effective teamwork. Pointing out the other facet of this behavior, Sarah underlined the significance of the researchers' timely fulfillment of their obligation towards teachers, "Another thing that is very important to me is… paying our teachers fast enough." The second interpersonal relational trust behavior was demonstrating genuine caring, which was described as researchers putting effort into empathizing with teachers' experiences, struggles, and needs. For example, Will expressed his appreciation for Jessica’s constant efforts to acknowledge his needs and struggles, “She understood when I said, I'm just fried. I need to take a couple of days off of doing this because my kids… were overwhelmed with a lot of it… [She said] no problem.” Similarly, Jessica emphasized the importance of acknowledging teachers’ struggles and needs and offering support when needed, "I know that you are not given as much support as you need [in your institutions]. I've been there. I know what that's like, so how can I help you?" Here, she empathized with teachers’ frustration by acknowledging their lack of support in their institutions and further demonstrated her caring by offering support to address this problem. Genuine care was often coupled with partners' willingness to go beyond their immediate obligations to support each other, bringing us to the final and most commonly reported interpersonal relational trust behavior: mutual personal regard. It was enacted in the partners' interrelational dynamics in the form of teachers and researchers being accessible and flexible for each other's needs. For example, Jimmy reflected on how Jenny, his facilitator, was always available and flexible to address his needs, "she has a schedule… But at the same time, she always kind of had like a drop everything…. she was willing to come in when she couldn't come…help out." Personal regard, as the participants further highlighted, was mutual as the teachers also made themselves available to support researchers' needs, e.g., "... she [Molly] was very… flexible, and try to be available most of the time" (Jenny). Demonstrating genuine caring and personal regard were interrelated with the pragmatic dimension of relational trust since they were often followed by targeted activities and professional support or investment in research efforts.

Targeted activities and professional support was described as researchers' investment in tailoring project-related activities and professional support to the teachers' needs, goals, and interests. For example, Will appreciated how Sarah adapted the expectations based on teachers' feedback by saying, "Sarah's really good… listens to us, and doesn't just pacify us if it can't be done. she's very good on the teacher side of it, listening and taking our feedback" (Will). Will further expressed his appreciation for the professional support the research team offered by reflecting on how having Jessica regularly in the classroom supported his teaching practices, which ultimately helped them develop a collaborative partnership with shared authority.

> when I was delivering the information, Jessica was there… She noticed that I was struggling with something, and she chimed in… she didn't mind helping out… we're going over the formulas… and I said mean. She said, no, it's average. There's no mean. That's right… that relationship that we had was really good, that it was almost like a second teacher. It didn't make me feel like I was being judged.

Here, Will shared an incident where he used the wrong terminology in class, and Jessica corrected him. However, as he further posed, being corrected did not bother him as he did not feel judged; on the contrary, he enjoyed having Jessica as a second teacher in the class. This might suggest (1) the presence of a collaborative partnership between Jessica and Will, as he did not feel threatened to be corrected in the class, and (2) the shifts in the partners' roles, as Will shared his authority with Jessica as she gained the role of co-teacher.

The second pragmatic relational trust behavior for this theme was the investment in research efforts, and it was described as teachers' willing contributions to the research activities. The three researcher-participants emphasized this behavior as one of the main criteria for choosing the codesign partners. Jenny further explained this behavior's role in forming their codesign partnership, "We asked teachers to provide feedback. Some teachers would just give a line or two, but some teachers really put a lot of thought on it, and they give really in-depth feedback… an indicator for their commitment."

Theme 2. Affinity building with a respectful and supportive environment

All participants underlined affinity building and fostering a respective and supportive environment as the conditions for partners’ autonomy building and taking ownership of the collaborative process and outcomes, thus, shifting the role and power distribution of the partnerships towards a more equitable form. For example, Jimmy discussed how researchers’ expression of their confidence in and respect for his professional expertise fostered his autonomy during curriculum implementation and encouraged him to take ownership of this process:

> I might have just modified entirely what that plan was. She [Jenny] was fine with that...What I did with the virtual year…I didn't really ask for permission. I felt that I had a lot of freedom from the team to kind of do what I wanted… I don't think I had a ton of failures, but at the same time, I was fine with the results either way. I don't think that I was explicitly told any of that, but it was definitely implied, like, ‘You've been doing this for a while. We think you're great. You can keep doing what you want.’ I think that that's been helpful throughout.

Jimmy's reflection on his experiences with the research team indicates that the team demonstrated their respect for and confidence in Jimmy's expertise by giving him the freedom and space to make changes in the curriculum and try different paths, fail, and try again. They also repeatedly vocalized their confidence in his abilities and appreciation for his efforts, which ultimately fostered his autonomy, as evident with his exclamation, "I didn't really ask for permission." The interview data further yielded three prominent relational trust dimensions pertaining to this theme: intersubjective, interpersonal, and intellectual. In their efforts to build affinity with a respectful and supportive environment, the partners attended to the intersubjective dimension of trust by identification through shared participation, the interpersonal dimension of trust by rapport building and demonstrating respect and appreciation, and the intellectual dimension of trust by recognition of expertise.

The participants described identification through shared participation as positioning teachers and researchers as members of an affinity with a shared goal. For example, emphasizing the shift in the research team's positioning of teachers in the partnership, Jenny noted, "as a whole team, we put a lot of effort really not just to consider our teacher participant as like research participant. It's not that anymore. They are part of our team." She further explained how their shared participation in the project fostered their sense of belonging:

> They [teachers] all acknowledged that this is exploratory… Jimmy would also say it is a guinea pig that he is testing out the curriculum whether it works. And then he knows this is a process that we are all in together, teachers and researchers. Altogether, we are, as a team, trying to figure out what's the best way to teach this to our high school students. So that sense of belonging.

Here, referring to her conversation with Jimmy, Jenny reflected on how the exploratory nature of the project prompted partners to unite as a team to handle the ambiguity of their explorative experience better, and this joint exploration prompted their sense of belonging. The emphasis on the 'We' language, as exemplified in Jenny's reflection, was also effective in supporting partners' identification, which was echoed by Sarah's sentiments about their partnership with teachers, "One of the things that I do is a very intentional language which has to do with 'We' us all of us working together."

Interpersonal relational trust was the second dimension associated with affinity building, and two related behaviors were identified: rapport building and demonstrating respect and appreciation. Rapport building was described as teachers and researchers demonstrating personal interest in each other and spending social time together. For example, when asked how he and Jessica developed their relationship over time, Will posed Jessica's interest in his personal life, "...she never met my family, but every time we talked, she asked 'How's your wife? How are kids?'" and his personal updates, "...I had to take my son to an urgent care. He cut himself really bad…two weeks later, we had our next meeting, and she asked about him." All participants further pointed out spending social time as a prerequisite for rapport building. For example, Jessica reflected on how her relationship with a teacher in the project developed over time through their social interactions after the class sessions:

> I was like helping Hallie to reset the chairs in her classroom for her next class… She would just talk, and I would talk, and… that developed a real rapport when we were in their classroom because you just got a chance to sort of talk to catch up and all of that. So, I definitely think that [I have] a much stronger relationship with Hallie.

The second interpersonal relational trust behavior was demonstrating respect and appreciation, which was described as researchers acknowledging and appreciating teachers' efforts, time, and accomplishments. For example, Will commented how the facilitators' encouragement and positive feedback eased his stress during the implementation process, "I was nervous… I don't think they [students] have done anything like that. They [facilitators] were like Your students are awesome. Just getting that feedback when things didn't go well…" Jimmy further underlined the role of positive feedback and encouragement in his motivation to invest in the project by saying, "...just getting like really positive feedback like you guys are really good teachers, or you're really doing a good job is sometimes really really helpful because they [teachers] might not be getting it from their administration…."

The final relational trust dimension associated with affinity building was the intellectual dimension, and one predominant associated behavior was the recognition of expertise, which was described as researchers demonstrating confidence in and respect for teachers’ expertise and experiences as practitioners. One example quotation was shared earlier by Jimmy, where he discussed how researchers’ confidence in and respect for his professional expertise fostered his autonomy.

Discussion

By investigating the formation of equitable participation through the lens of relational trust over multiple years of partnership, as reflected in the partners' experiences, this study is an exploratory attempt to contribute to the emerging body of research efforts to foster equitable participation in research-practice design partnerships (e.g., Gomoll et al., 2022; Ko, 2022) and the need for developing a systematic understanding of how trust is enacted, experienced and maintained in codesign partnerships (Lezotte et al., 2022).

Our first research question concerned the extent to which equitable participation was achieved in the codesign sessions, as reflected in teachers' and researchers' experiences, and the findings suggested that the participating partners shared authority and power as they collaboratively redesigned the curriculum through democratic and collaborative dialogues. However, the partners did not always interact with each other in ways that created and facilitated the conditions for shared authority and power since the initial partnership was not formed as a collaborative design partnership. Over the course of three-year curriculum implementations, a trajectory from imbalanced participation to an increasingly equitable and collaborative one was attained. This trajectory has often been examined during the codesign interactions of the partners (e.g., Kyza & Agesilaou, 2022), which are highly facilitated, and the roles of the partners are clearly defined (Matuk et al., 2016). Alternatively, this research positioned codesign interactions as the equitable and collaborative end of the trajectory attained over the course of teachers and researchers' three-year imbalanced partnership and building on the significant role of thrust in the sustainability and evolution of partnerships (Denner et al., 2019), it used relational trust situated at the interpersonal interactions of the teachers and researchers as a lens to understand this trajectory.

Accordingly, our second research question concerned how relational trust was cultivated throughout a three-year partnership in ways that facilitated equitable participation during the codesign sessions. Our findings yielded two primary ways of cultivating relational trust for equitable participation: commitment to supporting partners' diverse needs and interests and affinity building with a respectful and supportive environment, and further identified and redefined five dimensions of relational trust (Edwards-Groves et al., 2016; Edwards-Groves & Grootenboer, 2021) and the associated behaviors to cultivate equitable participation. Other bodies of literature, such as school leadership and action research with community partners, have long valued and recognized the multidimensional and multifaceted trust in shaping the efficacy and sustainability of the partnerships (e.g., Edwards-Groves et al., 2016; Edwards-Groves & Grootenboer, 2021). However, the contextual and relational differences challenge the utilization of those theories in the researcher-teacher design context (e.g., Jardí et al., 2022). Moreover, the original relational trust framework focused on how middle leaders in school partnerships develop unilateral relational trust; thus, it was limited in offering a more comprehensive lens to examine mutuality or reciprocity in trust building, which is an increasingly demanded focus of research in design partnership literature (Goldman et al., 2022).

Similarly, many of the identified behaviors have already been documented to cultivate trust in partnerships, such as rapport (e.g., Slater & Gazeley, 2018) and personal regard (Bryk & Schneider, 2003). However, our findings offered contributions to the literature by (1) showcasing the interrelated, multilayered, and multifaceted nature of relational trust developed over time between the partners in an authentic setting and (2) offering a preliminary conceptualization of relational trust situated in the interpersonal dynamics of the partners. This conceptualization might further offer implications for creating infrastructures to support the equitable participation of codesign partners (e.g., Tabak, 2022).

Finally, the findings of this study should be interpreted with caution, mainly because of three reasons. First and foremost, it was a small exploratory study that focused on the organically evolved shifts in partners' roles over time and thus, the participant pool was limited to three teachers and three researchers, and one teacher-partner could not participate in the study because of a time conflict. We will continue our exploration by applying the same lenses to our other projects, as the same procedures were followed in those projects. Second, our only data source was the corpus of interviews with the partnering teachers and researchers. However, the findings suggested other potential data sources that could be used to explore the cultivation of relational trust (e.g., recordings of the after-implementation chats). Thus, we will further triangulate our findings with these resources.

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The Impact of Collaboration on Students' Processing of History-Related 360°-Videos

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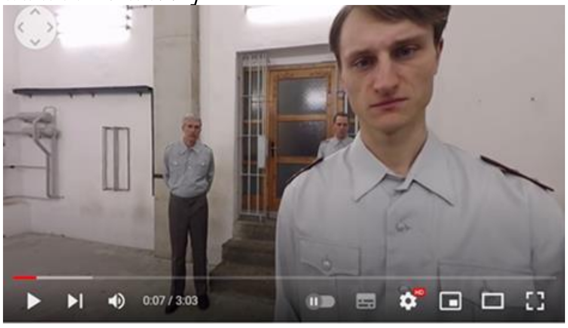
Abstract: History-related 360°-videos are characterized by immersive features and an emotionalizing presentation of the content. These features bear the risk to emotionally overwhelm learners, preventing them from critically evaluating the video content. In the present quasi-experimental study, we explore whether a collaborative examination of a history-related 360°-video affects students' critical processing of the content. Based on inconsistent findings on the effects of co-viewing and collaborative learning, one could assume that a collaborative evaluation of the 360°-video either promotes a more cognitive (especially critical) and less emotional engagement with the content or vice versa. To investigate these assumptions, we compare the processing of an emotionalizing history-related 360°-video between students who collaboratively conduct a written analysis of the video with students who analyzed the video individually. Our findings suggest a positive impact of collaboration showing that students who worked collaboratively examined the 360°-video in a more critical way than students who worked individually.

Introduction and background

Imagine yourself being imprisoned in a former remand prison of the GDR State Security Service. Prison guards yell at you and aggressively interrogate you about your motives for wanting to flee the country. You might imagine feeling discomfort and anxiety. This is exactly the situation that students experience when they use history-related virtual reality (VR) media, such as 360°-videos (see Figure 1), as these media are designed to create presence (Cummings and Bailenson, 2015). This sense of being present in a virtual world (Slater and Wilbur, 1997) is achieved through immersive features of the VR technology, such as the first-person perspective or a wide field of view (Cummings and Bailenson, 2015). Due to these immersive features, history-related VR media promise that users can travel in time and, thereby, re-experience or even witness historical events (Bunnenberg, 2018). In addition, the history-related content is often presented in an emotionalized way in order to promote empathy and identification with historical figures (Brauer, 2019). This impression of (emotionally) reexperiencing and participating in historical events can help learners to "feel more connected to the narrative" (Parong and Mayer, 2021, p. 1436) which may increase their attention and learning outcomes (Parong and Mayer, 2021).

Figure 1
Screenshot of the 360°-video "Was wollten Sie in Berlin?" ["What did you want in Berlin?!"]



However, the immersive and emotionalizing features of history-related VR media can overwhelm learners (see Bunnenberg, 2018), leading to a more emotional and less cognitive processing of the content (Parong and Mayer, 2021). Specifically, the immersive and emotionalized presentation of the content can prevent learners from critically questioning and distancing themselves from the represented content (see Bunnenberg, 2018). Thus, in order to avoid an unreflected adoption of the presented perspective(s) on certain historical events or situations (Bunnenberg, 2018), it is necessary to find ways that help learners to process history-related VR media more cognitively and less emotionally.

Based on research on the effects of co-viewing and collaborative learning, the present study explores whether collaboration has an impact on students' processing of history-related VR media. More specifically, we investigate whether a collaborative examination of an emotionalizing history-related 360°-video promotes a more cognitive and less emotional processing of the content.

Findings from research on the effects of *co-viewing* suggest that being around other viewers and communicating with them while watching a high-arousal video can reduce their perceived suspense (Zillich, 2014). Findings from Gehrau et al. (2014) also showed that the perceived emotional intensity differed between viewers who did or did not communicate with each other while watching a video. Based on these findings, Gehrau et al. (2014) concluded that talking about emotional experiences while watching a video constitutes a way to distance oneself from the presented content, leading to a more critical opinion about the content. Research on the effectiveness of *collaborative learning* further suggests that collaboration can promote critical thinking through interactive discussion, clarification, or evaluation of each other's contributions. As a study by Glokhale (1995) demonstrated, students who worked in small groups more likely clarified, analyzed, and evaluated information than students who worked alone. Also, a study conducted by González-Cacho and Abba (2022) demonstrated that students who created a social-media posting in small groups relied more strongly on critical-thinking processes (e.g. reflecting on assumptions and conclusions or evaluating different perspectives) while creating their postings than students who worked alone. Collaborating with others and being around others when examining a high-arousal video might be particularly important for processing immersive 360°-videos. These videos are usually designed for being watched with head-mounted displays (HMDs), whereby the users could feel isolated from others (Rothe et al. 2021). This isolation could increase the feeling of being overwhelmed and, thereby, hinder a reflective, critical, and distanced processing of the content of 360°-videos. Hence, based on the aforementioned findings from research on co-viewing and collaborative learning, one could assume that a collaborative examination and analysis of a history-related 360°-video may help learners to focus less strongly on their feelings aroused by the emotionalizing and immersive video (due to a decreased perception of emotional intensity) and instead to concentrate more strongly on critically discussing and evaluating (due to increased processes of critical thinking) the presented perspective(s) on the historical event.

However, research on *co-viewing* has also shown that watching a video together can increase the feeling of transportation into the narrative and the identification with characters of the narrative. More specifically, findings from Tal-Or (2016) showed that the feeling of being absorbed into the world of the narrative and the identification with its protagonist increased when the co-viewer reacted positively and enthusiastically about the movie while watching it. Moreover, research on *collaborative learning* suggests that working in groups can cause different cognitive challenges. For instance, paying attention to the contributions of other group members can block one's own thinking process (see Nokes-Malach, 2015), and sharing ideas in a group brainstorming process can restrict the breadth of ideas and lead to conformity with other contributions (Kohn & Smith, 2011). Considering these findings, one could assume that a collaborative evaluation of a history-related 360°-video leads to a more emotional (due to an increased feeling of transportation into the narrative and a high identification with the characters) and a less cognitive (due to production blocking and conformity with other contributions) processing of the content.

Given these inconsistent findings from research on co-viewing and collaborative learning, the present study aims to explore the effects of a collaborative analysis of a history-related 360°-video on students' processing of the video (Research Question 1). Based on the two contradicting perspectives outlined before, we are particularly interested in investigating how students who collaboratively examine a history-related 360°-video handle their emotions raised by the video, that is, whether they process the 360°-video more emotionally or more cognitively than students who individually analyze the video (Research Question 2).

Method

To investigate our research questions, we analyze data from a quasi-experimental study that was conducted as part of a larger project in which students underwent different training interventions to promote their cognitive processing of history-related 360°-videos. The analyses presented in this paper focus on video analyses that students conducted individually or collaboratively prior to the training interventions. Thereby, we are enabled to examine the mere effect of collaboration on students' processing of immersive and emotionalizing 360°-videos.

Participants

Data were collected in an out-of-school lab at a university in Germany. The participating secondary school students visited the out-of-school lab with their whole class to attend a day-long project on "Virtual Time Journeys - Experiencing History through 360° Videos?". Our sample consists of 145 secondary school students (female: 57.2%; age: $M = 17$, $SD = 1.05$) from grades 11 and 12 (eight classes in total).

Design and procedure

Classes were randomly assigned to two conditions: individual video analysis (ind) and collaborative video analysis (collab), leading to the following two subsamples: ind: *n* = 87 individual students; collab: *n* = 58 students in *n* = 17 small groups. The random assignment to these two conditions was conducted prior to the main study where we compared different training interventions as mentioned above.

Students in both conditions first received an introduction to the topic of the project and the procedure of the study and then watched a neutral 360°-video about swimming dolphins with VR glasses for mobile devices (e.g. smartphone, iPod) in order to familiarize with the VR technology. Afterwards, they watched the history-related 360°-video "What did you want in Berlin!?" which is available on YouTube and is about the former remand prisons of the GDR State Security Service. In the video, the viewer takes on the role of a prisoner who is interrogated about his/her motives for leaving the country (see Figure 1). The students were then asked to analyze and evaluate the video - depending on the experimental condition - either collaboratively (in small groups of three or four) or individually. For their analysis, students were provided with a laptop and a Microsoft-Word template which included the instruction for the analysis (see Table 1).

Table 1
Procedure in both conditions

Condition	Prior to the Analysis		Analysis	
(1) Individual video analysis (ind)	Introduction + Test video *360°*	History-related video *360°*	Instruction: "Take on the role of (a) history expert(s) who professionally deal with history-related 360°-videos. Analyze [1] the 360° video 'What did you want in Berlin!?' and evaluate [2] whether or not it is suitable for learning about imprisonment in the GDR. Think about the aspects that, in your opinion, constitute a good analysis and evaluation. (Select one person who takes on the writing.)"	
(2) Collaborative video analysis (collab)				
Duration:	15 min.	30 min.	30 min.	

Measures

To investigate our research questions, we assessed the elements of students' video analyses. For this purpose, we used an extended version of a code book that we had developed in a previous study (Nachtigall et al., 2022). The code book includes both codes derived inductively from students' written video analyses and deductively generated codes building on the literature, for instance, elements from film analysis and based on the definition of historical learning. Specifically, to assess the elements of the students' video analyses, we used the 11 codes described in Table 2. The code book includes categories that can be characterized as (1) content- and medium-related, (2) task-related (focusing on the second part of the task that asks students to evaluate the video), (2) emotion-related (3) reflective-evaluative, and (4) unreflective-evaluative. We look at all codes in order to investigate our first research question. With respect to our second research question, we particularly look at the categories pointing to an emotion-related or reflective-evaluative processing of the video. We coded students' video analyses in a binary way, that is, we assessed whether elements occurred (1) or not (0). Two raters coded 100% of the data and reached satisfying agreements ranging between $\kappa = 0.74$ and $\kappa = 0.96$ prior to discussion. Afterwards, all disagreements were resolved by discussion.

Results

Prior to investigating our research questions, we examined whether the length of students' written video analyses differed between the two conditions, as students in both conditions had the same amount of time for analyzing the 360°-video. Thus, the collaborating students had to split up their time for both analyzing the video and coordinating tasks in the group (e.g. choosing one person for typing down their joint analysis). However, an ANOVA revealed that the word count of the written video analyses did not differ between students who conducted the analysis collaboratively ($M = 152.28$, $SD = 70.96$) and students who examined the video individually ($M = 162.55$, $SD = 80.22$), $F(1,103) = 0.253$, $p = .62$, $\eta^2 = 0.002$.

To investigate our research questions, we conducted two analyses. We firstly conducted Chi-square tests of independence and examined whether certain elements of the analysis were more likely to occur in the video analyses from students of the collab-condition versus the students of the ind-condition. We secondly conducted an Epistemic Network Analysis (ENA). ENA measures and visualizes the connections between the categories used for coding a dataset by weighting the structure of these connections and illustrating this structure in dynamic network models (Shaffer, Collier, & Ruis, 2016). ENA, thereby, enabled us to identify the interplay between the elements that students included in their analyses and to investigate whether these patterns of included elements differed between the two conditions.

Table 2
Codebook used for assessing the elements of students' video analysis

Code		Definition
Content-/medium-related	Summarizing	Students summarize the content of the video.
	Examining the representation	Students describe/analyze features of the medium (e.g., first-person perspective) and their influence on the representation.
	Examining the atmosphere	Students describe the atmosphere or analyze how different features of the representation (e.g., sound) have an impact on the atmosphere in the video.
Task-related	Formulating conclusions	Students draw reasoned conclusions about the video.
	Describing learning outcomes	Students describe things that can or cannot be learned from watching the video.
Emotion-related	Describing emotions	Students describe emotional impressions (e.g., sadness, boredom) of the video.
	Analyzing emotionalization	Students analyze features of the representations that trigger certain emotions while watching the video.
	Transportation	Students make statements that suggest empathy for the characters of the narrative and a feeling of being absorbed into the narrative.
Reflective-evaluative	Reflecting transportation	Students describe the feeling of transportation as a learning outcome, but in a reflective and distanced way.
	Critical conclusions	Students formulate critical conclusions about the video.
Unreflective-evaluative	Accepting the represented past	Students make statements that indicate an adoption of the video content as a valid representation of the past.

Differences between conditions in elements of the video analysis

To investigate the differences between collab-students and ind-students with regard to each element of their video analyses, we conducted three Chi-square tests of independence in order to address potential difficulties underlying the comparison of small groups with individual students (see Kenny et al., 1998). Specifically, we compared (1) the groups in the collab-condition ($n = 17$) with the individual students of the ind-condition ($n = 87$), (2) the individual students of the collab-condition ($n = 58$) with the individual students of the ind-condition ($n = 87$), and (3) the groups in the collab-condition ($n = 17$) with nominal groups composed of individuals of the ind-condition ($n = 27$). For the second analysis approach, we assigned the result of the coded video analysis of the group multiple times, namely to each member of the group. The use of nominal groups in the third analysis approach was inspired by research on knowledge convergence in collaborative learning (e.g. Jeong & Chi, 2006) and refers to an artificial and post-hoc construction of small groups containing students who did not actually collaborate with each other. We created nominal groups containing three to four students of the same class. Per element of analysis, the means of *each* nominal group were either rounded up to 1 (when $M > 0.5$) or rounded down to 0 (when $M < 0.5$) in order to ensure comparability to the binary coded video analyses of the real small groups of the collab-condition. Table 3 shows the descriptive statistics for the elements included in students' video analysis.

The first Chi-square test (i.e., small groups compared to individuals) revealed significant differences between the small groups in the collab-condition and the students of the ind-condition with regard to the following three elements of the analysis: summarizing ($X^2(1) = 9.11$, $p = .003$, $\varphi = .30$), describing learning outcomes ($X^2(1) = 5.99$, $p = .01$, $\varphi = -.24$), and reflecting on transportation ($X^2(1) = 9.00$, $p = .003$, $\varphi = -.30$). Thus, students of the ind-condition focused more strongly on summarizing the content of the video in their analyses, while groups in the collab-condition focused more strongly on describing the potential of the video for learning something as well as on evaluating the feeling of transportation into the narrative in a reflective and distanced way (see Table 3).

The results of the second Chi-square test (i.e., individuals compared to individuals) showed again significant differences in summarizing ($X^2(1) = 29.16$, $p < .001$, $\varphi = .45$), describing learning outcomes ($X^2(1) = 13.93$, $p < .001$, $\varphi = -.31$), and reflecting on transportation ($X^2(1) = 14.39$, $p < .001$, $\varphi = -.32$). But additionally a significant difference with regard to the element of examining the representation ($X^2(1) = 5.64$,

$p = .02$, $\varphi = .20$), showing that students of the ind-condition more often included an examination of the features of the medium in their analysis than students of the collab-condition (see Table 3).

The third Chi-square test (i.e., small groups compared to nominal groups) demonstrated again significant differences with respect to the elements summarizing ($X^2(1) = 14.01$, $p < .001$, $\varphi = .57$), describing learning outcomes ($X^2(1) = 5.80$, $p = .02$, $\varphi = -.36$), and reflecting on transportation ($X^2(1) = 6.99$, $p = .008$, $\varphi = -.40$), but also a significant difference in drawing critical conclusions ($X^2(1) = 5.45$, $p = .02$, $\varphi = -0.35$). Thus, the small groups of the collab-condition formulated significantly more often critical conclusions about the video in their analysis than the nominal groups of the ind-condition (see Table 3).

Taken together, the results of the three different Chi-square tests all suggest that students of the ind-condition focused more strongly than students of the collab-condition on describing rather obvious and content-related aspects (as well as medium-related aspects) of the video in a factual and technical way by summarizing the content (and examining the representation). In contrast, students of the collab-condition focused more strongly than students of the ind-condition on task-related aspects by describing potential learning outcomes as well as on reflective-evaluative aspects by reflecting on the feeling of transportation in a distanced way (and by drawing critical conclusions).

Table 3
Descriptive statistics for the elements of students' video analysis

	Collab-condition		**Ind-condition**	
	Small groups (*n* = 17)	Individuals (*n* = 58)	Individuals (*n* = 87)	Nominal groups (*n* = 27)
Elements of the analysis	Relative frequencies in %			
Summarizing the content	47.1	36.2	62.8	96.3
Examining the representation	35.3	36.2	48.3	59.3
Examining the atmosphere	52.9	48.3	42.1	44.4
Formulating conclusions	52.9	48.3	49.0	51.9
Describing learning outcomes	70.6	70.7	51.7	33.3
Describing emotions	52.9	48.3	51.0	55.6
Analyzing emotionalization	17.6	15.5	13.8	7.4
Transportation	64.7	63.8	55.9	40.7
Reflecting transportation	23.5	24.1	11.7	0
Critical conclusions	35.3	32.8	26.9	7.4
Accepting the represented past	70.6	69.0	59.3	48.1

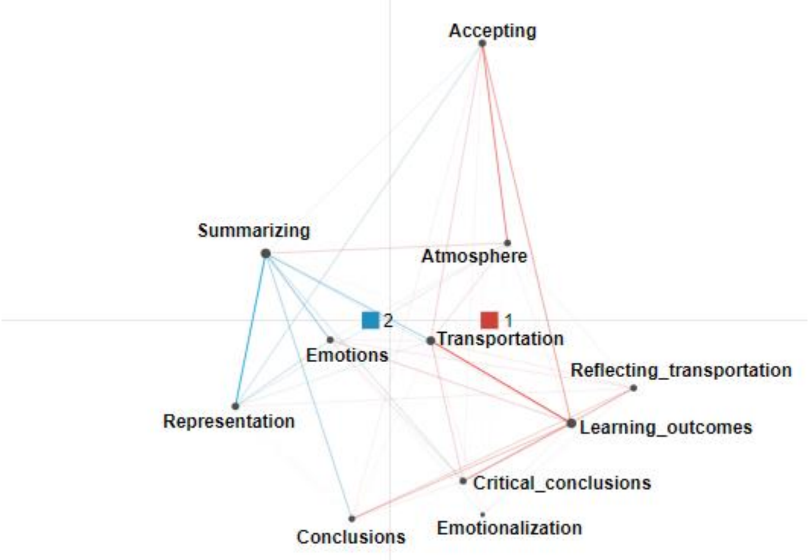
Differences in the interplay of elements of the video analysis

As the results of the three different Chi-square tests revealed highly similar results and as the first analysis approach - the comparison of groups to individuals - constitutes the most strict and sound procedure, we decided to conduct the ENA accordingly. For the ENA, we first constructed mean epistemic networks for each condition and then subtracted the networks in order to make the differences between the groups in the collab-condition and the individual students of the ind-condition salient. In the resulting difference graph (see Figure 2), the darker and thicker lines display larger differences in the strength of connections, and the color of the lines demonstrates in which network the connections are stronger (Shaffer et al., 2016).

As Figure 2 shows, the video analyses of students in the ind-condition (blue) show strong links from summarizing to four further elements of the analysis, namely examining the representation, describing emotions, transportation, and (although less strong) formulating conclusions. On the contrary, the analyses of groups in the collab-condition show strong connections from describing learning outcomes to the following four analysis elements: transportation, critical conclusions, accepting the represented past, and (although less strong) formulating conclusions. They, moreover, show a strong connection between describing the atmosphere and accepting the represented past.

A Mann-Whitney test demonstrated that groups in the collab-condition ($Mdn = 0.41$, $n = 17$) significantly differed from students of the ind-condition ($Mdn = -0.05$, $n = 87$) on the first (x) dimension with a large effect ($U = 1255.00$, $p < 0.01$, $r = -0.70$). This significant difference on the first (x) dimension suggests that students of the collab-condition have their strongest connections in the right part of the space (see red network in Figure 2) and students of the ind-condition in the left part of the space (see blue network in Figure 2).

Figure 2
ENA difference graph for the coded video analyses of collab-groups (red) and ind-students (blue)



Discussion

In the following, we discuss our findings from the ENA and the Chi-square tests in light of examples from students' video analyses. The ENA results supported the findings of the Chi-square tests suggesting that students of the ind-condition focused more strongly than their counterparts of the collab-condition on content- and medium-related aspects of the video in their analyses (i.e., giving a summary of the content and describing the characteristics of the medium) in a rather technical and factual than critical and reflective way. However, the ENA results additionally demonstrated that students of the ind-condition linked these content- and medium-related aspects to emotion-related elements by describing their emotions and feelings of transportation. The following exemplary video analysis (example #1) from a student of the ind-condition nicely illustrates this interplay of content-/medium-related as well as emotion-related elements:

> "The video [...] is about a person who ends up in prison [...]. It describes the situation of the imprisoned people: It begins by showing how it is to live in a prison [SUMMARIZING]. [...] The intention of the video is to look through the perspective of the prisoners. There is a guard who watches over the prisoners [...] [EXAMINING REPRESENTATION]. In addition, they have to live in a room with a toilet, a bed, and a sink [SUMMARIZING]. I found it quite scary there and I felt sorry for the prisoners as they were yelled at [DESCRIBING EMOTIONS]. I kind of empathized with them [TRANSPORTATION]."

The ENA results further supported the findings of the Chi-square tests as they suggested that students of the collab-condition included more strongly than students of the ind-condition task-related (i.e., describing learning outcomes and formulating conclusions) as well as reflective-evaluative (i.e., reflecting on transportation and drawing critical conclusions) aspects. This finding is exemplified in the following video analysis (example #2) of a group in the collab-condition:

> "[...] You can get a sense of reality [TRANSPORTATION] [...]. In addition, it can lead to a better remembering and understanding of the learning content [DESCRIBING LEARNING OUTCOMES] because of the emotional involvement [TRANSPORTATION]. […] On the other hand, not every historical event can be represented by those videos [REFLECTING TRANSPORTATION]: For example, in the case of failed attempts to escape across the border, or even the execution of people, cannot be represented and one must resort to photo sources or the like. In conclusion, VR videos can be a good way to better engage with the topic [FORMULATING CONCLUSIONS] which leads to the need to find a good balance between video sources and other sources [CRITICAL CONCLUSIONS]."

However, the ENA additionally demonstrated that some students in the collab-condition also evaluated the video in a less critical and distanced but more emotional and unreflective way as they referred in their descriptions of the learning outcomes to the feeling of being absorbed into the narrative and the conviction that the video constitutes a valid representation of the past. This might be illustrated by the following exemplary video analysis (example #3) of a group in the collab-condition which includes the elements "describing learning outcomes", "transportation", and "accepting the represented past":

> "[...] In the video, we find ourselves in the situation of the prisoner [TRANSPORTATION] who was questioned and badly treated by the authorities. They spoke with the prisoner in a very derogatory manner and treated him as a serious criminal, based on an assumption that turned out to be false in the end [SUMMARIZING]. The video is very depressing [DESCRIBING EMOTIONS] and it shows how bad the situation was in the GDR at that time [LEARNING OUTCOMES; ACCEPTING]. In summary, the video helps to put yourself in the situation of a prisoner [TRANSPORTATION; FORMULATING CONCLUSIONS] [...] and to empathize with what people had to go through and had to experience [TRANSPORTATION]."

Taken together, with respect to our research question 1, the results of both the Chi-square tests and the ENA point to an effect of collaboration on students' processing of an emotionalizing and immersive 360°-video. Specifically, the Chi-square tests and the ENA demonstrated significant differences between the ind-condition and the collab-condition with regard to the elements included in students' video analyses. Students of the ind-condition included significantly more often content- and medium-related elements in their analyses, while students in the collab-condition included significantly more often task-related and reflective-evaluative elements in their analyses. With respect to our research question 2, both tests showed that students differed in their cognitive processing, as students in the collab-condition examined the video in a more reflective-evaluative way than students of the ind-condition. Regarding students' emotional processing, the Chi-square tests demonstrated no differences between the two conditions, and the ENA also illustrated that students in both conditions included emotion-related elements (especially "transportation") in their analyses. Moreover, the ENA and the exemplary video analyses showed that collaboration does not per se lead to a more cognitive and less emotional processing of 360° videos, pointing to differentiated impacts of collaboration: While some groups in the collab-condition indeed examined the video in a critical, reflective-evaluative, and distanced way (see example #2), some groups processed the video in a more emotional and less critical way (see example #3).

Conclusion

The impact of collaboration on students' cognitive processing of an immersive and emotionalizing history-related 360°-video, as demonstrated by the findings of the present study, can be nicely described through the lens of both the ICAP framework (Chi & Wylie, 2014) and Bloom's taxonomy of educational objectives (see Krathwohl, 2002). However, these frameworks have to be treated with care due to the difficulty of empirically examining their theoretically assumed dimensions of cognitive engagement and processing (see Chi et al., 2018). Consequently, these two frameworks did not constitute our initial theoretical lens and, thus, did not affect the present investigation. Instead, they merely provide an interesting perspective on the interpretation of our findings. According to the ICAP framework, Interactive behaviors (i.e., arguing, debating, and discussing) and Constructive behaviors (i.e., generating "new ideas that go beyond the information given", Chi & Wylie, p. 222) constitute modes of high cognitive engagement with the learning material at hand. As collab-students focused more strongly than ind-students on evaluating the 360°-video in a reflective and distanced way by formulating their own critical conclusions, their cognitive processing of the video might be described as constructive and interactive. In contrast, as ind-students focused more strongly than collab-students on describing rather obvious and striking features of the video by summarizing its content and describing the features of the medium, their cognitive processing might be described as active. The ICAP framework describes activities in which learners only Actively repeat contents of the instructional material or just Passively receive instructions as modes of low cognitive engagement (Chi & Wylie, 2014). Moreover, according to Bloom's Taxonomy, activities such as summarizing constitute less cognitively complex processes than activities such as evaluating (Krathwohl, 2002). Consequently, ind-students' analyses of the 360°-video point to lower levels of cognitive engagement and complexity, while collab-students' video analyses suggest higher levels of cognitive engagement and complexity. This conclusion is also in line with the findings from Gokhale et al. (1995) showing that working in small groups promotes more critical-thinking processes than working alone.

However, although our findings suggest that a collaboratively conducted video analysis promotes a more cognitive processing of a history-related 360°-video than an individually conducted analysis, our results did not demonstrate significant differences in students' emotional processing of the video. Therefore, one could conclude that collaboration does not result in either more cognitive or more emotional processing of 360°-videos but that both processes can run in sequence (e.g. emotional followed by cognitive processing as in example #2). Alternatively, and as already discussed above, one could conclude that collaboration has differentiated effects on students' processing of 360°-videos and that these effects depend on the collaboration processes. This conclusion is in line with the "interactions paradigm" (Dillenbourg et al., 1996) emphasizing that collaboration is not per se effective for learning but rather particular interactions and processes during collaboration. To get insights in collaboration processes that promote either a more cognitive or a more emotional processing of history-related 360°-videos, it would be interesting to record and analyze the group discussions. As this was limited by feasibility due to the whole-class situation in the present study, it might be useful to collect process data of students' discussions in a lab setting in addition to the data from the field in a future study.

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Relational Connective Tissue: The Role Relationships Play in Freedom of Movement Across Culinary Learning

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Abstract: Often intangible and invisible, relationships are pivotal in connecting soft/hard realities in ways that allow for participation in learning that imparts material and lasting impacts for marginalized youth experiencing complex, multidimensional barriers. We present the case of an immigrant Latinx youth who experienced *freedom of movement*—"supporting crossing physical boundaries of location, domain-specific boundaries of different topical areas, and conceptual boundaries of value and goodness of fit" (Pinkard, 2019, p. 40)—in an understudied area: culinary learning. We expand on the concept of *connective tissue* by analyzing a youth's movement across the Healthy Learning Ecosystem Framework to render visible the *relational connective tissue* that afforded freedom of movement across *infrastructures* of learning (Pinkard, 2019). Through an ecological life history case study approach, we demonstrate and discuss the potential that theorizing relational connective tissue holds in surfacing the assets Communities of Color bring to educational experiences, which presents implications for designing more equitably around how nondominant learners access freedom of movement across space, time, and multiple axes of marginalization.

Introduction

Prior work in the learning sciences that addresses equity through understanding how nondominant communities experience learning has pointed to the need to "understand how complex learning ecologies support learning," particularly for youth most overlooked by educational and learning systems, including "immigrant youth, dual language learners, and youth from under-resourced schools and communities" (Gutiérrez & Jurow, 2016, p. 566). This paper builds on how relationships affect how marginalized youth experience physical, social, and cultural realities—and by extension, how their learning is supported or constrained across their ecosystems and lifetimes (Pinkard, 2019).

Scholars studying geospatial space in tandem with sociocultural aspects of learning have created frameworks of analysis to render visible and improve upon the "interactions, routines, and practices" that afford or constrain learning (Erete et al., 2020, p. 1630). However, these social practices are deeply tied to relationships across the lifetime—which, despite holding deep political and materially transformative possibilities in learning (Freire, 1970), are often invisible and thereby difficult to track, and thus understudied in discourse around marginalized youths' learning experiences (Vossoughi et al., 2020).

We address this need by attending to how relationships inform realities of learning in a life history case study of an immigrant Latinx youth's learning ecology in an understudied area of the learning sciences, culinary arts. We apply an ecological framework that posits agency and exploration in learning as *freedom of movement,* and which makes explicit the various physical, topical, social/cultural boundaries (understood as *hard* and *soft infrastructure*) that youth traverse in their learning, as well as the strands of *relational connective tissue* that make such movement possible (Pinkard, 2019). We recognize the many possible forms connective tissue can take, and build on Pinkard's (2019) conceptualization of the concept to focus on theorizing connective tissue through the lens of relationality. We theorize relationships as central to connecting these infrastructures, and identify what we call *relational connective tissue* as invisible, intangible agreements and dynamics which constrain and afford various degrees of freedom of movement in a learning ecosystem. For learners from Communities of Color who experience disparities in accessing educational opportunities due to missing connective tissue, we highlight relational connective tissue as refigured stepping stones demonstrating rich cultural assets, typically overlooked by deficit lenses. The following question guides our inquiry into our case study: *What relational connective tissue mediated freedom of movement across physical, topical, and conceptual boundaries in an ecosystem of culinary learning for an immigrant Latinx youth?* This paper analyzes the retrospective life history case of Elias (pseudonymized), an alumnus of an out-of-school culinary arts program in Los Angeles. By identifying the essential role that relational connective tissue plays in bridging infrastructures of learning, we render visible inequities that shape the ways marginalized youth experiencing complex, multidimensional barriers (often preordained or transformed by relationships) experience and access learning across an ecosystem and lifetime.

Conceptual framework

We build on scholarship that makes visible the social practices that undergird learning, to consider what Vossoughi et al. (2020) refers to as the *relational histories* of learners and stakeholders in space. Specifically, we focus on the pivotal, connective role of relationships in learning across the lifetime—thereby expanding upon the ways sociocultural learning scientists theorize the role of relationality in the ways nondominant learners access and experience learning across time, as well as across the physical, social, and cultural spaces which comprise their learning ecologies (Nasir & Hand, 2006; Pinkard, 2019; Vossoughi et al., 2020).

We gravitate to the space of out-of-school culinary making for the dynamic, quotidian, and deeply imbued cultural nature of its learning—which lends to its significant potential for democratized, interconnected learning across a variety of domains, knowledge spaces, and critical competencies across the lifecourse. Of consequence, according to the US Bureau of Labor Statistics, nearly 30% of those employed in the food/service industry in 2021 were Hispanic/Latinx, 13% were Black and 7 % were Asian. While scholars like Scribner (1985) have documented the robust forms of learning and distributed expertise amongst dairy farmers, the extant literature in the learning sciences around culinary learning view it as a means to access more meaningful STEM learning (Clegg et al., 2010; Clegg et al., 2014; Yip et al., 2012). Though innovative, this focuses on an output of domain-specific learning in a controlled setting rather than what Pinkard (2019) refers to as *movement of learning*, which refers to a sociocultural conceptualization of learning across multiple physical and social boundaries from an ecosystemic lens.

We apply this view on learning to a case study of an immigrant Latinx youth to understand how culinary learning occurs across the lifecourse and beyond physical, social, and cultural spaces. Specifically, we focus on the concept of learning as *freedom of movement* in this paper to refer to the degree to which youth are able to engage in exploration and participation across a variety of boundaries—"physical boundaries of location, domain-specific boundaries of different topical areas, and conceptual boundaries of value and goodness of fit" (Pinkard, 2019, p. 40). We apply the Healthy Learning Ecosystem Framework (HLEF) to our case study to map movement across these boundaries and make explicit the factors that allow for such movement. HLEF consists of five domains strung together by *connective tissue—stakeholders*, *soft infrastructure, information infrastructure, hard infrastructure*—all leading to *outcomes* (Pinkard, 2019). This paper focuses on the operationalization of soft/hard infrastructures in order to further theorize connective tissue. Soft infrastructures consist of the abstract and institutional agreements which make learning possible, (*domain-specific/topical boundaries* and *conceptual boundaries of value and goodness of fit*). Hard infrastructure consists of the *physical or material boundaries* of learning such as the buildings, roads, and physical spaces through which learning occurs. Connective tissue serves then as the binding force between infrastructures, and can take many forms including but not limited to: caring adults in spaces that plan carpooling systems to shuttle youth between physical spaces of learning. Nonetheless, connective tissue may go overlooked in the design of learning opportunities, or center dominant forms of access and experience that lead to inequitable outcomes. We highlight these structural inequities and demonstrate some of the ways they are bridged by community stakeholders through the development of relational connective tissue across a learning ecosystem.

HLEF was intended for the collective sensemaking, improvement, and design of collaborative learning environments across different stakeholders of a learning ecosystem. We expand on this purpose by making explicit the pivotal roles various stakeholders play across the learning ecosystem in how learning outcomes are accessed and experienced, which can serve as focal points of design in learning ecologies. For the purposes of this paper, we further theorize connective tissue to focus on the concept of *relational connective tissue*—the relationships that often go "unnoticed," or unacknowledged, particularly within Communities of Color—to get at the often-invisible dynamics and (re)negotiated solidarities forged between community members, essential to tying together hard/soft infrastructures which constrain and afford freedom of movement for marginalized youth (Pinkard, 2019, p. 44). Our application of the framework presents an opportunity to understand how a marginalized youth experienced learning across an ecosystem across their lifetime, and elucidates some of the many essential relationships and intimacies within their community which connected them to experiences and opportunities which manifested into lasting, material impacts on their future.

Data and methods

This case study was one of 102 retrospective life history interviews, conducted ten years after concluding program participation, as part of a larger project around the long-term effects of participating in community arts programs. Given its holistic, reflective nature, our life history approach lends itself to understanding how learning was experienced and understood by a participant over the life course, and informed by their movement across physical, domain-specific, and conceptual boundaries. From the start, we bookmarked cases indicating tensions reflective of structural issues of marginalization across domains of their life to better understand how inequities shaped the learning experiences of the youth whom these programs most aimed to serve, both during and beyond the program space and time. Echoing factors of marginalization outlined in the extant literature, many of these cases tended to feature themes around immigration, dual language learning, socioeconomic status, and complex cultural narratives which came in tension with participants' interests and career choices (Gutiérrez & Jurow, 2016).

The study for this analysis was chosen as the only one in the sample for its focus in an understudied area in out-of-school culinary making which encompassed the aforementioned themes, and seeks to generate new insights around learning within this domain. The case is a life history interview with Elias, who at the time of the interview was a 22-year-old former participant of an out-of-school culinary arts program in the urban Los Angeles area. In a two-hour interview, the lead author asked Elias reflective questions spanning various life domains (i.e., home life, childhood, academic experiences, experiences in the OST program, current life and perspectives) to capture the role of relationships in his movement across a culinary learning ecosystem through seemingly disparate, yet interconnected nodes of his life.

Elias's case was chosen for analysis because it centers on how a nondominant learner navigated and experienced infrastructures usually taken for granted in learning: language and cultural acclimation to local space and culture. As a Latinx immigrant who did not know English moving through spaces of learning which lacked formal infrastructures fit for his needs, Elias nonetheless resisted in many ways and formed relationships that helped him participate meaningfully in culinary learning and all that came with it—traversing xenophobic negotiations of acclimation around language and local social dynamics, as well as cultural, gendered narratives around interests, and career aspirations. Through his time in the program and the relationships across his ecosystem, Elias learned English to deepen his culinary learning, and went from being a shy, introverted youth to one who starred in videos speaking enthusiastically about various curricula within the program—and who would later return as an alumnus employed in the culinary industry to speak about his experiences.

We chose Elias's case because it demonstrates the pivotal role of relational connective tissue in allowing not just access to learning opportunities, but *meaningfully experienced* learning for often overlooked marginalized youth that arose through relational histories to supplement minimal or lacking connective tissue in under-resourced areas. Elias's case exemplifies not only freedom of movement across various physical, cultural, and social boundaries for a nondominant learner—but also demonstrates the transformative potential of relationships on learning through the lifecourse across multiple barriers/axes of marginalization.

Analysis

Interviews were audio recorded, transcribed, and deductively coded for *soft infrastructure, hard infrastructure,* and *relational connective tissue* (Bingham & Witkowsky, 2021). In the context of our analysis, soft infrastructures consisted of school offerings, out-of-school culinary arts program offerings, and peoples' assumptions of culinary learning (i.e., learning about different countries and their cultural norms/cuisines, hydroponics gardening techniques, business pitch activities, field trips, etc.). The hard infrastructure consisted of the school, the culinary program space, the roads and transportation to each site, the tools students would use in their culinary learning, and the farmers markets, restaurants, and photo stores students would visit to learn about multiple aspects of the food industry. Relational connective tissue was mapped backward from interactions and routines featuring various stakeholders which made it possible for Elias to access these soft and hard infrastructures across the ecosystem (i.e., the friends who walked with him to school and the program through the city).

The lead author wrote reflective memos around excerpts, coded for relational connective tissue to surface insights around how relational dynamics shaped experiences around infrastructures, then clustered these memos and excerpts into the following three specific categories of boundaries traversed under hard and soft infrastructure which relational connective tissue bridged: *physical* boundaries (nested under hard infrastructure), and *domain-specific* boundaries and *conceptual/value-based* boundaries (both nested under soft infrastructure) (Pinkard, 2019).

Findings

In this section, we walk through the relational connective tissue which served as bridges for Elias's movement through physical boundaries, domain-specific boundaries, and conceptual/value-based boundaries. At the time of writing this paper, Elias works as an ingredient consultant and chef at a market/cafe in Los Angeles which offers produce and grocery products from around the world. He immigrated to California from Honduras in 2015, and experienced challenges to his participation in his educational pursuits across familial and academic spaces. In addition to difficulties in acculturating to a new space and common language, he was often bullied at school by peers, and even by educational staff, for his difficulties with English—describing his experience at school as being "traumatized with being in a cage." Elias found a "safe spot" in an after school culinary arts program in Los Angeles, and described the many ways his relationships with people in his life were central to moving through culinary learning. We emboldened excerpt segments exemplifying relational connective tissue for emphasis.

Relational connective tissue across physical boundaries

In this section, we analyze Elias's movement across physical boundaries, and relational connective tissue that aided and hindered such movement across the lived challenges of hard infrastructure for youth situated in downtown Los Angeles. He recalls the distance between his home, school, the culinary arts program, and the relationships around movement between these physical infrastructures (see Table 1).

Table 1

Finding 1: Relational Connective Tissue across Physical Boundaries of Hard Infrastructure

	Excerpts from Elias's interview	Researcher comments on relational connective tissue
1a	So, but **I had to walk like [...] around 10 blocks** from my house to the school and **I was feeling too scared because I, when I was going to school, I was going with my, one of my best friends**, that he is **still one of my best friends**, since we met in 2017. So we're still friends, so we were going, he was living close to me [...] sometimes he was like, because schedules change, so we have to um, um go in group because it was nice, you know, sometimes it was still, **the light was up**, but…[the program] was, it was close to my house, it was not too far, not too close.	Elias experienced safety concerns surrounding hard infrastructure as a lone youth getting around in the city, especially when it got dark. A close friend and group of friends accompanying him on his walk served as relational connective tissue connecting physical boundaries to help him get safely between home, the program, and school.
1b	**Sometimes [the program director] was also giving us a ride home** so she was very kind and, and very care person that she was like sometimes taking us home if it was super late and we were living super far and we were on her way.	Caring adults like the culinary arts program director comprised additional relational connective tissue between physical boundaries of the program space and home.

This finding exemplifies the importance of considering within a learning ecology how peers' and adults' solidarity around youth needs of accessing hard infrastructure play key roles in the ways youth are able to move across spaces of learning. In excerpt 1a, Elias refers to a reality and challenge which many youth face around transportation and safety in the city, and the commonly understood safety practices for youth getting around on foot—to "go in [a] group," and to do so when "the light was up." Elias refers to a relational history with one of his best friends that has continued "since [they] met in 2017" when describing the relational connective tissues tacitly understood by marginalized youth in urban settings (walking with friends) bridging his home, school, and subsequently the culinary arts program, which is located near the school.

Elias also speaks of another relational connective tissue to the physical space of culinary learning which highlights the unique affordance of the out-of-school space: the relationships youth form with caring adults in this space that are neither parents, teachers, nor caretakers. The resulting relational connective tissue between material spaces described in excerpt 1b are, in fact, made possible through *affective informality* (Chew et al., 2022) in the space—moments of rupture centering a political commitment to care, which result in new possibilities and intimacies—furthered by the familiar, typically domicile practice of culinary making. There is something to be said about the ways relational connective tissue is negotiated between stakeholders and hard infrastructures in urban settings around marginalized youth—the ways safety and varying resources among stakeholders are tacitly understood and arranged to result in relational connective tissue that makes freedom of movement across physical boundaries of learning possible.

Relational connective tissue across domain-specific/topical boundaries

In this section, we speak to the ways that relational connective tissue bridged physical boundaries to domain-specific/topical boundaries in Elias's learning. Throughout our talk, Elias spoke of the ways that not knowing English shaped the ways he was able to engage in educational spaces, and the ways people engaged with him—like the peers who bullied him, or the teachers who "[spoke] Spanish but [who] didn't want to speak Spanish to

[him].” In contrast to these in-school experiences, Elias recalls how relational dynamics differed in the after school culinary arts program, and how they aided his movement through various topical boundaries (see Table 2).

Table 2

Finding 2: Relational Connective Tissue across Topical/Domain-specific Boundaries in Soft Infrastructure

	Excerpts from Elias’s interview	Researcher comments on relational connective tissue
2a	It was super cool because **the environment in the program was about making feel people loved and welcome** and every time I would say, I wish I can, and I was telling everybody I wish I was, I was, like you, that you know the language you understand everything and if I was you, I would be able to answer all these questions and be on top of it, but unfortunately I am not. **And then people were helping me translating to [our program director], [to]** our interpersonal person that was helping us with our personal interpersonal skills, you know, it was, it was just a very lovely environment there.	Elias’s ability to access domain-specific knowledge shared in the culinary program is blocked by language barriers unaided by a lack of hard infrastructure in translation services. However, surrounding peers and program staff contributed to a positive environment through their patience and translation—serving as relational connective tissue for Elias to move across topical and domain-specific knowledge: linguistic, culinary, cross-cultural, agricultural, and socioemotional learning.
2b	And then **my English got better, then my anxiety got a little bit down, we learn how to do hydroponics, and interpersonal skills, uh, information about ingredients from other countries’ food, from other countries**, and it went so deep that it got my attention so much that [...] it took my mind off a little bit from the depression that I was going through, the anxiety I was having, it helped me a lot.	

In excerpt 2a, Elias highlights how his ability to access domain-specific knowledge is blocked by structural barriers of language (“if I was you, I would be able to answer all these questions [...] but unfortunately I am not”). This, in itself, reflects the barriers Elias experienced as an immigrant youth in acknowledgement of the missing connective tissue in place for him to move through culinary learning. However, in contrast to the complex language-based alienation he experienced in school settings, he emphasizes the *relational* connective tissue that allowed him access—the “lovely environment” people around him created which made him feel “loved and welcome,” and the translation that his peers would take up on their own accord since the program director and staff did not speak Spanish.

This finding exemplifies the importance of considering how proximal community members’ attitudes and actions around brokering soft infrastructure affect the degree of freedom of movement youth experience in learning. Where there was no connective tissue to soft infrastructures in place, endeavors of patience and care from the peers and adults in the program knit together the relational connective tissue that allowed Elias to move across topical, domain-specific knowledge (i.e., the linguistic, agricultural, interpersonal, and cross-cultural culinary learning as described in excerpt 2b). This cross-domain learning served meaningful in each domain-specific instantiation, and served as a solid foundation for culinary knowledge and learning which would later assist Elias in his professional journey through the culinary arts. Nevertheless, it also coalesced into an outcome more than the sum of its parts for Elias in the moment: helping him through the depression and anxiety reinforced by his experiences of acculturation. This movement, in tandem with Elias’s other movement through boundaries, exemplifies the potential of how broadened freedom of movement in culinary learning can be experienced, materially leveraged for future goals, and its felt restorative potential for marginalized youth experiencing a complex constellation of structural oppression lived in everyday ways.

Relational connective tissue across conceptual boundaries of value/goodness of fit

In this section, we speak to the relational connective tissue that worked in tension and tandem with Elias’s movement across conceptual boundaries of his values and perceived goodness of fit in culinary engagement. Elias reflects on his movement through how he perceived his goodness of fit in culinary spaces, as impacted through conflicting messages from family members and teachers (see Table 3).

Table 3

Finding 3: Relational Connective Tissue across Conceptual Boundaries of Value/Goodness of Fit in Soft Infrastructure

	Excerpts from Elias's interview	Research comments on relational connective tissue
3a	My dad at first, he wanted me to be a doctor [...] because my dad was a type of person that, who was [like] [...] **you have to do something that a man does because the kitchen is only for women** because when you come to the home when you, once you're married the woman has to have your food ready. **Because, it's a woman thing, you shouldn't be cooking.** So a couple of times, he hit me really bad because he found me in the kitchen.	Elias's relationship at home with his father constraints movement across culinary learning. His father expresses gendered perspectives around interests and future careers and punishes him for violating them—instilling in Elias negative perceptions of his goodness of fit in culinary spaces.
3b	But my grandma teaches something else right [...] my grandma was so patient, she was like your dad is wrong [...] So my grandma teach me how to cook. She showed me that not only womans cook, and **she showed me the movie Ratatouille,** and she said, you see all those people in there? **There's only one woman cooking. The rest are mans. Your dad is wrong.** And **she showed me Master Chef**, where I met one of my friends from the competition, and she said, "you see? **There's womans and mans cooking, your dad is wrong."**	Elias's relationship with his grandmother in the same familial space grants him movement across cooking, pop culture, and media spaces which allows him to renegotiate his goodness of fit in culinary spaces as a young boy with interests in cooking.
3c	So I got here, and one of my teacher, one day, my ELD teacher, she asked me, "**Elias, what do you want to do for life? For your life, for living in your future?**" I was like, "I don't know. I…I love cooking," but I felt afraid because of my dad. And I was not living with my dad anymore—but [...] I still felt scared and afraid for my dad—what if he finds out that I'm cooking, and he comes and hit me?	This excerpt highlights the role of caring adults in the learning ecosystem. These adults help Elias reframe his focus on what he wants to do for his future work. This interaction leads to further questions Elias has to negotiate in himself around what he values, is interested in personally and professionally.

In excerpt 3a, Elias describes the ways his relationship with his father around the domain of culinary engagement—and by consequence the gendered narratives his father expressed and punished him for violating—instilled fear and apprehension around the ways Elias regarded his values and goodness of fit in culinary engagement and spaces as a young boy. However, as exemplified through excerpts 3b and 3c, his relationships with his grandmother and ELD (English Language Development) teacher across domestic and in-school settings, Elias was introduced to different conceptual spaces to traverse, and found different narratives and cultural values that countered those shared by his father (that men *can* and *do* cook, and to center what *he* wants to do for the rest of his life) that asserted his personal feelings around goodness of fit in the culinary landscape. His grandmother's use of various food-centered media (Ratatouille, Master Chef), further introduced digital, popular cultural spaces which Elias moved through to renegotiate his understandings of how he fit in culinary spaces as a young boy negotiating gendered conceptions around culinary practice.

These interactions demonstrate the ways that relational connective tissue set up conditions for Elias to move across considering culinary practice as an interest to a career possibility. Despite strong, reinforced discouragement from his father, Elias's relationships with other caring adults in his life who centered and supported his interests in their interactions allowed him to focus on honing his emerging personal values and explore how he perceived his goodness of fit, and ultimately his career path, in the culinary arts. Excerpts 3b and 3c demonstrate how relational connective tissue facilitated movement across conceptual values, which was pivotal in the negotiation of meaningful, lasting material decisions a marginalized youth made around his professional career directions. This finding exemplifies the importance of considering how the conceptual narratives around participation, values, and goodness of fit youth are exposed to through their relationships affect the ways youth are able to and ultimately decide to move—or not move—through learning.

Conclusion, limitations, and future directions

Through our analysis, we demonstrate how theorizing relational connective tissue highlights an undiscussed point of focus in the design and improvement of learning: the roles that various stakeholders play in how marginalized youth may access and experience movement across a learning ecology, across the lifecourse. Elias's case demonstrates the ways in which relationships often undergird lasting, material outcomes on the decisions, directions, and development of marginalized youth. His movement across physical, topical, and conceptual boundaries of culinary learning was made possible through pivotal interactions—not purely one-off, serendipitous interactions, but interactions rooted in relational histories and tacit interpersonal negotiations. Moreover, this mode of navigation speaks to the community cultural wealth (Yosso, 2005) inherent in marginalized communities—that of Elias, his friends, family, and peers—which is apparent through the ways Communities of Color knit relational connective tissue to hold one another, and supplement where connective tissue may otherwise be missing.

By understanding how relational histories tie stakeholders, infrastructures, and outcomes together, frameworks such as HLEF can be leveraged by stakeholders across learning ecologies to ensure that expanded learning opportunities are accessed and meaningfully experienced by marginalized youth in urban settings. Our ecosystemic analysis signals the importance of bringing together various community stakeholders, spaces, and opportunities in the design and support of freedom of movement across a learning ecosystem for youth facing varied, complex barriers to access and participation. Stakeholders across in-school and out-of-school settings can work together to surface the ways relationships are currently supporting or constraining the ways youth access learning infrastructures. With these insights, stakeholders can collaboratively design intentional safeguards and policies that function in ways similar to relational connective tissue to more systematically and equitably support the ways marginalized youth are accessing and experiencing learning across the ecosystem.

Elias's case demonstrates the unique affordance of out-of-school culinary learning as a naturalistic, culturally-imbued venue of learning dynamically cultivated through familial histories, (re)negotiation of tensions, values, and solidarities—rich with potential to study how sociocultural learning map onto issues of equity for nondominant learners through the learning sciences. Future work around culinary learning which examines quotidian relationships "through the prism of race, class, geography, and history" (Pinkard, 2019, p. 44) can speak to ways the domain can be leveraged for democratized learning opportunities and design which support freedom of movement in and beyond currently conceptualized boundaries and spaces, as well as speak to the experiences and realities of people from a range of diverse, marginalized populations.

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Constructing “Kinds of People” With Data in Classroom Talk: Operationalizing Racial Data Literacy

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Abstract: In this conceptual paper we use vignettes from classroom interactions to examine the construct of *racial data literacy*. Two cases of teaching and learning with data visualizations about racialized populations in the United States – African Americans and Mexican Americans – are used to illustrate the ways racial literacy and data literacy can intertwine in classroom discourse, with stakes for learning and learners. Examining our own teaching, the paper invites the Learning Sciences community to take up the project of further operationalizing racial data literacy, and building a shared understanding of how we can promote it in classroom practice.

Introduction: Where are we with *racial data literacy*?

In 2016 Philip, Olivares-Pasillas and Rocha published the paper “Becoming racially literate about data and data literate about race” (Philip et al, 2016), which has been cited over 100 times. In part a cautionary tale, they argued that the push to integrate data literacy into school subjects has overlooked the ways race and data come together in classroom talk. Their call for “racial data literacy” has been echoed by many learning scientists (e.g., Lee, Wilkerson & Lanouette, 2021; Warren, Vossoughi, Rosebery, Bang & Taylor, 2020), but much work remains to articulate how such a literacy develops. Philip et al’s *racial data literacy* includes the capacity to critically interpret data that invokes the concept of race, while recognizing the ways societal meanings of race can be reproduced, challenged, or transformed through the use of data. It combines sensitivity to the operations of power and ideology in racialized discourse, with awareness of the ways data are used to construct models of social phenomena.

In this paper, we advance the understanding of racial data literacy by examining our own attempts to develop it in instruction, using examples of classroom interactions to highlight particular attributes of race-talk with data. This is primarily a conceptual paper elaborating the construct of racial data literacy, using classroom vignettes as illustrations of these ideas. We present two classroom discussions of data visualizations in which racialized identities become both the focus of instruction, and also the field of identity positionings made available for participants in the discourse event. The depictions of teaching and learning in the vignettes are not presented as models of exemplary practice, nor as empirical evidence of learning, nor as cautionary pitfalls to be avoided. Rather, they offer insights into moments in classroom talk in which racial literacy and data literacy come together. We explore them for the purposes of more clearly operationalizing the construct, and better understanding the sometimes-complex interactional dynamics that accompany data-mediated discussions of race and racism.

Theoretical framing: Making up “kinds of people” with data

Philip et al (2016) illustrated the ways racial identities and ideological discourses are negotiated and contested in moment-to-moment classroom interactions. While any text can be invoked in these processes of positioning and contestation, data play a particular role in sense-making about race. Representational practices involve the interpretation of data to invoke a “represented world” in the shared discursive space (Latour, 1999). We follow Radinsky (2020) in operationalizing data as “representations of quantity, space and time – numbers, charts, graphs, maps – as they are mobilized for inquiry and argumentation” (p. 375), with a particular focus on the kinds of demographic data used in the social sciences. Hacking (2007) points out that *kinds of people* get “made up” through processes of creating and using such data. The categories are brought into being by institutions and experts, with consequences for the experiences and identities of the people to whom these categories get applied.

Data literacy and racial literacy are competencies that often fail to come in contact with each other (Benjamin, 2019): one can be a highly competent data scientist in other respects, yet incompetent in recognizing ideological and interpersonal racial dynamics, and vice versa. Racial data literacy requires an awareness of the processes of “making up people,” by which categories of people are brought into being through classification systems, and the ”looping effect” by which “the classified people enhance and adjust what is true of them” (Hacking, 2007, p. 289) *(1)*. Making sense with social-scientific data involves participating in these processes.

Methods: Data collection and analytical approach

The classroom discussions analyzed here are drawn from a program of design-based research in which online geographic information system (GIS) tools were deployed in the development of curriculum to study migrations of different populations in the history of the United States. The project included middle school, high school, and college classrooms, and involved collaborating teachers at each level in the design of curriculum materials and assessments, as well as co-teaching lessons. The excerpts analyzed here are drawn from one of the middle school classrooms (Case 1), and one of the first author's undergraduate, pre-service classrooms (Case 2).

Class sessions were videotaped by a research assistant and transcribed by a member of the research team. The two classroom discussions analyzed here were among several identified in the larger data corpus as events in which racialized people were the focus of the historical discussion, and in which racialized identities were at stake in the discursive event. For the present analysis, the authors coded each transcript to identify discursive moves that invite, model, or give feedback on racial characterizations; take up, shift, or challenge racializations of people and/or data; or exemplify data visualization practices explicitly or implicitly valued in the lesson. We focus on the ways racialized identities of the people in the room might be engaged by these moves: risks, exposure to extant racial narratives, opportunities for epistemic agency, and constructions of agentic racialized identities.

The first author's analysis of race talk in classrooms is mediated by his identities as a White educator, a co-teacher in Case 1, and instructor in Case 2. Facilitating classroom conversations about race, particularly as a White teacher with students of color, creates power dynamics that can undermine honest, open discussion of race and racism, requiring work to build trust and establish shared norms and understandings (Conklin, 2022). Given the prevalence of White educators in American schools, we see this as an opportunity to understand how racial data literacy can develop in such classrooms. There is also a risk of teacher-researchers telling stories of their own practice being overly self-congratulatory, overly self-critical, or otherwise untrustworthy. In studies of race talk, there is a risk of a White research perspective perpetuating dominant narratives about people of color and White people alike. The second author was not present in either classroom, and her White identity is nuanced by being Israeli, affording an "insider-outsider" perspective on race talk in American classrooms, challenging and exploring the interpretations of the first author, and making implicit assumptions explicit for inspection. We seek to leverage insights from these contrasting perspectives, while maintaining a non-evaluative yet critical analytical stance.

Illustrations: Negotiations of racial data talk in two classrooms

Case 1: Co-constructing 100 years of Black and White people on a US map

The focal lesson was the first day of a 7th grade social studies unit in a neighborhood public school whose enrollment was identified by the district as 99% African American, in a hyper-segregated Black Chicago neighborhood. In a whole-class discussion, the teachers used an exploration of a USA population data map, created with the website *Social Explorer (2)*, to introduce historical African American migrations. The classroom teacher and co-designer of the unit was a Black woman, and the researchers were a White man (co-teacher, first author) and a Black woman (research assistant). Five aspects of the discourse are illustrated here: 1 normalizing talk about race; 2 making it OK to talk about White people; 3 maintaining an inquiry stance through strong emotional reactions; 4 adopting a Black perspective in sense-making about a represented world of Black people; and 5 looking closer at surprising data.

1.1. Normalizing talk about race

The data talk in the lesson included repeated and specific references to people as "African American" and "Black," the two terms used interchangeably by both co-teachers. While students would initially refer to the data as "people" without any racial indicator, the teachers modeled making "clear and specific observations" that included racial identifiers, and scaffolded students' use of the labels when they left them out:

63. Student: There's a lot of people over there [*pointing to map*]
64. Co-teacher A: There's a lot of people over there. Specifically? [*pointing to data legend*]
65. Multiple students: African American people
Similarly:
89. Student: More people in Louisiana than in Washington
90. Co-teacher A: He picked two places, Louisiana and Washington. Louisiana had more -- ?
91. Student: Black people
92. Co-teacher A: More Black people in -- ?
93. Multiple students: 1910
94. Co-teacher A: In 1910. Now we got a nice, specific comparison: Louisiana had more African American people than Washington in 1910.

This modeled the appropriateness of mentioning race, as part of data practices. Altogether there were 77 mentions of racial identifiers in the 20-minute discussion, with an increasing share of them coming from students as the lesson progressed. In the context of building racial data literacy, it is hard to overemphasize the prevalence of "colorblind" discourse in American classrooms (Bonilla-Silva, 2006; Stoll, 2014). When teachers use euphemisms for racial categories, students may also avoid mentions of race, or use them as potent, counter-script disruptors. Having Black and White co-teachers both insisting on clear and consistent use of these labels with the data created a context in which talking about race became normalized. The interchangeable use of the terms "Black" and "African American" also supported this normalization, as "Black" better matched discourse norms in the larger community, offering a less formal name for students' own identity.

1.2. Making it OK to talk about White people

A key development in the progress of the lesson was when a student introduced White people into the discussion: "Arkansas had African American and Whites, but more African Americans because it was a little bit darker at the bottom [*gestures*] than at the top." Another student picked up the idea and asked about states that had very few Black residents in 1910, and both teachers encouraged the questioning:

119. Student 2: The other states, they're all White people there?
120. Student 3: Yup
121. Co-teacher A: In these other states, does that mean it's all White people? [*pointing to map*] Up here? Over here? …
123. Student 4: No
124. Co-teacher A: Well, she asked a question, that's how you do research – you ask a question because you're curious about it. [*Reads through population variables in the map, finds % White.*] You want to check and see?
125. Students: Yeah … …
127. Co-teacher B: Predict – how do you think it's gonna change?

This shift to attending to the White population persisted through the rest of the discussion. American taboos often prevent teachers from talking about race, but we have noticed that many teachers are more likely to racialize Black people in classroom talk than White people. Students' move to ask about White people in the map, and the teachers' endorsement of the query, created space for more authentic questions about racial history.

1.3. Maintaining an inquiry stance through strong emotional reactions

The switch of the 1910 map from representing African American population to White population, in response to the question by Student 2, created a strong reaction in the classroom. Figure 1 juxtaposes the two maps.

Figure 1

Reproductions of maps: (a) African American % by county, 1910, (b) White % by county, 1910

(a) *(b)*

The map depicting White population (Figure 1b) makes the Black population (1a) appear tiny, beyond the reality of the data: many of the 90-100% White counties in the map's center (darkest color) had very small total populations, while large Black population concentrations in the southeast are not discernable in the visual language of the choropleth map (see Radinsky, Loh & Lukasik, 2008, on design tradeoffs of choropleth versus scaled centroid maps). The reveal of the overwhelmingly-White map created a palpable feeling of diminution of the Black people in the represented world, reverberating into the classroom. The volume and energy rose, with cries of "Daang!," "Woah!" and "That's crazy." The teachers pushed students to describe what they observed:

131. Co-teacher A: What happened? … [*to Student 2*] Did you get an answer to your question?
132. Student 2: Yeah
133. Co-teacher A: OK, let's listen to her
134. Co-teacher B: OK, what did you conclude from that? Your observation? You asked the question, is the rest of the United States all White. …What have you observed?

The first observation, co-constructed by the class, was that "The majority of … the United States in 1910 was … White." In this moment, there was a danger of this simple observation being interpreted as "the point" of the data visualization, foreclosing further investigation. Both teachers quickly pushed for more close observations:

> 140. Co-teacher A: Anyone want to make a more – this is an interesting map, this is very different from the other ones …
> 143. Co-teacher B: Make some observations about this map.

1.4. Adopting a Black perspective in sense-making about a represented world of Black people

Student 5, whose hand has been strenuously raised for some time, shares an explanation:

> 145. Student 5: I think that, we observed that the population, most of the population was down in the South, most of the Black people. Most of the slavery was down there — slavery had just ended, and since most slaves ran away, they didn't know, {in the North} they didn't have a place to go so they stayed in the South.

Student 5's narrative offers an explanation for the concentration of the Black population in the Southeast (Figure 1a), contextualized by the overwhelmingly White population outside that area (Figure 2b). His comment shifted from the shock of the 1910 White map to a reflective, historical account from the perspective of Black people in 1910, post-enslavement yet still concentrated in the South, trying to find another place to go. Both teachers ratified Student 5's comment as a "very good observation."

1.5. Looking closer at surprising data

Student 2 raises her hand and, rather than build on Student 5's comment, returns to the overwhelmingly-White 1910 map with a question: "In Illinois it was all White … in Chicago?" Co-teacher A models how to click on the map to find data values, confirms Chicago's location in Cook County, and clicks to get the 1910 White population:

> 156. Co-teacher A: Cook County, we're in Chicago. Let's see if I can click on it, just as an example, here we go [*clicks, data window appears*]
> 157. Student: Dang!
> 158. Co-teacher A: [*pointing to data window*] In Cook County in 1910 there were 2,405,233 people in Cook County. Out of all those people, how many of them were White people?
> 159: Students: 98%
> 160. Co-teacher A [*pointing to data window*]: 98%
> 161. Student 2: So the other 2% was what?
> 162. Co-teacher A: The other 2% was what? I don't know. Could be Black? What else?
> 163. Multiple students: Hispanic. Mexican. Puerto Rican

Whereas Student 5 drew back from the data to seek a historically-referenced explanation, Student 2 zoomed closer into the data map to seek a data point relevant to her life in Chicago. Having asked if it was "all White" and then found that it was 98% White, she immediately sought clarity about the other 2%, thereby helping the class think beyond a Black/White binary of race. We return to these observations in the cross-case discussion.

Case 2: Accounting for missing Mexican people in US census data

The focal lesson in Case 2 was part of a curriculum unit in an undergraduate, pre-service, elementary education, social studies methods course taught by the first author, examining the theme of migrations. In it, pre-service teachers (PSTs) represented their own family migrations to Chicago on maps and timelines; read Takaki's (2012) *A Different Mirror: A History of Multicultural America*; and used children's literature on African American, Mexican, and other migrations. The class was racially and ethnically diverse, with a majority of Latinx students.

Through a jigsaw lesson, the PSTs used the GIS website *Immigration Explorer*, a free, online resource created in 2009 by the *New York Times* for browsing historical census data for the years 1880-2000, to study waves of immigration. The GIS displayed the number of people identified as foreign-born in the census for each US county in each decade, from 23 countries-of-origin. After a preview of the site, each group of PSTs chose one country-of-origin immigrant population to study. The analysis here focuses on one group's discussions in their small group, consisting of two PSTs who self-identified as Mexican (Rogelio and Yesenia, pseudonyms) and one non-Mexican, White PST (Jesse, pseudonym), as they examine the data for Mexican-born people *(3)*. Six aspects of the racial data discourse are illustrated here: 1 seeking an explanation for a data anomaly; 2 questioning candidate explanations for data patterns; 3 personalizing “horrible data”; 4 attributing agency to Mexican-born people in the represented world; 5 maintaining an inquiry stance through strong emotional reactions; and 6 narrating racism and oppression into the represented – and representing – world.

2.1. Seeking an explanation for a data anomaly

One of the notable features of the “Born in Mexico” data set is the disappearance of nearly all counties’ data in 1930, reappearing in greater numbers in 1940. The group discusses possible explanations for this anomaly. Rogelio has read in the Takaki book that Mexicans were deported in large numbers at the start of the Great Depression, and Yesenia and Jesse contemplate the enormity of Rogelio’s explanation for the missing data, deportation, which has the authority of a history text to support it, and the specificity of 400,000 deportations:

> 291. Yesenia: They deported all the Mexicans?
> 292. Rogelio: Not all of them, they, um, 400,000 of them
> 293. Jesse: In the United States as a whole?
> 294. Yesenia: That’s insane, look at that [*waves hand around counties in the Southwest with Mexican-born population in 1920*], they like, they were pretty –
> 295. Jesse: They were all over! [*hand gesture showing data distribution*]
> 296. Yesenia: Yeah!
> 297. Jesse: I think – I mean --
> 298. Yesenia: Look at this!
> 299. Rogelio: They weren’t just deport - After the Great Depression they *started* deporting them

2.2. Questioning candidate explanations for data patterns

Some doubt remains about whether deportations could account for the disappearance of nearly all the data in 1930, or whether they might be seeing a decrease in total population rather than just the population of immigrants:

> 378. Jesse: Well you gotta look at the population as a whole, though, cause we’re only looking at the immigration, but the [*gestures*] population might be getting cut short too so I mean –
> 379. Yesenia: That’s a good point. So it’s at – … …
> 383. Jesse: Because I think these circle sizes are relative, are the immigrants relative to the total population, so –
> 384. Yesenia: [*checking total population*] No! It’s still – no, the total population stays the same.

Yesenia remains unconvinced that deportation accounts for the 1930 data anomaly, returning to the topic. Yesenia weighs Jesse’s candidate explanation (an overall drop in total population); disproving it with the data; doubting the adequacy of Rogelio’s deportation explanation (despite his insistence); and questioning the data visualization as possibly distorting the data (“Maybe it’s just the mapping?”):

> 414. Yesenia: I’m confused – I still want to know what happened in 1930
> 415. Rogelio: Like I said, the deportation -- deportation
> 416. Yesenia: Deportation, was it just that though?
> 417. Rogelio: Well, the Great Depression, the Great Depression, people were probably leaving too, there wasn’t that many jobs anymore
> 418. Yesenia: Was it only that? Maybe it’s just the mapping? Let’s check that

2.3. Personalizing “horrible data”

Yesenia is unable to find another immigrant group with a similar disappearance in 1930, eliciting a teasing joke from Jesse (the only non-Mexican group member):

> 426. Yesenia: So yeah. So it’s really just Mexicans
> 427. Jesse: Sorry guys! [laughs]
> 428. Yesenia: That’s horrible {data}. That’s ridiculous.

It is unclear whether Yesenia’s reaction (428) is in frustration with not finding an explanation, or irritation at Jesse’s personalization of the data about Mexican-born people as representing Rogelio and Yesenia (“Sorry guys!”). This may make Yesenia feel vulnerable by belittling the disappearance of Mexican-born people.

2.4. Attributing agency to Mexican-born people in the represented world

Rogelio seems to pick up on her vulnerability, and extends the narrative beyond their disappearance:

> 429. Rogelio: Yeah but in the '40s they came back, they came back in the '40s, they say in the book you know, they found it easy to cross back to the U.S. anyways, so they just did that
> 430. Yesenia: And they even started expanding toward the Midwest [*gesturing on 1940 map*]

Here Rogelio and Yesenia recover the narrative of the Mexican-born people who may have been deported out of the 1930 map, using the Takaki book and the 1940 map as resources to replace them in the historical narrative with greater agency ("they came back"; "even started expanding"). When the instructor (first author) comes to talk with them shortly afterwards, Yesenia offers another possible reason for the data disappearance:

> 464. Instructor: So did all those deported people get back across the border?
> 465. Yesenia: Or maybe they just didn't report themselves
> 466. Jesse: That's, that's another possibility. Cause if they didn't want to be {deported}

This explanation goes further in attributing agency to the represented Mexican-born people. Their absence in the data may be explained by their own decision not to "report themselves" to census takers, especially in the context of widespread deportations described by Rogelio. The attribution of agency to Mexican-born people clearly gave Yesenia a sense of pride in her personalization of the data. This was seen earlier, when she navigated to the 1970 map and moused over Cook County, where a large bubble indicated a growth in the Mexican-born population of Chicago: "This is when young Pops came, in the '70s. Boom! My dad was part of that." This connection is not only an individual celebration of her father, but also tied to her Mexican identity: the "Boom" is a celebration of the visible growth of the Chicago Mexican community.

2.5. Maintaining an inquiry stance through strong emotional reactions (again)

Bubble maps like *Immigration Explorer*, when animated to show change over time, sometimes elicit emotional responses. For example, when another student presented her group's findings about the Ireland-born population decreasing by decade in the 20th century, her animation of the maps brought a round of laughter from the class: "And then as the years go by the waves of immigration are starting to decrease. … [*sliding the timeline control forward through the decades*] And then as you can see its still getting smaller -- smaller – smaller – smaller – smaller" [*general burst of laughter*]. The historic progression of the Mexican-born bubble maps presents a very different animation (Figure 2). The growth of these absurdly oversized county-centered circles elicited strong reactions ranging from giggles to laughter to sounds of alarm during the whole-class presentation. Some students used sounds like "Boom!" which appeared to show pride or joy at the giant circles, but others seemed to react to the image as menacing. In a different class, a student referred to the 2000 map image as "messed up," suggesting that it made Mexican immigrants seem dangerous. This animation could thus intersect with extant racist narratives that provide specific, racialized meanings to the data graphics (Radinsky, 2020).

Figure 2
Maps showing increasing Mexican-born populations by decade: (a) 1970, (b) 1980, (c) 1990, (d) 2000

(a) *(b)* *(c)* *(d)*

During small group work, Yesenia seemed to react to the overwhelming bubble size in the 2000 map. She sought data that would show a decrease in Mexican-born populations in the years after 2000. Yesenia's desire for data that she believes must exist ("I want to see a decrease," 497) drives her to go beyond the GIS, wanting to find a decrease in Mexican-born population to counter the map's implicit narrative:

> 495. Yesenia: You know what I'm looking for, I'm looking for the … I don't see them -- I don't see them decrease, like, I don't know where {to look for that …} Remember about that law?
> 496. Rogelio: I think between this [*2000 census*] and the 2010. You were probably seeing –
> 497. Yesenia: No but like the decrease. I want to see a decrease in it. [*gesturing on the map*]
> 498. Rogelio: You'll probably see it in the next one, 2010 census. I think so between 2000-2010
> 499. Yesenia: What's that law called?

500. Rogelio: A lot of the stuff came out after the whole Patriot Act [*Yesenia googles the act*]

2.6. Narrating racism and oppression into the represented – and representing – world

Jesse comments that the Patriot act "instilled the fear of foreigners," which elicits a direct, personal explanation:

501. Jesse: Oh yeah, the Patriot Act, yeah. Instilled the fear of foreigners, yeah.
502. Yesenia: Do you know how bad it is? It's horrible. That's why my friend moved over here
503. Jesse: What's horrible?
504. Yesenia: Like they, they just like, they hunt you down basically
505. Jesse: Uh -- where? Or -- the - immigration?
506. Yesenia: I guess -- there'll just be kids who look Hispanic, or look non-White, and then just go like, flump! [*hand gesture*] You're for deportation. And apparently they warn each other, so if they're like at a grocery store they'll warn each other – that sort of thing
507. Jesse: In Arizona?
508. Yesenia: [*Nods*] That'd be, that'd be {inaudible}
509. Rogelio: Even if you aren't [undocumented] it would just be
510. Yesenia: It would just be scary. What if they don't believe you?
511. Rogelio: No, cause that's what even -- cause some of the people who got, like, sent back during that time period, during the 1930's, some of them were United States citizens and they still got sent to Mexico
512. Yesenia: See? See that is a possibility. They don't believe me, like, "Oh, what are --"
513. Jesse: Oh, I mean it's a little bit more far-fetched today, because there's different – [*awkward hand gesture and smile*]
514. Yesenia: You'd think so –
515. Jesse: You'd think so. Of course there's gonna be, there's gonna be those select few people that are like, "Send them all home," but –
516. Yesenia: I remember my sister went to go get her taxes done, and the guy was like, "Are you a legal citizen?"

In this exchange Yesenia and Rogelio build on Jesse's comment "Instilled the fear of foreigners, yeah" (501) by shifting the tone from one of detached, historical investigation to one that is immediate and personal. Yesenia locates the "horrible" racism in her friend's need to move from Arizona, where "they hunt you down" if you "look non-White." They emphasize how this would feel (lines 508-510), and Rogelio underlines the reality of the scenario by corroborating it with the historical record from the 1930s (511). Jesse shows doubt about this account being relevant today (513, 515), calling it "far-fetched" and attributing racism to "those select few people," prompting Yesenia to offer the example of her sister being confronted by her own tax preparer. Importantly, this clarification about the realities of racism is directly relevant to the data-based inquiry they are engaged in. This racial awareness is necessary for the group to evaluate alternative interpretations of the data set.

Discussion: Emergent themes for teaching and learning racial data literacy

Numeracy and statistical competencies are interdependent with racial competencies

In each of these classroom discussions we see specific competencies for reasoning with data: making clear and specific observations, distinguishing among available variables, distinguishing intensive from extensive measures, questioning the reliability of data sources, and evaluating competing interpretations. We also see specific competencies for reasoning about race: naming and distinguishing racial categories, contextualizing racialized experiences in historical contexts, considering the impacts of racism on racialized people, questioning whether the "kinds of people" represented in a dataset accurately reflect the people in the represented world. As Philip et al (2016) suggest, these sets of competencies should not be considered separately from each other in understanding the learning opportunities available in this classroom talk. They necessarily must advance in tandem, in order for these learners to make sense of a racialized social world with these data.

Managing the social-emotional risks and vulnerabilities of racialized data

In each case there were moments when the data interpretation was placed at risk by an emotional response to an unanticipated impact: the reactions of "Daang!" "Woah!" "Boom!" "That's messed up" – or simply laughter. Palpable in such moments is the risk created for learners whose identities are at stake in the societal narratives that are invoked, with a risk of students of color withdrawing from discussion. The cases above suggest possibilities for how classroom talk can maintain an inquiry stance through such moments, allowing learners to process both their emotional responses and the inquiry focus. In Case 1, after being encouraged to make more careful observations from the overwhelmingly-White 1910 map (beyond "The US was mostly White in 1910"), Students 2 and 5 each offered a next step for making sense of the realities of Black people in 1910. In Case 2, Yesenia pushed her group-mates to help her go beyond the off-putting impact of the giant circles on the Born-in-Mexico map to construct a counter-narrative ("the decrease"), and to take seriously the racism inherent in narratives about dangers of Mexican immigrants that lie behind unjust deportation policies.

Curricular positioning of different racial identities

Teaching with data that offers personal connections can provide deep opportunities for learning. When the connections invoke racialized identities, people who are racialized differently – learners and teachers – are positioned differently. A Black teacher and a White teacher position students differently when they ask them questions like, "Is the rest of the United States all White?" (Case 1, lines 121 and 134). Similarly, the discussion in Case 1 would proceed very differently with an all-White class than an all-Black class, in ways that need to be explored empirically. Similarly, Yesenia and Jesse experienced different emotional involvements with the data as they explored the history of Mexican migrants. Jesse, who is White, joked with his Mexican group-mates about them disappearing (line 427). Yesenia, on the other hand, had to manage strong emotional reactions to the "horrible data" (428), and reveal painful realities faced by her friend, sister, and imagined self being deported due to racism. This inequality of stakes and vulnerability is an essential consideration for teaching racial data literacy.

Conclusion

Studying our own teaching, and building a clear and explicit set of considerations to inform the design and enactment of lessons, units, and practices, are promising directions for deepening our understanding of racial data literacy. This paper invites to the larger learning sciences community to take up this project together.

Endnotes

(1) Hacking's (2007) mechanisms for "making up people" exclude consideration of "race science," but his framework accounts for the categorizations in the U.S. census, from which the data in these classrooms were drawn, and the corresponding dynamics of individuals, institutions, knowledge and expertise.

(2) Social Explorer^{TM} (http://www.socialexplorer.com) is a public-use and privately-licensed online resource with a free census data browser (used in Case 1), as well as a for-profit company which licenses a paid version. The first author has no financial interest in this company, but has a long-term research collaboration with Dr. Andrew Beverage, its CEO.

(3) Distinctions among national, ethnic and racial categories are constructed, contested (Chávez-Moreno, 2021), and change over time. Mexican and Mexican-born are not recognized in social-scientific parlance as racial categories, but anti-Mexican narratives common in US politics, discussed by the PSTs, are racist, and racialize Mexican identity.

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Maker Identity Development: What and How?

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Abstract: Focusing on developing maker-identities, especially for historically marginalized students in the computational field, can empower them to recognize and take ownership of their space in the field. Drawing from identity related literature in maker and computing related fields we identified seven factors of maker-identity - interest and motivation, competence and performance, confidence and self-efficacy, recognition, utility value and meaningfulness, perceptions of community, and external factors. Using this, we analyzed semi-structured interviews of students who participated in our summer makerspace camp to understand how these identity factors manifested in their reflections of the camp. We tie back our findings of positive impacts on maker-identity structures to the design structures of our makerspace such as co-design of the space, use-modify-create strategies, and open-ended design projects.

Introduction

Despite efforts to allow for participation and engagement of historically marginalized racial, ethnic and gender groups in STEM and computing fields, its demographic distribution is nowhere close to reflective of the general population. NACME's 2021 Research Brief showed that despite over 30% representation of underrepresented minorities in the United States, they only represent 18% of computer (CS) and information (IS) sciences and 15% of engineering bachelor's degrees. Hispanics or Latinos earned only 10% of CS and IS and 11% of engineering degrees, and Black or African Americans only earned 8% and 4% respectively.

Makerspaces are one approach that scholars, practitioners, and administrators recognize as having the potential to address this issue given their ability to provide students with access, resources, expertise, and a space to engage in hands-on computing and STEAM activities (Halverson & Sheridan, 2014; Blikstein, 2013; Presidential Proclamation - National Day of Making, 2014).

However, lack of access is only one of the innumerable barriers that minoritized youth must face when navigating the fields of STEM and computing. Despite their potential to bring more people into CS and engineering, makerspaces continue to be mostly dominated by White and Asian males. Thus, with systemic racism and traditional gender norms having impacted these fields over the years, access to makerspaces alone is not going to allow traditionally minoritized youth to recognize it as a space for them and to start engaging in these activities as their own. To make these spaces more inclusive and inviting to these young learners, we need to design these spaces and their curriculum in ways that are more culturally responsive and empower them to engage with the material on their own terms (Scott et al., 2015).

Various factors impact how students learn. As highlighted by Vermunt (1996) and Trujillo & Tanner (2014), cognition, metacognition, and affect play a role in learning; cognition being the mental process associated with learning, metacognition being the awareness of those processes, and affect dealing with the feelings arising when learning. In the case of historically marginalized students, who have received implicit and explicit messages about their participation in STEM and computational settings, affect is a very important factor to consider. As detailed by Trujillo & Tanner (2014), the affective domain consists of - but is not limited to - self-efficacy, sense of belonging, and science identity. Further, as discussed by Nasir & Hand (2008), identity, engagement, and learning are heavily intertwined such that when an individual feels that their identity is linked to a setting, they are more engaged and learn more. Additionally, while there has been research recognizing the importance of identity in CS and engineering (Mason & Rich, 2020; Godwin, 2016), there has been far less research on how this manifests itself in computational makerspaces specifically, and even less on what specific constructs define one's maker identity. In response, as part of a two-week long makerspace with students from Black/African American and Hispanic/Latinx communities, we aimed to understand the following two research questions:

1. Which factors of our participants' computational maker identity did our makerspace impact and how?
2. What particular design structures of our makerspace and curriculum resulted in these impacts?

In this paper, we refer to the development of computational maker identity as an expansion of computational identity (Tissenbaum et al., 2019), to include crafting, building and other non-computational skills.

Background

Identity as described by Gee (2000) is being recognized as a certain kind of person in a given context. A simple breakdown of this definition indicates that identity is contextual. Gee (2000) outlined four different ways to view identity, one of which is Affinity-identity, which he describes as a way of looking at who the person is. He suggests that those with a specific A-identity are a part of an affinity-group i.e., a group of people who share little besides their interest in something i.e.: the affinity. Along the same lines, Nasir & Hand (2008) define practice-linked identities as those that are linked to participation in particular social and cultural practice.

With makerspaces becoming a popular community of informal learning and tinkering over the last decade or so, scholars like Pinkard et al. (2017) are doing valuable work to incorporate identity, sense of belonging and computing empowerment into makerspaces like Digital Youth Divas. However, there is still work to be done to recognize what constitutes a “maker-identity.”

Factors impacting identity development

In order to develop a framework for operationalizing identity in our computing makerspace we reviewed the research into science and engineering identity (Carlone & Johnson, 2007; Hazari et al., 2010; Godwin, 2016), computational identity and empowerment (Kong et al., 2018), coding attitudes and identity (Mason & Rich, 2020; Washington et al., 2016) and engagement and persistence of minority students in certain STEM fields (DuBow et al, 2017; Nasir & Hand; 2008). Students in our makerspace utilized a variety of these computing topics when engaging in making. Conducting a thematic analysis of prominent computational identity literature, we extracted and grouped the various identity factors under seven broad themes that would contribute to computational making identity development in our makerspace (see Table 1).

Table 1

Factors influencing computational making identity

Theme	Description
Interest & motivation	Defined as “A person’s likes, preferences, favorites, affinity toward, or attraction to a subject, topic, or activity” (Godwin, 2016, p. 4). Interest is used by Godwin (2016) and Hazari et al. (2010) as a measure of engineering and physics identity respectively, and by Mason & Rich (2020) and Washington et al. (2016) as a construct to measure students’ coding attitude, and CS attitude and identity respectively. Talley et al (2017) use motivation as a measure of self-efficacy when measuring the change in maker-identity in college students.
Confidence & self-efficacy	Confidence has been shown to impact coding attitudes (Mason & Rich, 2020) and identity (Washington et al., 2016). Talley et al. (2017) used self-efficacy as a measure of change in maker identity. Kong et al. (2018) measure creative and coding self-efficacy as factors of programming empowerment.
Competence & performance	Competence and performance are defined as “students’ beliefs about their ability to perform the practices of their discipline and understand the content of their discipline” (Godwin, 2016, p. 4). Used by Godwin (2016), Hazari et al. (2010) and Carlone & Johnson (2007), as a measure of science/engineering identity development. Nasir & Hand (2008) suggest that becoming competent in a subset of activities is essential to the engagement and practice in the space.
Utility value & meaningfulness	Entails the students’ ability to see the practice fit or apply into their current or future lives (Wigfield & Cambria, 2010). Used by Mason & Rich (2020) to measure student coding attitude and identity. Kong et al. (2018) use meaningfulness (Schiefele, 1998) and impact as factors of programming empowerment.
Recognition	A key measure in science and engineering identity framework (Carlone & Johnson, 2007; Hazari et al., 2010; Godwin, 2016), recognition has been defined as the feeling that others see you as a good science or engineering student.

Perception of the community	Mason & Rich (2020), Washington et al. (2016) and DuBow et al. (2017), show that how a student perceives the community (stereotypes about it, and what being a part of it means to outsiders) impacts a student's willingness to identify with the community.
External environmental factors	Factors such as access to domain, social support, preparation, family influence, structural barriers, social value, school attitude towards the practice play a significant role in whether a student engages and eventually identifies with the community and practice. (Mason & Rich, 2020; DuBow et al., 2017; Nasir & Hand, 2008)

Methods

Study design

The Connected Spaces makerspace curriculum was conducted over two weeks in the summer of 2022. The participants were 18 middle school students, who were recruited from two local community organizations: DREAAM, working primarily with African American/Black and Latinx/Hispanic boys and The Well Experience with African American/Black and Latinx/Hispanic girls. The makerspace was set up on the campus of a large Midwest public university. The students participated in maker activities from 9am to 12pm for 10 weekdays, followed by lunch at a university dining court. Learning from a similar camp run the previous summer, we knew that significant support would be needed, particularly for students' final projects. To this end, 6 researchers and 3-4 mentors from the community organizations were present throughout to support the students.

The structure of the makerspace was intentional, but also flexible, with the researchers debriefing at the end of each day, to modify the next day's activity. For Week 1 of the camp, the students engaged in a modified use-modify-create structure (Lee et al., 2011), in which they started by making a simple mini project centered around the Circuit Playground Express microcontroller (with basic maker components such as LEDs, Neo pixels, sounds, touch sensors, and motors) by following instructions, that they would then modify and add onto. The choice of the microcontroller was driven by its compatibility with block-code, which we concluded would work best for middle-school students. On Day 6, students took part in mind-mapping activities to help them think about their own identities and values. On Day 7, the students were provided outline worksheets, on which they brainstormed their final individual project ideas and started thinking of the materials they might require. The last three days were spent building their final projects. On Day 10, community members, parents, and university staff were invited to an "open-house" of the students' projects, where the students demoed their projects. They also created display boards, to talk about their process and intention of creating these projects.

Data collection

On the last two days of the camp, we interviewed five of the eighteen students. These students were chosen due to a variety of factors: consistent attendance (with some variation), prime demographic (age), and being relatively representative of the entire group (previous skill and experience). The semi-structured, one-on-one interviews were recorded and transcribed. Each interview lasted approximately 10 minutes and mainly consisted of questions regarding their makerspace experiences and final projects. We conducted a thematic analysis (Nowell et al., 2017) of the literature above to derive 36 initial factors (some repeating) indicating or influencing identity. After an initial inductive qualitative (Thomas, 2006) review of the transcripts, 18 of the factors were shortlisted as being present in the interviews. These 18 were then further grouped down into 7 categories (see Table 1). The interviews were then coded with these 7 categories each time a student indicated an impact on or due to a category. Iterative review of literature and analysis of coded data led to in vitro coding of the subcategories for each of the five students analyzed (see Table 2). Reflecting on the researcher debriefs after each camp day, as well as the planning documents and conversations, we were able to connect our findings to the curriculum design and decisions we made while creating the makerspace. Other data such as field notes, observations, photos, videos and audio recordings were also used to support these findings and connections to our makerspace design.

Findings and discussion

In this section, we will highlight some of the key instances in the interviews, where students indicated how certain factors of their identity were impacted, or in turn played a role in their makerspace experience. We will also further analyze the design decisions and structures of our makerspace that might have led to these impacts. Table 2 shows the maker identity factors each student mentioned in their respective interviews.

Table 2

Ways that each maker mentioned the structures of maker-identity

Makers:		Alexandra	Jasmin	Keith	Leo	Trinity
Interest and motivation	Interest was shown	*	*	*	*	
	Making was tied with previous interests	*	*	*	*	*
	Previously interested in some part of making	*	*	*	*	
	Showed continued interest in making	*	*		*	
	Making interest was developed	*	*	*	*	
Confidence and self-efficacy	Confidence was developed	*	*	*		
	Showed confidence to be a mentor		*	*	*	
	Self-efficacy was developed			*		*
Competence and Performance	Showed competence	*	*		*	*
	Competence was developed	*	*	*	*	
	Had previous competence				*	
Utility and Meaningfulness	Could see utility in making	*	*		*	
	Showed meaningfulness in making	*	*		*	*
Recognition	Showed recognition of self	*				
	Wanted to be recognized		*			
	Was recognized by mentor			*		
	Showed recognition of their friend					*
Perception of community	Showed change from previous perception of community	*	*			
External factors	Previous access to a part of making		*		*	
	Lack of previous access to a part of making	*		*	*	
	Mentioned social factors				*	*
	Making interfered with other interests			*		

Figure 1

Final Projects: Alexandra's dog collar project (a) and Leo's trash-pick-up robot project (b)

(a) (b)

Interest and motivation

All five participants were able to tie in their experience at the makerspace to some previous interest that they already had. Some talked about how their interests could be impacted through making, while others created final projects that integrated making into something they were passionate about. For instance, Alexandra decided to make a dog collar (Figure 1(a)) that would light up in different colors based on the dog's health conditions because she “[wants] to be a vet. [She wanted] to invent something for animals, especially dogs, because [she] has a dog.” Leo created an automated trash-pick-up robot (Figure 1(b)), inspired by a video game he enjoyed. Four of the students came in with previous interest in either electronics, making, or inventing and the same students showed interest during the camp. When Jasmin was asked about her interest before the camp, she “thought [making] was boring,” but at the end of the camp her view changed to it being fun and her stating “I want to come back!”

These experiences can be tied back to several of our early design decisions for the camp. For instance, based on earlier co-design sessions with other youth at these organizations, we creatively grounded the mini-project activities into pop-culture (like Marvel) to make them more relevant and build interest in the students about the tools being used. Secondly, the success of the open nature of the final projects seems to have stemmed from the two days of self-reflection of their identities, interests, and values. Examinations of the students' mind maps largely showed a tight connection between what they wrote during these sessions and their final projects.

Confidence and self-efficacy

We anticipated that having students engage in the use-modify-create in each mini project during Week 1, would enable them to develop their confidence by allowing them to progressively take on more personal and creative agency in their work. Students could build a simple basic project by following a step-by-step guide, and once they gained confidence in that skill, they could modify their projects in their own ways. This allowed for a low-floor-high-ceiling model where the students could slowly increase their confidence. The success of this approach was shown in students recognizing their growing confidence in making as they went through the camp. For example, Jasmin stated that the camp “changed me, ‘cause like I didn’t know [before the camp]… like… me? doing this?! It's hard. But now it’s like, kind of easy for me to understand stuff and how it comes together and makes lights and movement.” Some students also showed increased confidence in mentoring others, with Jasmin indicating excitement around being able to teach others how to do what she learned.

Competence and performance

Based on observations from the previous summer's camp, we recognized that students often failed to build their competence if their learning was not scaffolded first. This prompted us to have Week 1's curriculum expose the students to various maker components in low-stakes, scaffolded projects. This was also in response to the “keychain syndrome” which highlighted that students tended to fixate on basic projects they are first introduced to (Blikstein & Worsley, 2016). When interviewing students and examining their final projects, we found that they were able to extend the components and their making skills in exciting ways. All five of the students indicated that they were competent or developed competence through their projects and the maker activities. When Alexandra was asked what valuable skill she learnt, she said “coding is really easy when you just like pay attention.” Alexandra also showed surprise at her own performance that she “actually just made a dog collar like this”, which used several of the Week 1 components (light sensor, temperature sensor, LEDs) in ways that extended far beyond the originally scaffolded activities. Across all the students' projects, we observed similar outcomes where they extended the maker skills, they learned in Week 1 in new ways around personally relevant projects.

Utility value and meaningfulness

Researchers observed that many of the students were able to see the utility value and meaningfulness in their making through the intentionally open-ended final projects. Most students created projects that were driven by their previous interests and communities, which they identified during the two days of project brainstorming and self-reflective mind-mapping activities. For instance, Alexandra weighed in on her dog-collar’s utility: “It will help vets, it’ll help new or first-time dog owners … Or like people that don’t understand dogs’ body language. So, this will help them, like if your dog is overheating […] it will turn red for you so you will know.” Three of the students indicated that they could see the utility of making in their future lives. Jasmin said the camp was valuable in helping her see how making could be useful in their lives in the future “Cause like when they [students] grow up and are like ‘I don’t know what I want to be’ and they remember that they took this class, it’s going to be easier.”

Figure 2

Mind map of a student (a) and all the Mind maps displayed with feedback from peers (b)

(a) (b)

Recognition

To foster a sense of recognition, researchers provided opportunities for the students to recognize each other as makers, as well as allow them to show community members their work. After the mind-maps were created (Figures 2(a) & 2(b)), we stuck them up on a wall and encouraged them to walk around and give feedback and recognition to their peers. We also built in some peer feedback into the project brainstorming day, where students had to explain their idea to a partner. On the last day, we invited parents, community members and university staff to visit our makerspace and talk with our makers about the projects. This allowed the participants to receive a lot of feedback and recognition from the people they look up to. The interviews highlighted how this process resulted in recognition across students' experiences. As quoted above, Alexandra surprised herself with her ability to make a dog collar, stating she never believed she could do something like that. Jasmin wanted to feel recognized for her maker skills, saying she made her project "to show that I can actually make something." Trinity recognized the competencies of her peers, directly stating that Alexandra did not need help because "she got it so fast". Keith mentioned how he valued the recognition from the facilitators and how this impacted his self-perception noting that "Mr. C said that I did a really good job for my first time ever!"

Perception of the community

Two of the makers showed that they had preconceived notions of who could and could not work with electronics, neither believing themselves to be a part of the community to begin with. However, for both Alexandra and Jasmin, their perceptions changed and they felt like they could make on their own too, with Alexandra stating that "At first I thought I wasn't going to be able to get it, because you know, I thought I wasn't one of those kids that are like good at technology and stuff, but it's like really simple like when you get the hang of it. So that's something I changed. I feel like I can do coding more, outside of this". This highlights how participation in the camp changed their own perceptions of what a community of makers is and their inclusion in it.

External environmental factors

Keith had never coded before. Leo had never worked with electronics. Alexandra believed she had coded before, but never worked with electronics. Jasmin had worked with both before. Trinity indicated that she never liked working with electronics. Even though the participants had various levels of access to makerspace activities, they were all able to engage with the space and tools on their own terms. To this end, it was important that the makerspace feels like a place where the students can collaborate with their peers, while having fun. Alexandra indicated that access to the makerspace gave her the resources to build her ideas. She said that although "this [dog collar project] was something I'd thought about making before, I just didn't know quite what I wanted to make, but now […] I found what I wanted to make"; the makerspace gave her the resources to actually find out what she wanted to make: "'Cause when they said LED lights, I'm like what can I use for a dog or animal in general that I can use LED lights with? I can use a collar and stick the lights on it and make something out of that." Leo and Trinity stated that they enjoyed the social aspect of the makerspace, with Leo expressing joy that he "made a couple of friends."

Challenges

Despite showing positive impacts in creative self-efficacy and competence, and showing meaningfulness in her project, and recognition of one of her peers, Trinity indicated a strong dislike for making, saying: "I don't like coding and I don't like building stuff. I don't know why I don't like it, but I just don't like it. It's not my thing, that's why I don't like it." Whether we can attribute this to her lack of interest, preconceived notions of making, or some other factors, would require a deeper dive into her experience and mindset. Some other student hesitations included conflicts with previous commitments, for instance time at the makerspace for Keith was replacing time at his job. This goes to show the importance of situating making in a flexible environment, without hindering students' ability to participate in other parts of their identity. Lastly, brainstorming, mind mapping and peer-feedback were challenging for the students to grasp initially, suggesting that the work of maker-identity building, could have been incorporated into the curriculum and discussion from day one. This might have eased the students into it and allowed them to frame making as a reflection of their identities, instead of having it be separate from the identity construction parts of the camp.

Limitations and future work

While finding the general themes for the identity framework used in this paper, research focused on the technical side of making: i.e.: science, coding and computing were focused on. However, making is broader than that - it involves art and creativity along with collaboration and problem solving. Future work will focus on reviewing identity frameworks in those domains in addition to more identity frameworks in the STEM domain, to find commonalities and differences, to then investigate those structures of identity within our makerspace implementations. A large amount of data, including screen recordings, audio recordings and video recordings, along with photos of the makerspaces, projects, and mind-maps were collected during the two weeks of the makerspace. Due to space constraints, only the semi-structured interviews of five students were included, along with our review of photos and planning material to support our findings. More work could be done to triangulate additional data (e.g., whole camp video and audio recordings) with respect to this identity framework. Future work involves setting up another makerspace of a similar structure during the summer in 2023, with ongoing after-school makerspace activities during Fall 2022 and Spring 2023 semesters. With everything that we have learned about how our 2022 makerspace impacted their identity, we are working to incorporate structures that better allow for identity development. We will continue to investigate the impacts of our makerspace on identity, with more intentional and pointed observations and interviews, based on the realized framework.

Conclusion

Identity plays an important role in the learning process and engagement of students (Nasir & Hand, 2008). With the development of makerspaces, built to serve marginalized communities and youth, it is essential to engage their pre-existing identities with the practice-linked maker-identities that are being constructed in these makerspaces. Scholars such as Blikstein (2013), Halverson & Sheridan (2014), and Pinkard et al. (2017) are doing important work in constructing makerspaces that allow marginalized students not only access, but also agency to create in these spaces. The importance of considering affective factors that impact student engagement and learning in making for marginalized students is highlighted by these scholars. Our goal of tying identity with making is in line with such important work. Making personally relevant projects tied to one's identity allows for students' computational empowerment (Tissenbaum et al., 2019, Kong et al., 2018) empowering them to decide what they want to make and why, creating a more equitable approach to computing. Through this study, we attempted to find common factors that impact students' computational maker identity development, so that they are taken into consideration when building an equitable makerspace. We recognize that various factors of identity, including but not limited to - interest and motivation, competence and performance, confidence and self-efficacy, recognition, utility value and meaningfulness, perceptions of the maker community, external factors - can be impacted when the makers engage in the space. Keeping these factors in mind when designing makerspaces and their curricula can allow for computational identity development of students from all backgrounds, by grounding their maker identity in computational action (Tissenbaum et al., 2019).

Further, this study showed that structures such as co-designing the makerspace, open-ended projects, use-modify-create mini-projects, reflection and brainstorming activities can impact the utility value, interest, confidence and competence factors positively. Ensuring that the students receive feedback and are able to collaborate with each other, mentors, and community members, can provide additional opportunities for them to feel recognized. Creating a fun, open, and engaging atmosphere while allowing the students to build with access and agency, may allow them to discard preconceived notions of maker communities and build their identities as valued members of the making community. Structuring the design of makerspaces with the intentions of developing the students' maker identities across the factors highlighted in this paper, while they explore and tinker is key to ensuring that the students engage and learn in these spaces with agency as they begin developing their maker identities.

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Emotion Recognition in Educational Written Dialogues on Civic and Social Issues

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Abstract: In this study, we explore emotion recognition (ER) processes in educational dialogues on civic and social issues (EDCSI) by assessing the accuracy of ER and the factors that affect ER of external readers. Twenty speech-therapy students with linguistic and emotional training were asked to read a written EDCSI in which they had not participated, to rate the emotional intensity in each speech turn, and to explain which markers affected their rating. A positive correlation was found between the discussants' self-ratings and the mean ratings of the readers, although inter-rater reliability was low. The analysis of the reports of the raters showed that they based their rating on markers at the levels of the local turn, the entire discussion, and the broader context of the author's identity. The findings provide basis for a comprehensive framework to identify emotions in EDCSI and to train teachers to moderate and regulate emotions in EDCSI.

Introduction

The importance of discussions revolving around civic and social issues was recognized two decades ago (Parker, 2003). Such discussions are generally emotionally loaded. Slakmon & Schwarz (2019) provided a theoretical framework they call *Deliberative Emotional Talk* to study a new type of educational dialogues about civic and social issues (hereinafter EDCSI), as they perceive the regulation of emotions in such discussions both as a political need and an educational goal. However, research on such dialogues is still embryonic. The emotions that arise during discussions dealing with civic and social issues are relevant to the participants' lives, and often make salient personal and cultural differences. As such, these discussions are fueled not only by the emotions triggered by the issues discussed, but also by the emotions created during the interactions among discussants with different, and often conflicting, viewpoints. The idea of *intersubjectivity* – shared beliefs during social interactions – has been recognized as crucial for human communication. We conjecture that the sharing of emotions is crucial too, especially in discussions about civic and social issues. However, research in this domain is scarce.

The ability of the participants to feel empathy towards other participants and to understand their positive and negative feelings are much dependent on their ability to identify and recognize the emotions of others. Accordingly, the emotion recognition (ER) ability of interlocutors is one of the bases for their emotional perception, which enables them to understand and respond to the emotions of others. It is especially important in EDCSI, as ER mechanisms can affect the participants' ability to create an encouraging and supportive environment for discussing and learning. Moreover, the ER mechanism is a valuable tool for teachers to use in moderating discussions. It increases awareness of possible biases, and promote the development of socio-emotional competence of the students.

In face-to-face discussions, ER relies on linguistic, para-linguistic, and extra-linguistic cures. However, EDCSIs often take place in digital environments where the text is not supported by para-linguistic and extra-linguistic information, and ER is based solely on the linguistic information produced from the written text per se (Farahani, 2003). Relying on the written text alone may produce gaps in the discussants' understanding of each other and affect their sense of freedom to express themselves, their dialogic moves, and the emotions they feel during and following the discussion (Firer et al., 2021).

To understand ER during digital EDCSI, markers indicative of emotions in written discourse must be characterized. Attempts to do so have been made in linguistic research, but these attempts have usually been applied to texts written by a single author, rather than discussions conducted by multiple authors interacting with each other. Existing research on emotions in written texts primarily focuses on linguistic markers, but pioneering research indicates that in EDCSI the emotional processes are much affected by interactions between participants, as well as their identity and personality (Firer et al., submitted). Accordingly, ER in EDCSI is extremely complex.

Social Emotional Learning (SEL) programs flourish in Western countries, and professionals such as speech therapists, psychologists, or even teachers are trained to recognize and regulate emotions. Our general research direction is to understand ER processes in digital EDCSI, and specifically, to investigate the effect of training on ER, by investigating commonalities among individuals with professional training. To do so, we asked participants with linguistic and emotional training to rate the emotional intensity level they identified in discussions that they had not participated in, but which were marked by participants as emotional. They were asked to explain what markers affected their decision. We raise the following questions:

1. Does the identification of the intensity of discussants' emotions in EDCSI by trained external readers correlate with the discussants' identification of the intensity of their own emotions in such discussions?
2. What are the linguistic markers the readers use to identify the emotional intensity level in written EDCSI?
3. What other factors affect the reader’s ER in written EDCSI?

Theoretical background

Emotion recognition

Understanding the inner emotional state of others in conversations and their emotion regulation strategies is a complex task that depends on recognizing and interpreting the expressions of these emotions. Extensive research focuses on linguistic, paralinguistic, and extralinguistic markers for recognizing emotions in interactions. Extralinguistic markers include, for example, facial expressions (starting from Ekman's research, e.g., Ekman & Oster, 1979) and physiological activation (e.g., Törmänen et al., 2021). Paralinguistic markers include elements such as intonation (Bänziger & Scherer, 2005) and vocal elements (Scherer, 2003), and language markers include lexical and grammatical modalities, as well as other contextual and pragmatic elements that may attest to the presence of emotions (Argaman, 2010; Martin & White, 2005). Subsequently, theorists and researchers perceive language both as an object for studying emotions and as a research tool (e.g., Enfield & Wierzbicka, 2002). Moreover, Lindquist & Gendron (2013) review neurological evidence for the constitutive role of language in emotion perception from typical and impaired emotion perception research, as well as from research on developmental processes in children.

In face-to-face interactions, the perception of the emotions of others is dependent on a combination of linguistic, paralinguistic, and extralinguistic information, and it relies not only on the content and expression of the speaker, but also on the interpretation of the interlocutor (Tubbs & Moss, 2006). ER in interactions in digital media is substantially more challenging. Readers cannot rely on non-verbal clues or on the speakers' tone, and their ER is entirely dependent on the text. Early research claims that words provide only 7% of the information in face-to-face communication (Mehrabian, 1971). Though this percentage may be controversial, it gives perspective to the problematic task of ER based on written texts alone.

Regarding political and civic discourse in digital media, the picture may be even more complex. Digitally mediated interactions magnify the affective aspect of civic life (Papacharissi, 2010, 2015) and therefore render accurate ER even more important, given that discourse in digital media is often quarrelsome. Moreover, even in designed and regulated written discussions, like EDCSI, participants often misinterpret the authors' emotions (Firer et al., 2021) and identify different levels of intensity than those reported by the authors themselves (Slakmon et al., 2022). Therefore, it is extremely important to examine whether trained readers of e-EDCSI share some perception on the authors' emotions in EDCSI, what affects their ER, and what the theoretical and practical repercussions are.

Emotions in written texts

Previous research on emotions in written texts provides information on language markers that can imply the presence of emotions in texts. Martin & White (2005) mention that systemic functional linguistics (SFL) identifies three modes of meaning which operate simultaneously in all utterances – the textual, the ideational, and the interpersonal. Regarding the interpersonal meaning, they provide a comprehensive theoretical framework for analyzing writers' emotional stance and appraisal, and the way they position their readers to do likewise by using linguistic mechanisms. Bednarek (2010) draws on SFL but links it to cognitive approaches that refer to emotion schemata, which are created from the organization of people’s actual emotional experience and from observing emotional experiences of others as well as the exposure to discourse on emotions and other socializing processes. As she explains, "the different linguistic resources work conventionally to realize affective meanings because speakers are aware of the various components of such schemata (and vice versa, exposure to such discourse contributes to the construal of such schemata, even if not exclusively)". Nevertheless, SFL and emotion schemata do not provide an applicable framework for ER in EDCSI, since they refer to emotions from the speakers' perspective, mostly in personal narrative texts, and thus seem inappropriate for the treatment of emotions arising in group discussions.

Other attempts have been made to create emotional lexicons that enable the identification of emotions in texts. For example, the Linguistic Inquiry and Word Count (LIWC-22) (Boyd et al., 2022) provides a computerized text analysis tool for understanding socio-emotional states by identifying words, word stems, phrases, and select emoticons in the text (see also Strapparava & Valitutti, 2004; Mohammad & Turney, 2010 for other tools). However, these tools do not apply to the unique linguistic characteristics of Hebrew – the language used in the present study.

Argaman (2010) explored relationships between the intensity of emotions and the lexical modalities for expressing those emotions. She identified linguistic markers for emotions in Hebrew texts that were written after watching films that evoke feelings of sadness and joy. The markers she identified consisted of intensifiers, lexical reducers, lexical repetitions, first person singular, emotion words, the Hebrew root "feel", similes and metaphors, exclamatives, words and phrases expressing exclamation, and outstanding graphical symbols. These markers may serve as a basis for the identification of emotions in EDCSI in Hebrew.

Nevertheless, referring to the linguistic level may be insufficient regarding conversations. Poria and colleagues (2019) point out that even models of artificial intelligence aimed at analyzing emotion in conversations provide a limited analysis as they struggle to address linguistic means that cannot be identified without context and interpretation (e.g., sarcasm). As they explain, ER in conversations must refer to the context of the utterance within the conversation. Indeed, Polo et al. (2016) refer to some of the linguistic markers identified by Argaman (2010) in their theoretical model of group emotions in collaborative learning activities, namely the use of first person singular, but they also refer to context-dependent dialogue-level markers such as the use of justifications, the elaboration of arguments, etc. These findings suggest that argumentative moves may also serve as markers when analyzing learning discussions.

The ER challenges that are consistent in written conversations – the lack of paralinguistic information, the need to refer to the text within the context of the conversation, the specific features of the language – are intensified in the context of written discussions, and especially in EDCSI. Personal factors, design-related factors, and the encounter with the 'other' and their group affiliations often affect the emotional processes (Firer et al., submitted) and the emotional perception of the other participants, who sometimes project their perceptions and beliefs on the author (Keynan et al., 2022). In this research we would like to examine whether prior knowledge of linguistics and emotional processes affects the ability of readers to identify emotions in written EDCSI.

Method and analysis

Participants

Participants were twenty speech-therapy undergraduate students. They were all orthodox Jewish females in their twenties, in their third year of study or in the first semester of their fourth year, which is the last semester of the degree. All students spoke Hebrew as their native language or passed a Hebrew proficiency test upon their admission to college. As a part of the curriculum in assessment and intervention of speech, language, and communication disorders, all of the students had completed courses in linguistics and psychology, and had supervised sessions during their clinical education, in which they discussed emotional processes in interactions as part of their training as clinicians. The courses in linguistics provided them with a theoretical background on language components (semantics, morphology, syntax, phonology, and pragmatics).

Materials

The research materials consisted of two non-moderated written digital discussions given as assignments in two different undergraduate university courses. The first discussion served as the basis for an analysis of ER at the episodic level and will be discussed in another paper.

The second discussion was the basis for the analysis of a turn-by-turn ER. It dealt with the topic of Holocaust education in early childhood and involved five participants. This discussion was chosen from the two discussions described by Slakmon et al. (2022) for ER by participants, because it contained a larger number of participants who produced a larger number of speech-turns. The participants were asked whether the Holocaust should be taught in kindergartens. The discussion was a-synchronous, took place on a shared Google doc and contained 12 turns.

The discussants were interviewed after the discussion and were asked to state the level of emotional intensity they felt (low, medium, or high) in the turns they composed and in the other discussants' turns.

Procedure

The participants in the present research received the two written discussions by email and were asked to read them. In the episodic discussion they were asked to mark specific turns or sequences of several turns that they identified as emotionally loaded, and to write down what they thought had happened in these episodes. In the turn-by-turn discussion, which dealt with the teaching of the Holocaust, participants were asked to read the discussion and rate the emotional intensity they felt was present in each turn (low, medium, high). In both parts they were asked to explain based on the emotions they identified.

The participants were given the liberty to code the level of intensity and were not provided with a specific practice set or a defined rating criterion. The goal was to examine the participants' intuition and their ability to apply the knowledge they had acquired in their professional training in a written context.

After the participants coded and explained their choices in writing, they were interviewed and were asked to elaborate their answers. At the end of the interview they were asked whether the professional knowledge they acquired had helped them in the task.

The interviews were conducted and recorded, partly via ZOOM and partly in person.

Data analysis

A statistical analysis was conducted to determine whether the identification of the intensity of discussants' emotions by trained external readers correlates with the discussants' identification of the intensity of their own emotions.

The Krippendoff's alpha test (Hayes & Krippendoff, 2007) revealed that inter-rater reliability was low ($\alpha = 0.3401$), indicating that the external readers did not agree on the level of emotional intensity they observed in the various speech turns. Although reliability was low, and since the data was not normally distributed, a non-parametric correlation was run on the discussants' self-ratings and the mean ratings of the external readers, as will be presented below.

To determine what markers the readers used to identify the emotional level in written EDCSI and what other factors affected their ER, an extensive qualitative analysis was conducted. The analysis yielded references to visible cues as specific words, marks, phrases, as well as discourse moves the participants considered or interpreted as testifying on the existence of emotions. These references were classified into (1) turn level markers, namely, linguistic markers the participants identified within the text of the speech-turn, depending on Argaman's (2010) classification, (2) discourse level markers that were related to the context of the turn in the discussion, and (3) aspects related to the readers' world views, mostly their view of the author's identity, that contributed, influenced, and biased ER.

We then differentiated between markers for high, medium, and low emotional intensity.

Findings

Identifying emotions – accuracy

All the participants identified emotions in the discussions they read. They rated the intensity of emotions in each turn and explained their rating.

Table 1 presents the details of the various turns that were rated according to emotional intensity, along with the self-ratings of the authors of those turns and the average ratings of the external readers.

Table 1
Details of various turns rated according to emotional intensity by each turn's author and by external readers.

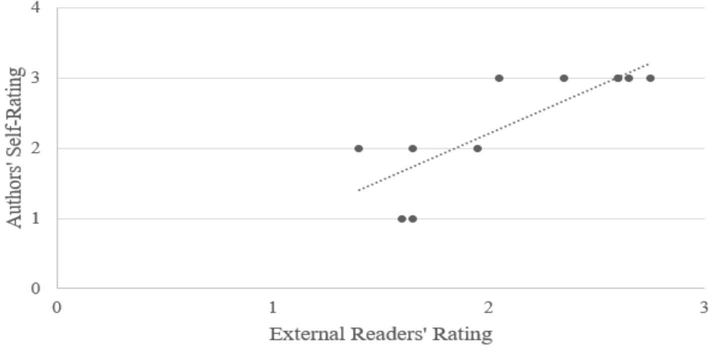
Turn	Author (pseudonym)	Author's Self-Rating	External Readers' Mean Rating
1	Toni	1	1.7
2	Dalit	2	1.4
3	Toni	3	2.6
4	Chen	3	2.7
5	Toni	3	2.1
6	Dalit	1	1.6
7	Moran	3	2.8
8	Dalit	3	2.6
9	Toni	2	2.0
10	Suha	3	1.5
11	Chen	3	2.4
12	Moran	2	1.7
Mean (SD)	N/A	2.4 (0.8)	2.1 (0.5)

Note. SD=standard deviation; N/A=not applicable

A Kendall's tau-b correlation was run on the discussants' self-ratings and the mean ratings of the external readers, excluding Turn 10, where the readers based their rating mainly on the Arab identity of the author instead of on the content she delivered. A strong, positive, and significant correlation was revealed between the two variables [$\tau_b=.71$, $p=.007$; see Figure 1], indicating that the higher the discussants rated their own turns, the higher the external readers rated those turns.

Figure 1

The relationship between the authors' self-rating of the emotional intensity in their turns and the mean rating of external readers of the same turns.



Identifying emotions – emotion markers in written dialogues

Participants were asked how they recognized the presence of emotions in the discussion. Because they were referring to a specific discussion, the answers were limited to the content of this specific discussion, the specific vocabulary, and the arguments used by the authors, etc. Nevertheless, the readers' answers were rich and diverse, and yielded three sets of factors that helped them to detect the presence of emotions – turn level, discourse level, and author's identity level.

Turn level

The first set of markers contained of *linguistic* markers that participants reported to confirm the presence of emotions. These markers were visible in the text, regardless of the context or the position of the turn in the flow of discussion. They were consistent with markers reported in research on narrative and personal texts (e.g., Argaman, 2010; Martin & White, 2005).

Some of the markers at the turn level concerned the *content* of the turn. The readers referred to *semantic* component of language, such as lexical items they identified as indicative of the presence of emotions. These included specific emotion words ("pride", "emotionally shaking") and words that participants defined as 'strong' or 'harsh' (e.g., "violent", "forcing", "dangerous"). Participants stated that the presence of such words in the text implied that the authors were emotionally involved when writing their opinion. Some of them also indicated that the lack of such words showed a low level of emotions (participant 18: "it's written rationally, without emotional words").

Another feature mentioned in relation to the content of the turn was the sharing of *personal stories* by the authors. Telling a personal experience was perceived by the readers as reflective of emotional involvement (participant 19: "her opinion relies on her own experience of how distressing it is, how scary it is").

Other markers concerned the *form* of the writing, namely grammatical and visual markers. The readers referred to *morphological* components, such as the use of first person ("us", "our families") as indicators of emotional involvement (participant 12: "she doesn't say 'the victims' families', she says '*our* families'…It's not in the third person, it's really present"). The lack of use of the first person was perceived as indicative of a low level of emotions (participant 1: "she doesn't say 'in *my* opinion', or '*I* think'. She says '*much has been said*'").

Participants also referred to *graphical* markers, namely the use of quotation marks (participant 2: "she uses quotation marks a lot…I would say she was really offended by what she said") as well as the use of question marks (participant 1: "the question mark shows me that there is emotion here") as suggestive of the presence of emotions.

The last marker that was found at the turn level was the *length of the response* and the level of *detail*, which were also identified as indicators of emotional involvement (participant 12: "she wrote a lot…it seems she really cares. She was very detailed and explained why she thought that way").

Discourse level

The second set of markers concerned the content of the turn and its location in relation to the other turns in the discussion. The readers perceived *argumentative moves* participants made as containing different levels of emotional intensity. For example, participants referred to expressions of disagreement and clarifications of one's opinion as containing high emotional intensity (participant 2: "she refines her words. It sounds like she's really afraid of being misunderstood and of being perceived as being against teaching the Holocaust...It's something that really bothers her, something that is very significant for her, so she is not willing to hear that the Holocaust shouldn't be taught; it's difficult for her to ignore it"). In contrast, agreement was perceived as containing less emotions (participant 18: "she's calm…she uses 'I agree with you' a lot…it doesn't seem to have a significant emotional effect on her"). Additionally, addressing opinions from both sides without taking a stance was perceived as less emotional and more balanced.

The *location* of the turn in relation to other turns provided additional information that affected the readers' rating. For example, the first turn was associated with less emotions because the author expressed her opinion but had not yet opposed anything because she there were no opinions to oppose (participant 19: "she states a strong opinion here but she's just starting the discussion so there is no objection here yet").

Reader's world view level

The last factor that affected the readers' rating of the intensity of emotions was the way they perceived the authors' connection to the topic of discussion based on their identity. Two of the participants revealed personal details about themselves during the discussion. One of the participants stated that her grandparents were Holocaust survivors, and the other identified herself as an Arab. The readers inferred the identity of the author from the text, but in contrast to the personal story that was part of the content, we chose to refer to the reader's view of the identity of the author as an extratextual factor that affected the judgment. In the turn written by the Arab student, the identity of the author led to a discrepancy between the author's report on the level of emotional intensity she felt when writing that comment, and the mean level of emotional intensity the readers rated. Only 15% of the readers rated this turn as the author did, and most of them explained their rating as dependent on her identity, sometimes even consciously ignoring other markers that were present in the text like strong words (participant 2 "she says '…I don't underestimate what happened in the Holocaust', 'It is a shocking event and against humanity', but the way she says it, it doesn't sound like she really feels it"; participant 19: "'Conflict' is a word taken from the Arab-Palestinian conflict, it's not related to the Holocaust at all").

The effect of the professional training

Forty five percent of the external readers pointed out that their professional training helped them to identify markers of emotions in the written discussion. Fifteen percent stated that their training affected their ability to identify those markers to a limited extent. Twenty five percent stated that their professional training had no effect on their ability to detect emotional markers at all. Fifteen percent did not answer the question.

Discussion

In this research, we investigated ER in digital written discussions. We asked whether the identification of the intensity of emotions in written EDCSI by trained external readers who had not participated in the discussions correlate with the discussants' identification of the intensity of their own emotions in such discussions. We also asked which markers readers use in the process of identifying emotions in written EDCSI, and what other factors influence their ability to identify emotions.

Twenty students with linguistic and emotional knowledge acquired during their professional training were asked to read a written discussion and rate the emotional intensity of each turn. We also asked them to indicate the markers that enabled them to identify the emotional intensity, and whether their professional knowledge helped them in the task.

The results showed a correlation between the average rating of the readers and the participants' rating of their own level of emotional intensity, indicating that the higher the self-reported emotional intensity of the authors, the higher the average rating of the external readers concerning these authors' level of emotional intensity.

To some extent, this correlation suggests an author-reader agreement about ER and opens the first steps into the inquiry of emotional intersubjectivity in EDCSI.

We are aware that the inter-rater reliability in this research was low, and there was no consensus among the external readers about the rating of the various turns, which seems indicative of a very weak model of ER in EDCSI. We attribute the low inter-rater reliability to two main factors. First, participants were not provided with a practice set in order to familiarize themselves with the task before rating the actual experimental items. Second, rating criteria were not clearly defined. Out of fear of "contaminating" participants' intuitions concerning the levels of emotional intensity in the experimental items, the experimenter refrained from providing examples for each level of emotional intensity (low, medium, and high) or clear characteristics for each of those levels. It is plausible that more specific training would have increased reliability. This assumption is supported by the fact that different readers used the same words and excerpts for ER but rated them differently on the emotional intensity scale. We also hypothesize that a larger sample of trained readers would increase inter-rater reliability and further strengthen the correlation found between the average rating of the readers and the participants' ratings. Meanwhile, we suggest that the readers' average rating be considered as representative of the readers' rating. Moreover, we believe a stronger indicator of inter-rater agreement in our case should lie in the cues based on which the external readers based their ratings, rather than on the ratings themselves.

External readers identified emotions using linguistic and content-related cues and considered the identity of the author and the position of the turn in the sequence of the discussion when determining the level of emotional intensity. The reports of the trained readers enable a deep understanding of the different factors that influence ER.

The linguistic and content-related cues that were identified as well as the readers' response to whether their acquired professional knowledge indicate that the professional linguistic and therapeutic knowledge may have helped the readers in the process of ER. This suggests that training with meta-linguistic and meta-emotional knowledge can be useful in the identification of emotions in EDCSI.

Nevertheless, the readers also based their rating of emotional intensity on the author's identity. This phenomenon of considering the identity of the authors while evaluating the emotional intensity they felt is described in detail in Keynan et al. (2022) and referred to by Slakmon et al. (2022) as the attributed closeness and sense of belonging of the authors to the topic of discussion.

Previous studies have shown that some of the emotions in EDCSI are directed towards participants while interacting with them at the inter-personal and group levels (Firer et al., submitted). In this study, the readers had no personal acquaintance with the participants in the discussion, except for the information revealed through their comments. Naturally, these details revealed characteristics specifically relevant to the subject matter. Not knowing the authors in person made the readers activate their system of beliefs, opinions, and perceptions about the authors' identities and influenced the way they rated the level of emotional intensity of the discussion and the way they interpreted the authors' intents. The details the authors provided served as emotional content markers. Moreover, these details evoked stereotypic preconceptions concerning the authors, which caused the readers to attribute strong feelings to those who are personally "related" to the subject matter and weak emotions to those who "have no right" to have an opinion on the subject, reverberating interactions taking place in the digital social media.

Although the readers activated their professional linguistic and therapeutic knowledge, under certain circumstances, when there was a contradiction between the professional knowledge and their personal opinions, the trained readers related to the author's identity rather than to the cues embedded in the text. Personal opinions influenced their ability to examine the content of the discussion objectively. The 'self', the personal identity, of the readers influenced their perception of the topic and their perception of the discussants, while their professional knowledge has not yet become part of their identity. Additionally, attributing a close connection or sense of belonging to the topic under discussion can imply that EDCSI emotionally activated both the participants in the discussion and the external readers.

The third aspect that affected ER was the position of the turn in relation to the other turns in the discussion. Martin & White (2005) describe three modes of meaning that operate simultaneously when perceiving the interpersonal meaning in language – the textual, the ideational, and the interpersonal. These modes are consistent with the linguistic, contextual, and identity markers we have identified. However, participants' reliance on the position of the turn in the sequence of turns in rating the emotional intensity, is a component that exists only in conversations. This component should thus be taken into consideration at the methodological level. The analysis of emotions in EDCSI, therefore, cannot rely solely on the turn level, but has to take the situational level into consideration. The importance of taking the situational level into account is consistent with findings from additional studies that have recently been submitted (Firer et. al., submitted).

The current study has theoretical and pedagogical implications. In the theoretical realm, it sets a basis for a comprehensive framework for the identification of emotions in EDCSI since it refers to the different levels of cues and information they consist of: linguistic markers, discourse level components, and socio-cultural influences. Considering how closely participants identified specific markers, the model may serve as a model-in-action, for which the emotions detected are checked through actions of the teacher. Considering the viability of the model as a tool for formative rather than summative ER is an exciting research path we are currently engaged in. In the pedagogical realm, the model can serve as a basis for training teachers to identify emotions in written discussions, and to increase their awareness of possible biases, especially in socio-culturally diverse groups and enable teachers to moderate EDCSI and to promote the development of socio-emotional competence of their students. Further research should include a larger sample of readers, which should help differentiate between the influences of emotional training and linguistic training as well as the ability of untrained teachers to identify emotions. Such studies should also examine the effect of training according to the three levels we have identified on the ability of discussants and external readers to identify emotions accurately.

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Two Changing Minds: A Journey to Culturally Responsive and Computational Thinking Infused Science Teaching

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Abstract: Integrating computational thinking (CT) in accessible and inclusive ways has been a challenge for elementary science teachers. To promote equitable integration of CT in elementary science lessons, we delivered a five-day professional development (PD) workshop for teachers to practice applying CT and culturally responsive teaching (CRT) in their science lesson designs. In this study, we examined how two elementary science teachers' understandings of CT- and CRT-infused science teaching changed during the workshop. We compared two teachers' understandings of CT, CRT, and the levels of CT-CRT integration reflected in their lesson plans using our integrated framework. Drawing on data gathered from surveys, observations, artifacts, and interviews, we found that the two teachers had varied growth in their understandings of CT and CRT from their different entry points and through distinct pathways. This paper illuminates effective PD interventions, presenting opportunities for elementary teachers to integrate CT and CRT into their science lessons.

Introduction

Promoting pedagogical practices that engage all students, especially students historically excluded in computing fields (underrepresented genders and Black, Latino/a/e/x, and Native American/Alaskan Native [BLNA] students), is essential for broadening participation in computing. Science lessons that integrate computational thinking (CT) are one way to expand computing education beyond traditional computer science classrooms (Lee et al., 2020; Yadav et al., 2018). According to Wing's initial definition of CT (2006), CT "involves solving problems, designing systems, and understanding human behavior by drawing on the concepts fundamental to computer science" (p. 33). CT's definition has changed over time, but researchers agree that CT is an effective on-ramp for younger students and teachers to first introduce computing concepts before teaching foundational computer science (CS) content. However, our research team's earlier project on CT-integrated science PD indicated the necessity of using equity-centered approaches to address the concern that some elementary science teachers believed that CT is best suited for only high-performing students, rather than for all (Ketelhut et al., 2020).

One way to address inequitable integration of CT in elementary science lessons is to co-develop culturally responsive science lessons with the teachers themselves. Gay (2002) claims that educators who apply culturally responsive teaching (CRT) practices to their teaching and situate students' lived experiences within the learning environment make learning more personally meaningful, interesting, and engaging. Moreover, various studies show that CRT is a powerful pedagogical mechanism for providing students, particularly BLNA students, with the academic and social support they need to meaningfully learn and enjoy science (Charleston et al., 2014; Ladson-Billings, 1992; Stanley & Brickhouse, 2001).

The successful implementation of CT, CRT, and science together requires elementary teachers to have an understanding of science, CT, and CRT knowledge in addition to a deep awareness of their personal teaching practices (Gay, 2002). A report evaluating K12 CS teachers' beliefs towards CRT practices showed that only 57% felt they could successfully implement CRT practices (Koshy et al., 2021). Hence teacher professional development (PD) focused on CT/science integration is needed to support teachers in integrating CT, CRT, and science into their lesson designs with a focus on equity and inclusion. As the initial launch of a 3-year PD project, we designed and implemented a five-day PD workshop to prepare elementary teachers to integrate CT and CRT by adapting their existing science lessons. This paper analyzes data from two of the participating teachers, both of whom teach fourth grade and developed similar final lesson plans by the end of the PD. This paper aims to answer the following research question: *How do elementary teachers' initial understanding towards CRT- and CT-integrated science instruction evolve throughout a 5-day PD workshop*?

Theoretical framework

Our research team drew extensively from Gay's (2018) definition of CRT to develop an integrated framework of CRT, CT, and elementary science (Mak et al., 2023). We saw CRT as a powerful pedagogical approach to engage all students in CT-integrated science learning and to build teacher awareness of structural barriers that may arise from their lessons. Specifically, our research team created a conceptual wheel that includes three main practices for teachers to apply CRT in their CT-integrated science curriculum: Equitable Instructional Practices, Student-Centered Content, Inclusive Relationships & Communities (Mak et al., 2023). Table 1 lists the three main opportunities and the surrounding seven CRT practices as outlined by Gay (2018).

Table 1
The Framework of CRT (Table Format)

Reflect on One's Cultural Lens		
Equitable Instructional Practices	**Student-centered Content**	**Inclusive Relationships & Communities**
Model high expectations	Incorporate student experience to promote respect for differences	Collaborate with family and local community
Draw on students' cultures to shape CT and science practices in the classroom	Bring real-world issues and experiences into the classroom	Speak up about and respond to prejudice, bias, and stereotypes
		Honor multiple modes of sensemaking and expression

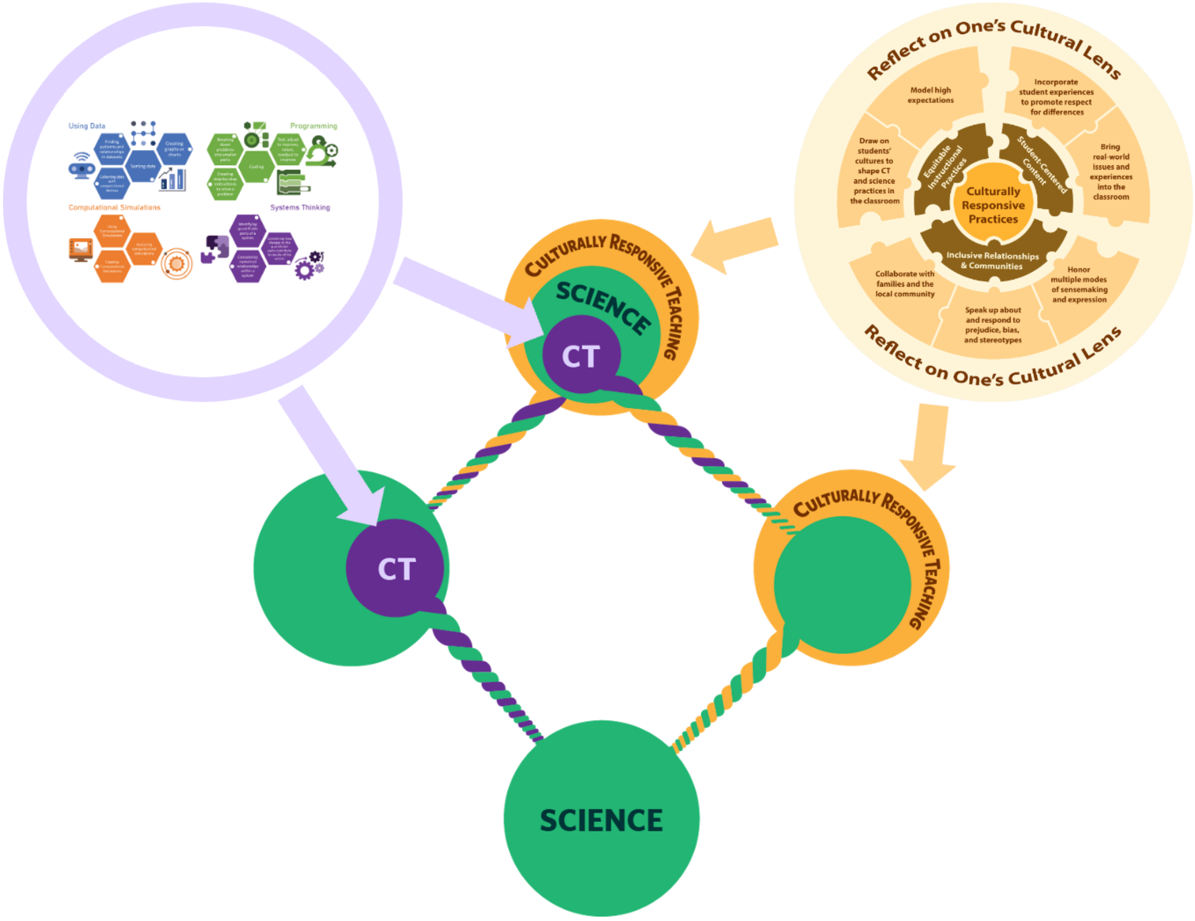
In addition to building a comprehensive understanding of CRT as it relates to elementary science instruction and teacher PD, the research team also developed a shared understanding of how CT fits into culturally responsive science instruction. Our team designed a CT framework that explicitly aligns with elementary science teaching (Ketelhut et al., 2020) when compared with other more general CT frameworks (e.g., Weintrop et al., 2016). This CT framework consists of four major CT practices: using data, programming, computational simulations, and systems thinking (Table 2).

Table 2
The Framework of CT (Table Format)

Using Data	**Programming**	**Computational Simulations**	**Systems Thinking**
Finding patterns and relationships in datasets	Breaking down problems into smaller parts	Using computational simulations	Identifying quantifiable parts of a system
Collecting Data with computational devices	Creating step-by-step instructions to solve a problem	Assessing computational simulations	Considering numerical relationships within a system
Sorting data	Coding	Creating computational simulations	Considering how changes to the quantifiable parts contribute to results of the system
Creating graphs or charts	Test, adjust to improve, retest, readjust to improve		

Our integrated framework takes the CT framework a step further by considering how each CT practice can be intentionally integrated to promote inclusivity and equity in each science lesson (Mak et al., 2023). CRT practices and CT practices intertwined with science and each other to arrive at a CT, CRT, and science-integrated framework, serving as a lesson reflection tool for teachers (see Figure 1). This framework allows teachers to start integration at multiple entry points depending on their prior knowledge of CT and CRT and to choose different approaches to CT and CRT-infused science teaching. Teachers may start from any one of the four circles and add a new CT or CRT layer to their lessons, or they may break an integrated lesson down to CT and CRT elements to work on. This study explores how our integrated approach influenced elementary teachers' understanding of CT- and CRT-infused science teaching changed throughout the PD.

Figure 1
The Integrated ACT-Lesson Reflection Tool (refer to Tabe 1 and Table 2 for texts in the frameworks)



Methods

We used a multiple-case study approach (Yin, 2018) to provide detailed descriptions of how teachers' understanding of CT and CRT infused science changed in different ways during the PD workshop. An overview of the PD agenda is listed in Table 3. Among the 24 elementary science teachers from two school districts in a Southwestern state, we intentionally chose two teachers, Ms. Casey and Mr. Alex (aliases), mainly because 1) they teach within the same grade band, both teaching 4th Grade; 2) they possess similar length of teaching experience, both having taught for about 20 years; 3) they created a final science lesson plan poster using the same initial lesson. Both teachers are White. They teach in the same large urban public school district with diverse array of schools, but in different schools: Ms. Casey teaches at K-8 school within a high socio-economic neighborhood in the northern part of the district boundary while Mr. Alex teaches at a K-6 school in the southernmost part of the district boundary with lower socioeconomic status. During the workshop, Ms. Casey and Mr. Alex engaged in most PD activities and group discussions separately as they were seated apart, but they collaborated with the other 4th grade teachers during lesson-planning times every day. Among all teachers, Ms. Casey and Mr. Alex had the most similar starting points in terms of their background and lesson plans. Comparing their cases will inform us of how their personalized self-reflections mediate their understandings of CT and CRT, which potentially leads to different approaches to and outcomes of integrated science teaching. We selected Ms. Casey and Mr. Alex in this case study as an initial exploration, through which we look for patterns and theories that will inform future larger-scale analyses involving more teachers within this first site of implementation and across multiple sites.

Data were collected from multiple sources: pre-workshop survey data, daily Google reflection forms, final lesson plan designs, and post-PD focus group interview recordings. Prior to the PD workshop, a pre-survey was sent to teachers to collect their basic information (e.g., district, school, years of teaching), initial understanding, and classroom practices related to CT and CRT. On each day of the PD, teachers were asked to submit responses to a series of reflection questions through Google Forms. Teachers wrote exit tickets at the end of each day. Observation notes were taken by 2-3 members of the team in turn. In the first four days, every day in a dedicated time, teachers adapted or designed their individual lesson plans to integrate CT and CRT components and get feedback from other teachers in the same grade band. On Day 5, each teacher presented their lesson plan in a final poster gallery walk activity. At the end of the workshop, teachers participated in semi-structured focus group interviews with their table mates. The interview questions were designed to capture changes in their understanding of CT, CRT, and their integration in science. The interviews were videotaped and transcribed for analysis.

Two researchers first conducted deductive coding for the data based on the three CRT opportunities (Equitable Instructional Practices, Student-Centered Content, Inclusive Relationships & Communities) and the four areas of CT practices (Using Data, Programming, Computational Simulation, Systems Thinking) in the frameworks guiding the PD design (Ketelhut et al., 2020; Mak et al., 2023). Based on the initial deductive categories, the two researchers conducted another two rounds of inductive coding, in which they looked for new themes to capture teachers' evolution of thinking. After the independent coding process, the two researchers discussed each code, converged on the coding scheme, and reached full agreement on the resulting codes.

Table 3
Overview of the PD agenda

Days	CRT focuses	CT focuses	Integration activities
Day 1	Overview of CRT	Overview of CT; CT and citizen science	Introducing everyone's name and animating it using Scratch
Day 2	A deeper dive into CRT; Equity in CS education	Data practices about weather using Micro:bits and data visualization tools	
Day 3	Providing language support in science; Teachers' journey to equity; CRT in a physics lesson	Simulations and systems thinking in science using SageModeler and Phet simulations	
Day 4	Identifying teachers' values	Programming using Edison Robot and Micro:bits	Integrating all aspects of CT and CRT in a lesson about urban heat islands
Day 5	Cultural affinity map		Poster presentation of teachers' integrated lesson plans

Findings

Case 1: Teacher ms. Casey

Prior to the PD workshop, Ms. Casey had an emerging but vague understanding of CRT. She was motivated to create an inclusive classroom as her yearly goal, describing her approach to this goal mainly as to "help foster unity and help students open up about their thoughts and feelings" (Pre-workshop survey, June 2022). Similarly, although she had not heard about the term CRT before, she speculated that CRT means "showing respect and acceptance to all students" (Pre-workshop survey, June 2022). She maintained this interpretation of CRT throughout the PD: across the five days, she consistently focused on creating a safe classroom environment for students to open up and share, yet she did not describe in detail what practices she might adopt to achieve inclusiveness or student-centered content. Rarely did she reflect on equitable instructional practices in her written responses.

Her broad understanding of CRT was explicitly observed on Day 2 when a facilitator explained in-depth the characteristics of CRT defined by Gay (2018), which includes acknowledging the value of students' cultural heritages, bridging between home and school experiences, using various student-centered instructional strategies, and teaching students to appreciate each other's culture. After hearing the facilitator's interpretation, Ms. Casey shouted: "...It makes me sad that we still have to talk about this because it is just good teaching (Observation note Day 2, June 2022)." While believing CRT is "good teaching," she did not expand on the deeper meaning of CRT or any concrete approaches to achieve it. She held onto helping students open up in her classroom as a key element of CRT, which was reflected in her lesson plan and focus group interviews expanded in the next sections of this paper.

With CT, Ms. Casey presented a complicated attitude. Although in the interest form and pre-survey she expressed excitement about integrating more technology into her science lessons, she tended to express discomfort when learning about new technological tools. On Day 1, she was asked for the first time to use Scratch (a block-based programming language that supports the creation of interactive stories, games, and animations) to create a short animation. When she could not make the objects on the screen move in the way she planned, she seemed very frustrated, talking aloud to the facilitators in an angry tone. But then, after the facilitators helped her solve the problem, she quickly returned to her normal voice with a more polite attitude and continued to focus on the project. She had similar reactions again in the following days when she experienced other new tools such as Data Wrapper (a data visualization tool that teachers used to create a local sandstorm frequency map) and Edison Robot (a programmable educational robot), but her reactions were not as intense as the first day. In the end, despite her initial resistance, she successfully completed all the technology-infused activities in the workshop. One of her group mates commented in the focus group interview on Day 5 that Ms. Casey "has changed tremendously" in terms of her acceptance of technology.

Ms. Casey's mixed attitudes towards technology were interwoven with her understanding and confidence in CT integration into science. Compared to her interpretation of CRT, she gradually adopted the language in our CT framework to describe CT-infused teaching practices in detail, but most of the time her responses solely focused on using data, which had already been part of her daily science teaching practices (as indicated in the pre-survey). Her self-reported comfort level with CT on Day 3 was 2.5 on a 1-5 scale compared to a mean of 3.15 among the 24 teachers, lower than her CRT comfort level of 3. Although she saw the value and need to expose students to CT activities, she still perceived CT as harder for her due to a major concern that CT-infused activities could not easily align with standards-based science learning. In her opinion, "many of the items I've been introduced to this week seem to be more STEAM related than specific standards I need to teach (Reflection Form 3, June 2022)." Correspondingly, she also reflected on not feeling comfortable with doing hands-on activities because students could not be directly assessed through formal grades.

Based on our observations, we only saw one instance in which Ms. Casey showed the idea of combining CT and CRT together: when her focus group talked about the benefits of involving computers in science teaching, she pointed out that collecting and charting data on a computer not only gives more meaning and real-life connection to students, but also makes students feel more responsible for the task. Other than that, she tended to consider CT and CRT separately in elementary science.

Case 2: Teacher mr. Alex

Before the PD workshop, creating an inclusive learning environment was already mentioned in Mr. Alex's teaching philosophy and science teaching practices reflected in his pre-survey responses. He emphasized collaboration and engagement for all learners in his classroom, specifically using game-based learning approaches to ensure equal participation in science activities. Although he mentioned no prior exposure to formal training on CT or CRT, he had provided examples of using CT and CRT practices in his lessons. For instance, students in his classroom were given hands-on opportunities to engage in real-world science topics (e.g., "students work in collaborative groups to build functioning water wheels in the Water & Climate unit," Pre-workshop Survey, June 2022). He also incorporated student experiences to promote respect for differences to some degree (e.g., "I also embed discussion time during morning meetings to allow students to share their opinions, differences, etc. We work in cooperative teams and learn to listen and appreciate each other's experiences and stories," Pre-workshop Survey, June 2022). When he learned more about CT and CRT, Mr. Alex quickly related the two concepts to his past efforts. In addition, he seemed to be comfortable with the new technologies introduced in the workshop, completing most workshop activities without technology assistance.

In the self-reflections he wrote, we found that Mr. Alex demonstrated an improved, concrete understanding of implementing CT and CRT practices:

> It's important to use a CRT lens to reach all our different learners in our classrooms. We have such diverse children in our room and finding a way to make science accessible is important. We need more representation in the math/science fields. The challenge right now is not knowing who are (our) students are and what the make-up of my class will be. Also there is internal diversity in our classes that we don't always know about. I also think teachers sometimes don't integrate CT in their lessons because there's a lack of knowledge and access to data and what to do with that data and how students can take ownership of their own data and use it in a way to make inferences. (Reflection Form 2, June 2022)

In this reflection, his written response implied two opportunities for adopting a CRT lens: 1) through creating student-centered content and making science accessible to all types of learners (i.e., he emphasized incorporating diverse children's experiences to promote respect for differences and giving students a sense of ownership of their learning processes); 2) through building inclusive relationships and communities (i.e., he recognized the need for using more representations or encouraging multiple modes of expressions). His reflection also demonstrated that he perceived CRT as inclusion with a central focus on diversity and designing lessons to improve representation in science and math.

In the focus group interview, he rated himself as super confident in teaching CT- and CRT-integrated science lessons in the upcoming school year. He showed clear intentions to create more opportunities for English language learners (ELLs) and special education (SPED) students in his class. Specifically, he appreciated the Activity before Concept (ABC) - Concept before Vocabulary (CBV) model introduced in the workshop and stated that he would modify and make accommodations for his ELL and SPED kids based on the ABC-CBV conceptual model. Moreover, Mr. Alex constantly emphasized the importance of establishing career awareness for all students, noting the importance of expanding CRT beyond one-off lessons in the classroom to long-term student participation in the STEM pipeline.

Mr. Alex's journey in the PD started with a strong recognition of the relationship between technology and learning, and an awareness of creating an inclusive atmosphere for diverse student learners (i.e., ELL and SPED learners). At the end of the PD, he presented a model of integrating CT and CRT more aligned with the framework facilitators presented in the PD.

Lesson plan comparison

Both teachers chose seasonal weather as their lesson plan poster topic. They also selected similar starting lesson plans, both containing some CT and CRT components. For instance, both original lesson plans asked students to analyze their local weather data in four months (Student-Centered Content), consider weather differences across the country (Inclusive Relationships & Communities), and emphasized inputting data into Excel to create bar graphs (Using Data). After the coding analysis, we noticed some similarities and differences between the two teachers' extensions of the lesson plans in terms of using CT and CRT practices. These similarities and differences are summarized in Table 4.

Table 4
Comparison of the Two Teachers' Lesson Plans

	Ms. Casey	**Mr. Alex**
CT	Both teachers highlighted data practices and included sorting data and creating graphs or charts in their lessons.	
	• Used Google Sheet as the main computational tool (*Using Data*) • Did not apply any new computational tools introduced in the workshop (*Using Data*)	• Stressed the importance of finding patterns and relationships in datasets (*Using Data*) • Extended the use of computational tools from recording and organizing data in Google Sheet to building visual map models with DataWrapper (*Using Data*)
CRT	Both teachers expanded the lesson by having students look at weather data in other places in the U.S. (relating local weather patterns with weather patterns elsewhere).	
	• Stressed the inquiry-based approach when expanding the topic to weather across the U.S. (*Student-Centered Content*) • Posed a question on weather differences across the U.S. and described a case scenario about unusual weather patterns (*Inclusive Relationships & Communities*)	• Emphasized bringing in local and national scientific data into the lesson so students can draw patterns and relationships between their communities and others around them (*Student-Centered Content*) • Stressed being aware of differences when comparing local weather to the national weather (*Inclusive Relationships & Communities*)
Integration	Emerging	Intermediate

The comparative analysis demonstrates that although the two teachers made similar adaptations to their original lesson plans, they integrated CT and CRT at various levels and interpreted their changes from different angles. Ms. Casey chose to enhance the inquiry-based approach of the original science lesson. She created opportunities for students to share their different experiences by expanding the source of data from local to nationwide. In comparison, Mr. Alex adapted his lesson plan to explicitly include more CT practices with a culturally responsive lens by purposefully incorporating more CT tools and creating opportunities to articulate the rationales behind the CRT elements with students.

Cross-case comparison

Other data further support findings from the comparisons between the two teachers' lesson plans. In focus group interviews, for example, when prompted to describe the changes in CT and CRT understandings, both teachers expressed that this PD workshop affirmed their past practices, but they showed multiple pathways to extend their science teaching by including CT and CRT practices. In Mr. Alex's case, he stated affirmation of his past CT-related practices:

> The layer of CT is already in our science lessons. So I just need to add a bit more tech pieces and the world view thing (Focus group interview Day 5, June 2022).

In Ms. Casey's case, she described the changes in her understanding of CRT as:

> I do it over the whole class period, but not maybe specifically to science. But it's gonna make me look at it a little bit differently and maybe make sure that I look for those opportunities when I need to (Focus group interview Day 5, June 2022).

Drawing back to the ACT integrated model (Figure 3), we could recognize that Ms. Casey and Mr. Alex started at different entry points and chose different approaches towards CT- and CRT- integration in science. Ms. Casey had relatively high confidence in CRT but was initially frustrated by CT tools. Hence, she developed a lesson plan based on her understanding of CRT by expanding the CT components, showing a science→CRT→CT pathway in the ACT model. On the other hand, Mr. Alex started with greater recognition of technology and developed a more nuanced understanding of CRT during the PD. His lesson plan focused on using data practices to promote cultural responsiveness, showing a science→CT→CRT approach.

However, despite emerging signs of CT- and CRT- integration, both teachers still understood CT and CRT in limited aspects and held misconceptions to various extents. Their interpretation of CT and CRT tended to remain general and vague, especially for Ms. Casey. For example, one of the few shared moments for them regarding equity was when a facilitator showed images of old White male figures that appeared in a Google Image search for "scientists." Both of them mentioned becoming aware of the prevalent use of such images and the importance of reducing stereotypical conceptions, which was an opportunity for them to examine their own identities as science teachers. Mr. Alex extended this topic by reflecting on the representations of ELLs and SPED students in the classroom and differentiated support for them. In contrast, Ms. Casey discussed little about who her students are and how her past or present teaching practices could support their different needs or promote socio-political consciousness. In addition, although the PD workshop embedded multiple scaffolded activities for teachers to share and reflect on their own cultural lenses, both teachers rarely mentioned how their own experiences could influence their perception of CT- and CRT-integrated science in their final lesson plan and focus group discussions.

Conclusions & implications

Ms. Casey and Mr. Alex's journeys to culturally responsive and computational thinking infused science teaching are diverse. Ms. Casey started with emerging conceptualizations of CT and CRT; during the workshop, she overcame great challenges to master the technology tools but remained relatively constant in her understanding of CRT. In contrast, Mr. Alex embraced technologies to a greater extent prior to the workshop; while feeling confident in integrating CT, he developed a finer-grained and multi-layered understanding of CRT.

The growth in understanding of CT and CRT in the workshop were not even for both teachers, drawing attention to the inherent differences between the two concepts and the role teachers' personal experience plays in their learning. We suggest there is a gap between teachers' perceived difficulty and actual understanding for both concepts, but the gaps in CT and CRT exist in different ways. Although CT has initial barriers for teachers who do not possess high self-efficacy for using technologies, it is more tangible and explicit for teachers to develop a concrete understanding. CRT, however, can be easily perceived by teachers as “just good teaching” despite it being much broader and deeper than that. CRT is more nuanced and multifaceted, highly dependent on the teacher’s active reflection on their own cultural lenses and experiences. Moreover, teachers tend to believe they are already integrating the whole of CRT when they are just working on one aspect of it. Both CT and CRT are complicated constructs with multiple layers, but they take effect in different mechanisms. While elements of CT can be extracted and implemented separately, different dimensions of CRT work as an organic whole, which requires fundamental changes in teachers’ beliefs and philosophies. Our research will continue to examine the ongoing evolution in teachers’ understanding of CT and CRT in classrooms and how their self-efficacy changes in the process. We suggest that future work should focus on providing teachers with more personalized and sustainable support for CRT in order to build CRT- and CT-infused science classrooms.

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Anxiety, Achievement, and Self-Regulated Learning in CueThink

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Abstract: The effects of educational anxiety have been observed across multiple disciplines; anxiety negatively influences cognition, self-regulation, performance, and educational outcomes. However, there has been limited research on anxiety within the context of interactive learning environments. In the current research, we expand this by assessing whether and how trait-level anxiety (assessed as a pre- and post-measure in a year-long study) is related to students' self-regulated learning strategies, behaviors, belief, and achievement in the context of an open-ended math problem-solving platform, called CueThink. Results indicate that anxiety is negatively related to key constructs involving math achievement. Altogether, our findings generally imply that students with higher anxiety may avoid interacting with their stressors, in this case, math content, effectively contributing to poorer outcomes. We discuss our findings within the context of research and pedagogical and system design.

Introduction

Anxiety is generally defined as the affective reaction to overwhelming cognitive and motivational demands that are tied to highly valued academic situations (González, Fernández, & Paoloni, 2017; Pekrun & Perry, 2014; Zeidner, 2014) often resulting in decreased performance (Hong, 2010). Individuals prone to anxiety are purportedly less likely to effectively manage uncertainty leading to difficulties around decision making, which contributes to negative outcomes on performance, motivation, and attention across various subject areas (e.g., Ashcraft, 2002, Na, 2007; González et al., 2017; Pardo, Han, & Ellis, 2016; Taylor, & Fraser, 2013; Woolf et al., 2010). Anxiety around specific subject matter, such as math or science, can also lead to avoidance behaviors, both in daily life and within educational settings (Ashcraft, 2002; Brunye et al., 2013). This can then impact competence and academic success (Plake & Parker, 1982; Brunyé et al., 2013). When learners engage with a subject in which they experience anxiety, they are more likely to underperform as a result of hyper-focusing cognitive and attentional resources on apprehension and concern regarding the demands of an educational task instead of strategies for problem solving (Ashcraft, 2002; Beilock & Carr, 2005; Jelici et al., 2004).

Although previous research has established the impact of anxiety on learning, few studies have examined this phenomenon within the context of interactive learning environments (ILEs; with some exceptions, see Andres et al., 2021, Hutt et al., 2021b). As ILEs become more prevalent at all levels of education (Allen & Seaman, 2014) it is important that we consider how individual differences between students may impact their experiences, so that ILEs can be designed to better support students' needs. The effects of anxiety may also be compounded in ILEs where there may be reduced immediate feedback from instructors and increased demands of metacognitive skills, proficiency with technology and complicated software (Hsu et al., 2009). The fine-grained data collection by ILEs allows for insights into the interactions and relationships between learner cognition and affect (Hutt et al., 2021a; Sinha, Jermann, Li, & Dillenbourg, 2014). For example, extensive work has considered the relationship between learning, interaction and epistemic (or academically-relevant) affective states (e.g., boredom, confusion, delight, engaged concentration, and frustration) in ILEs. However, this work has generally not considered anxiety.

By better understanding how anxiety may manifest in ILEs, we gain not only a better understanding of the phenomena, but the potential to respond to and scaffold students experiencing anxiety. Affect-sensitive interventions have produced better learning gains (D'Mello & Graesser, 2012; Clavel & Callejas, 2015; DeFalco et al., 2018), and support positive self-perceptions and attitudes (Karumbaiah et al., 2017). Additionally, interventions have been designed to impact constructs such as motivation (De Vicente & Pain, 2002) and self-efficacy (Beal & Lee, 2005).

This paper thus examines the effects of anxiety within a digital learning application called CueThink, an open-ended math problem-solving platform. Specifically, this study leverages a multi-faceted correlational approach to understand what constructs are related to anxiety in the context of a math-focused ILE. Specifically, we collected a broad range of measures that may be related to anxiety in order to identify how anxiety relates to:

1) survey measures to identify how trait-level anxiety relates to changes in student usage, belief, achievement, learning, and performance; 2) previously-developed detectors of self-regulated learning behaviors; 3) usage behaviors in the ILE (e.g., response patterns and language). Through these analyses, we attempt to build a better understanding of how anxiety can influence learners within an ILE and how features of learner experiences can be used to eventually build systems that can identify and mitigate the influence of the effects of anxiety.

Methods

CueThink

CueThink is a digital learning application that scaffolds math problem-solving and encourages mathematical discourse through open-ended problems and corrective feedback. Students are asked to think aloud while they solve math problems to create a shareable screen-cast video of their overall problem-solving process as well as their final answer. Within CueThink, students work on Thinklets, step-by-step processes for solving math problems. Each Thinklet consists of four phases: Understand, Plan, Solve, and Review. This was developed in line with the Winne & Hadwin model of SRL (Winne & Hadwin, 1998) and scaffolds a problem-solving process that includes unpacking the problem, choosing a strategy, and creating a plan. Students can move freely across the four phases, including going back to a previous phase or skipping phases.

The Understand phase asks students to structure their conceptualization of the problem by asking three questions: (1) “What do you notice?” (2) “What do you wonder?” and (3) “What is your estimated answer to the problem?” In the Plan phase, students are asked to select strategies they will use to solve the problem (either from a pre-written list or self-defined) then write a plan on how they will use the strategies to solve the problem. In the Solve phase, students explain and present their answer. During this phase, the students create a screencast video using an interface that provides them with a whiteboard and mathematical tools (i.e., number lines, ruler, etc.). Lastly, in the Review phase, students provide the final answer to the math problem and reflect on the accuracy of their answer, the clarity of their responses, and record this reflection using checklists.

Once students have completed the problem, they share their screencast explanation for Peer Review. Teachers and peers are encouraged to annotate both the textual responses and video with the goal of prompting the student to identify their underlying reasoning or for using specific methods. These annotations are then sent back to the video’s author for possible revision of the video.

Sample

A total sample of 213 of students (115 sixth grade and 98 seventh grade) participated in the larger study. However, as is common in classroom studies, not all students completed all measures. As a result, a varying number of students were included across statistical analyses in order to maximize the availability of data per analysis; final N’s for each test are reported alongside the results in the following sections. All students were drawn from three middle schools from a large, suburban school district located on the West Coast of the United States. The participants identified their gender as male (40.8%), female (53.1%) or non-binary (1.9%) or other (2.8%), with 1.4% of participants electing not to specify a gender. The participants also identified as Hispanic/Latinx (29.6%), Middle Eastern (28.6%), 2 or more races (16.4%), Asian (6.6%), Black/African American (4.2%), or White (2.8%), with 11.7% of participants preferring not to specify their ethnicity.

Pre-test and post-test survey measures were administered within the course of this study (details below). Students were given approximately 75 minutes to complete three different survey components. The first was a paper-and-pencil mathematics assessment developed by Illustrative Mathematics (approx. 35 mins.), followed by an online set of questionnaires distributed over Qualtrics (approx. 20 mins). This form contained prompts from the modified Abbreviated Math Anxiety Scale, Indiana Math Belief Scale, i-Ready Diagnostic, and Junior Metacognitive Awareness Inventory. For consistency across the varied scales, each item from all self-report surveys were reported on a scale from 1-100. Lastly, the third component was Adaptive Cognitive Evaluation, to measure executive function (UCSF, 2022). The content of the pre-test surveys and post-test surveys were identical. The three components were administered in no particular order. Pre-test surveys were completed anytime within a two-week period between November and December 2021 and the post-tests were completed anytime within a three-week period in May 2022.

Research instruments

Executive function

Executive function (EF) was measured using the Adaptive Cognitive Evaluation (ACE; Younger et al., 2022). ACE is implemented through a series of game-based cognitive tasks around three core EFs: inhibition, working memory (change detection), and cognitive flexibility (task switching; Miyake et al., 2000). Mean and standard deviation scores were calculated for both reaction time and accuracy measures.

Content knowledge

i-Ready diagnostic assessments were used a proxy for mathematics content knowledge by the partnering district (Curriculum Associates, 2022). The i-Ready (CDE, 2022) instrument is an adaptive assessment tool used to identify math topics students are struggling with. It examines students' understanding of mathematical sub-domains, including numbers and operations, algebra, geometry, and measurement. This assessment was administered three times throughout the school year. These testing periods were conducted towards the beginning (September), middle (December to January), and end (May) of the academic year.

Metacognition

An abbreviated version of the Junior Metacognitive Awareness Inventory (MAI, Jr.; Rhodes et al., under review; Sperling et al., 2002) was administered to record subjective metacognitive and cognitive strategies applied by learners. Objective metacognition was separately recorded through the use of confidence judgements wherein students estimated how well they would perform on problem-solving exercises and would evaluate their performance immediately after the task. Scores for objective metacognition were calculated by computing the absolute value of the difference scores between an individual's confidence judgements and their actual performance.

Affective instruments

Anxiety and mathematic epistemological beliefs were recorded using the modified Abbreviated Math Anxiety Scale (mAMAS; Carey et al., 2017), and belief scales 1, 5, and 6 of the Indiana Mathematics Beliefs Scales (IMBS; Kloosterman & Stage, 1992), respectively. The mAMAS uses a two factor structure that uses two subscales: learning math anxiety (Learning subscale), and math evaluation anxiety (Evaluation subscale; Hopko et al., 2003; Carey et al., 2017). The scale has shown good internal consistency, with an overall Cronbach's α 0.85, a Cronbach's α of 0.77 for the Learning subscale and Cronbach's α 0.79 for the Evaluation subscale (Carey et al., 2017; Cipora et al., 2015; Szczygieł, 2019). The scale was developed for children between 8 and 13 years old (i.e., overlapping with our research sample) and consisted of 9 items. The mAMAS was slightly modified to change adapt words to American English (e.g., "maths" to "math").

The IMBS measured beliefs around mathematics, more specifically about whether students believe they can solve time-consuming problems, about whether effort increases ability, and about the usefulness of mathematics in their lives, respectively. Students were also given five questions about their feelings about mathematics and the classroom and a question about how close they felt to the subject of mathematics. An abbreviated version of the IMBS (Rhodes et al., under review) was administered to reduce testing fatigue.

Problem solving measure

Members of the research team developed 3-item problem solving measures for each grade. All items for this measure were drawn from mathematics problems developed by Illustrative Mathematics (IM) and included in the current measure based on A) their cognitive demand and overall rigor, B) their alignment with district standards for the given grade level, and C) the degree to which students were required to explain their thinking. Each problem was scored for accuracy (IM accuracy) using IM answer keys. Problems were also scored by external researchers who assessed the degree to which a student demonstrated appropriate and sufficient mathematical understanding, regardless of their final answer (IM understanding). Each student received both scores.

Self-regulated learning behaviors

In addition to these surveys, we also analyzed the relationship between anxiety and students' self-regulated learning (SRL) behaviors, using a set of behavior detectors developed using qualitative codes of SRL behaviors originally developed by Zhang and colleagues (2022) and validated for generalizability using 10-fold student-level cross validation (summarized in in Table 1). Results were calculated for each fold and averaged to yield one AUC ROC score per detector; all the values in the table show relatively high accuracy for each SRL behavior.

Table 1
Detector Performance Measured by AUC ROC with Standard Deviations (Zhang et al., 2022)

SRL Indicator	AUC ROC	Working Definition
Numerical Representation	0.894 (.078)	Representation notes numerical components and how these are used in the math problem
Contextual Representation	0.813 (.132)	Representation notes contextual details (setting/characters/situations) in the problem
Outcome Orientation	0.761 (.076)	Only a numerical estimate of the final answer (suggests a focus on output over process)
Data Transformation	0.815 (.163)	Information is manipulated to find a solution (suggests active problem solving)

Usage data and linguistic features

Throughout this study, we extracted the amount of time each student spent completing tasks within each phase of their Thinklets. This data was recorded in seconds and summarized at the student level per phase (Understand, Plan, Solve, Review). Students' text responses were also analyzed for linguistic features using the Linguistic Inquiry and Word Count (LIWC) program (Pennebaker et al., 2015). LIWC analyzes 100 different lexical categories (Pennebaker et al., 2015) and uses a combination of computing methods and dictionaries that automatically tabulate text files for word counts and important psychosocial constructs and theories with words, phrases, and other linguistic constructions (Boyd et al., 2022). We attempted to minimize Type 1 errors by selectively choosing the lexical features under the *Cognition* category of LIWC (Boyd et al., 2022). This category reflects the different ways people refer to their thought processes. Table 2 below summarizes the subcategories that are included in this category as well as some of the same words that are recorded and coded for each of these.

Table 2
LIWC categories and most frequently used exemplars (Boyd et al., 2022)

Subcategory	Most frequently used exemplars	Subcategory	Most frequently used exemplars
Cognitive Processes	but, not, if, or, know	Differentiation	but, not, if, or
Causation	how, because, make, why	Memory	remember, forget, remind, forgot
Discrepancy	would, can, want, could	Insight	know, how, think, feel
Tentative	if, or, any, something	All-or-None	all, no, never, always
Certitude	really, actually, of course, real	Number	one, two, first, once

Statistical analyses

Spearman's Rho was used to correlate the survey-level and detector-based SRL behaviors with anxiety scores (pre-test and post-test scores). Spearman's Rho is commonly used in analyses where the assumptions of normality are not met. Linear regressions were used to regress interactions between anxiety scores and time spent in each phase onto measures of achievement, SRL behaviors, and linguistic features. Specifically, linear regression was used to examine the strength of the interaction of anxiety and time spent on the different outcome variables.

Results

Correlations with anxiety

Anxiety scores and survey measures were analyzed using Spearman correlations and Benjamini and Hochberg post hoc corrections (see Table 3). We find that pre-test and post-test anxiety positively correlate with one another ($\rho = 0.56$), where higher anxiety scores at the beginning of the school year corresponds to increases in anxiety scores later on in the school year. This is not surprising when considering the relative stability of trait anxiety. Higher anxiety before using CueThink is negatively correlated with math epistemological beliefs (IMBS scores) and achievement (iReady and IM scores), indicating that increased anxiety scores at the beginning of the study correspond to poorer mathematics performance and more negative beliefs around mathematics. A similar though less salient relationship can also be observed between post-texts of anxiety, as they negatively correlate to IMBS scores and achievement. The reduced effects of anxiety may potentially indicate that learners gain a better understanding of the requisites for solving mathematical problems throughout the study. Correlations between anxiety metrics and linguistic features were also conducted, however, did not yield any significant results.

Table 3
Spearman correlations for student level survey measures (p < .05, non-significant results were omitted from the table, red cells indicate negative correlations, blue cells indicate positive correlations)

	Anxiety (pre)	Anxiety (post)	jrMAI (pre)	jrMAI (post)	IMBS Solve (pre)	IMBS Solve (post)	MIBS Effort (pre)	IMBS Effort (post)	IMBS Useful (pre)	IMBS Useful (post)	iReady F2021	iReady W2022	iReady Sp2022	Overall iReady Avg.	IM accuracy (pre)	IM accuracy (post)	IM understand (pre)	IM understand (post)
Anx (pre)	1.00	0.56	-0.02	0.01	-0.36	-0.30	-0.27	-0.21	-0.29	-0.15	-0.28	-0.31	-0.24	-0.31	-0.25	-0.15	-0.23	-0.20
N	165	131	165	131	165	131	165	131	165	131	151	151	151	151	151	152	151	152
Anx (post)		1.00	0.05	0.07	-0.24	-0.27	-0.13	-0.19	-0.17	-0.10	-0.14	-0.23	-0.24	-0.22	-0.25	-0.01	-0.14	-0.07
N		134	131	134	131	134	131	134	131	134	127	127	127	127	121	133	121	133

Usage data

Correlations and post hoc corrections were calculated to examine the relationship between the different survey responses and the amount of time students spent (in seconds) in the Review and Solve phase of their Thinklets. The results indicate that more time spent in these phases is associated with students engaging more frequently in specific SRL behaviors (see Table 4). Additionally, increased time spent in the Solve phase negatively correlates to math performance on the IM metric. The relationships indicate that despite the increased opportunity of students to engage in SRL behaviors, this may not necessarily correspond to improved performance.

Table 4

Correlations between time spent and survey responses and detectors (non-significant results were omitted from the table, red cells indicate negative correlations, blue cells indicate positive correlations)

	Time Spent (Review)	Time Spent (Solve)	Anx (pre)	Anx (post)	IM accuracy (pre)	IM accuracy (post)	IM understand (pre)	IM understand (post)	Numerical Rep.	Contextual Rep.	Outcome Orient.	Data Trans.
Time Spent (Review)	1	0.44	0.04	0.04	-0.18	-0.01	-0.04	0.03	0.33	0.09	0.23	0.11
N	179	179	165	134	153	156	153	156	179	179	179	179
Time Spent (Solve)		1	0.03	0.01	-0.24	0.04	-0.11	0.12	0.43	0.09	0.29	0.08
N		179	165	134	153	156	153	156	179	179	179	179

Linear regressions were also conducted to examine the influence of anxiety (pre-test and post-test) and time spent in the Solve phase, as well as their interaction, on outcomes of achievement and SRL behaviors. The regressions between pre-test anxiety scores and time did not reveal any significant relationships between the anxiety and the outcome variables. The linear regressions examining the interaction between post-test anxiety scores and time spent in the Solve phase on achievement and the SRL behaviors reveal that post-test anxiety had a significant interaction effect with time spent on Solve phase. A simple slopes analysis reveals that this interaction effect was predictive of increased math achievement ($p = .034$, $R^2 = .097$) where more anxious students who spend more time in the Solve phase are likely to perform better on their iReady scores where the students who take less time are more likely to perform worse. Urgency, perceived threats of failure, or avoidance (Dickerson & Kemeny, 2004; Chrousos, 2009) resulting from anxiety may lead to poorer performance on math tasks and metrics. Regressions were also conducted to predict linguistic variables using anxiety scores and time spent in the Solve phase; however, there were no significant results from this analysis.

Table 5

Beta Coefficients for Linear Regressions Predicting Achievement (N = 127) and SRL (N = 134) p < .05). Significant (p< 0.05) coefficients shown in blue and bold type

	Dependent Variables						Dependent Variables				
Predictors	iReady Avg	Numerical Rep	Contextual Rep	Outcome Orient	Data Transform	Predictors	iReady Avg	Numerical Rep	Contextual Rep	Outcome Orient	Data Transform
(Intercept)	**0**	0	**0**	**0**	**0**	(Intercept)	**0**	0	**0**	**0**	**0**
Anxiety (pre)	-0.28	0.02	-0.03	0.01	0.01	Anxiety (post)	**-0.2**	0.1	0.03	-0.02	0.1
Time Spent (Solve)	0.14	0.35	**0.16**	0.27	0.19	Time Spent (Solve)	0.13	**0.43**	0.28	0.23	0.23
Interaction (Anx (pre) * Time)	-0.08	0	-0.09	0.06	-0.06	Interaction (Anx (post) * Time)	**0.21**	-0.02	0.02	0.02	0.01

Discussion and conclusions

The effects of anxiety within education are pervasive and diverse, however it remains to be comprehensively examined within ILEs. This work attempts to further research in this area by demonstrating the influences of anxiety on achievement, usage, and SRL within the CueThink platform. Overall, the combination of findings captures the influences of anxiety independently and in tandem with other significant interaction variables. Through this analysis, we found that higher pre-test anxiety corresponded to lower achievement scores within the math-based platform, and that a large proportion of the sample experienced anxiety. Though not a particularly surprising finding, these results are important in contextualizing the influence of anxiety within this kind of platforms and to better understand which aspects of the platform, usage, or content contribute to anxiety the most will be valuable to developing learning platforms that reduce student anxiety.

Further analysis shows that higher anxiety and changes in the time spent completing responses correspond to varying math achievement. More specifically, the results of this study indicate that students with increased levels of anxiety take more time in Solve phases but perform better on math-based assessments. Anxious students generally tend to avoid stress-inducing materials (Ashcraft, 2002; Brunyé et al., 2013), negatively impacting their academic outcomes (Plake & Parker, 1982; Brunyé et al., 2013). However, students who are able to overcome anxious reactions are also able to mitigate the effects of anxiety on their performance (Brunyé et al., 2013). The inclusion of time may aid in identifying anxious students and offer helpful interventions in response.

Overall, these results demonstrate the importance of student anxiety within ILEs. Our work seeks to highlight the differences in interaction that emerge among students based on their experiences of anxiety and how these, in turn, can impact various aspects of their learning experiences and outcomes. Future work should examine anxiety at the same level of the actions completed by students within the platform to support the development of automated detectors of anxiety. These detectors would support fine-grained analyses that can parse moment-by-moment experiences of anxiety and its influences on behavior, allowing educators, researchers, and designers to build anxiety-sensitive interventions to enhance educational experiences for anxious students.

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Probing Beyond the Biology: Centering a Relational Ontology in Middle-School Science Modeling Towards Rightful Presence

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Abstract: Modeling science phenomena serves as a tool to support science practices, where classroom environments and youths' relations with each other and those in positions of power shape how the activity unfolds and what models are created. Grounded in a relational ontology, we build on justice-oriented approaches to studying youths' learning towards their Rightful Presence by examining the expansive and political ways of knowing youth draw on while modeling. We followed a group of four middle-school youth and traced the human-human and human-more-than-human powered relations that shaped their models of short and long-term stress created across two multi-day lessons. We illustrate how models emerged as more-than-human entities with identities shaped through youths' intra-group, student-teacher, and human-more-than-human relations, entangled with who and how youth are in and with this world. We also argue ceding power to youth to re-author their and their models' rights supported more expansive understandings of youths' learning.

Introduction:

"Developing and using models" as outlined by the *Next Generation Science Standards* encourages learning science by engaging in embodied practices that integrate disciplinary content and processes, amongst other epistemic considerations (Gouvea & Passmore, 2017). In classrooms, models are considered representations of phenomena that serve as a tool to support learners' inquiry and exploration practices as they engage in sense-making around science phenomena (Guy-Gaytán et al., 2019). However, modeling is a social activity where classroom environments, pedagogical decisions, and youths' relations with each other and those in positions of power shape how the activity unfolds and what models are created (Shim & Kim, 2018). Both the act of modeling and the model created are not neutral processes or products, instead shaped by and through powered dynamics. While there is emerging scholarship that examines how social relations shape modeling practices, Schwartz et. el. (2022) argue that we need to be more explicit about *how* powered dynamics shape modeling activities so that we can support more "expansive, meaningful, and equitable modeling practices" in classrooms (p. 1087). Our study builds on this call by examining the sociopolitical and sociocultural powered dynamics that shaped how youth engaged in modeling practices in ways that led to the emergence of a model as a relational onto-epistemic entity. We develop expansive understandings of youths' learning to illustrate the "dimensions of knowing [that] are not currently valued in modeling competency frameworks and assessments" (Schwarz et al., 2022, p. 1089). Given calls for an expansion of our understanding of modeling and modeling practices, we learn from Indigenous scholarship to highlight the how youth are already engaging in these expansive and political ways of knowing when modeling in science classrooms. We ask: *How do powered human-more-than-human relations shape the emergence of a model on short and long-term stress created by middle-school youth?*

This work is grounded in a relational ontology, recognizing humans as existing in and with the world (Marin & Bang, 2018). From this purview, knowledge creation emerges in relation with the More Than Human (MTH; Bang et al., 2015) – in our case, the MTH in the classroom included laptops, digital tools like jamboard, poster papers, markers, etc. Through interaction analysis (Jordan & Henderson, 1995) we followed a group of four youth who named themselves the 'GLAY' group, making biology models of short-term and long-term stress across two multi-day lessons. We present three episodes to show how their poster-paper models emerged. Per the NGSS-aligned curriculum, the science content learning goal was for students to 'develop and/or use a model to describe phenomena'. We traced the powered relations that shaped the first paper model (of short-term stress) into 'GLAY - a genderless alien, everything and nothing at once, the center of the universe' and the second paper model (of long-term stress) into 'Maria/GLAY Jr. – a universal Goddess and GLAY the second'. When reflecting on the unit, the youth described their group and models as relations across space and time, where who they were as individual humans and as a "mis-functional Spanish family" group were not separate from but emerged in relation with and through their intergenerational family of paper models. Through this study, we illustrate how models were not just neutral tools for reasoning about science phenomena, but MTH entities with identities shaped with and through the youths' intra-group, student-teacher, and various human-MTH relations.

Theories that inform this work

We learn from Indigenous ways of knowing, to shift from a focus on human action to the relations between and within humans and the MTH world in our understanding of how reality emerges (Bang et al., 2015). Our understanding of the MTH is framed through braiding (Kimmerer, 2013) ways of knowing in Turtle Island (Marin & Bang, 2018) with Rishi's ancestral knowledge systems to reflect multiplicities and resonances in how we understand our experience in and with this world (Krishnamoorthy, 2023). Focusing on relations and the MTH as a unit of analysis helps us "expand understandings of how experience is constructed, and knowledge is generated as people interact in/with place" (Marin, 2020, p. 281) and therefore attend to human-human *and* human-MTH relations in knowledge creation as a whole-body activity across time and space. In doing so, we "recognize a multiplicity of histories, foster mutuality rather than extraction, and support theories that account for the role of more-than-human relatives in human development and learning." (Marin, 2020, p. 309). We also recognize our responsibility to learn from Indigenous scholarship as settlers on stolen lands, and work to resist the (re)production of colonial ways of knowing in how we study learning (Krishnamoorthy et al., 2021).

Guided by the Rightful Presence framework (RP; Calabrese Barton & Tan, 2020), we attend to how power shapes human-MTH relations through close attention to the ways in which historically sedimented powered dynamics are resisted and/or reauthored in classrooms. The RP framework takes a critical-justice oriented stance, challenging the positioning of youth as outsiders (guests) in classrooms where teachers are the hosts who author and extend rights to youth (to engage in practices such as modeling). Extending rights to youth and 'including' them into already sedimented classroom norms and practices limits the depth and breadth of youths' whole selves valued, in ways that can (re)produce existing inequities in education and the dominancy of canonical Eurocentric ways of recognizing learning (Tan & Calabrese Barton, 2020). The RP framework advocates for shifting guest-host student-teacher power differentials with adults working as sociopolitical allies by ceding power to youth, who reauthor their rights around ways of being and knowing such that their whole selves are valued in learning spaces. Using the RP framework, we trace sociopolitical and cultural powered dynamics that are de/settled in the classroom by examining human-human *and* human-MTH relations to illustrate the expansive and less extractive ways that youth engage in knowledge creation in science lessons.

Methods

This work was part of a grant-funded study that drew on critical participatory design research methods (Bang & Vossoughi, 2016) to create a 7th grade science unit focused on a health issue of concern to the local community – stress. The pilot unit was co-designed with eight youth and three teachers from local schools, and eight university partners from various institutions (Krishnamoorthy et al., 2022). Using a storyline approach (Reiser et al., 2021), the NGSS aligned unit drew on the RP (Calabrese Barton & Tan, 2020) and AIR (Chinn et al., 2014) frameworks such that youth learned about the biological phenomenon of stress as entangled with structures, policies, and procedures in the environment. Pilot data was gathered during Spring 2022, in one 7th grade science classroom, located in a sanctuary city in the NE-USA with 90.2% Hispanic students (2). Data included field notes, post-unit group interviews and video of whole-class and four focal youth's interactions: Batman, Ren, Star and Mario. Batman and Ren were long timers at the school, considered 'smart' by their peers while Star and Mario were new to the school that year. Youth had not worked together prior to this study. Adults included the science teacher (a cis-female Middle Eastern immigrant), a support teacher (a Black and African American cis-female), Rishi (a trans/genderqueer [they/them] South Asian) and Ravit (a Middle Eastern immigrant cis female).

Episodes analyzed were of youth modeling short-term and long-term stress (9 hours). Drawing on interaction analysis methods (Jordan & Henderson, 1995), we analyzed human-human and human-MTH interactions to trace the co-operative (Goodwin, 2017) construction of the models as emergent and non-neutral MTH phenomena in the classroom. Examining how youth built on, decomposed, and transformed each other's' substrates (Goodwin, 2017), layered with an analysis of how settled guest-host relations were de/settled illustrated the powered human-human and human-MTH relations entangled with the modeling activity. The three hot spot episodes highlight: 1) Team GLAY, a human community shaped by relations with each other and the classroom, 2) GLAY the short-term model, a MTH entity shaped by youths' intra-group and adult-youth powered dynamics, 3) Maria/GLAY Jr. the long-term model, a MTH entity with personhood, part of an intergenerational family.

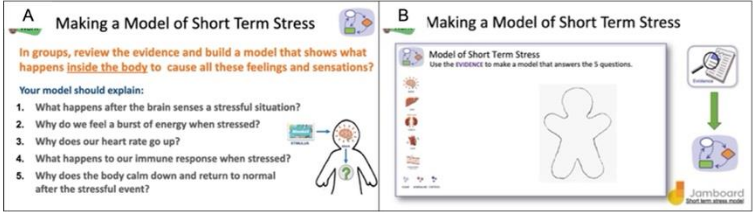
Findings:

GLAY: Mis-functioning Spanish family time

In the short-term stress lesson, youth reviewed evidence provided to them and built a model to show 'what happens inside the body that causes the sensations associated with short-term stress' (see Figure 1A). Youth were provided the option of a Jamboard with a ginger person and some visuals (see Figure 1B), or poster paper to make their models. The short-term lesson was the first time Mario, Star, Batman, and Ren worked together as a group and GLAY emerged as the group's team name – created from the first letter of each youth's name.

Figure 1

A) Slide with instructions and B) Jamboard provided to youth



A Making a Model of Short Term Stress

In groups, review the evidence and build a model that shows what happens inside the body to cause all these feelings and sensations?

Your model should explain:

1. What happens after the brain senses a stressful situation?
2. Why do we feel a burst of energy when stressed?
3. Why does our heart rate go up?
4. What happens to our immune response when stressed?
5. Why does the body calm down and return to normal after the stressful event?

B Making a Model of Short Term Stress

Model of Short Term Stress

Use the EVIDENCE to make a model that answers the 5 questions.

Jamboard

Short term stress model

Initially, team GLAY encountered some struggles navigating their group dynamic, disagreeing about how to draw the head of the model. Mario suggested they trace his head onto the sheet of paper, but his head was too big in relation with the body they had already drawn, and the poster dimensions. While passing by Rishi commented:

> [1] Rishi: Man, I love your group
> [2] Ren: It's a. It's a. It's like a family.
> [3] Rishi: Yeah, I like it
> [4] Mario: It's a drama! Because they couldn't even trace my head really good!
> [5] Star: Okay we good. What are you talking about you couldn't even do none of us!
> [6] Ren: it's just it's just..it's just a family! It's just a very…. misfunctioning family
> [7] Batman: okay you know I..I..
> [8] Rishi: ((to Ren)) Aren't all families misfunctioning families?
> [9] Star: I live in a Spanish household. This is worse. ((Rishi laughs and walks away))
> [10] Batman: I like his brain. I like his brain ..it's too small.. You know it's fine I guess.

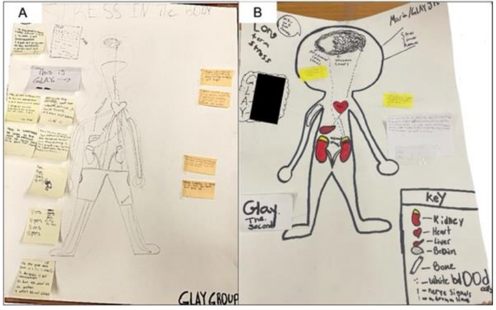
Rishi's utterance [1] affirmed the group's dynamic as desired [3] in the classroom space by; 1) Challenging traditional deficit framings of student discord during group work and 2) Reifying adult-student powered relations where adults author the forms of behavior allowed in classrooms. This substrate [1] was taken up by Ren who reframed it as "like a family" [2], transformed into a "drama" [4] by Mario because of his group mates' inability to trace his head onto the paper. Mario's utterance [4] and Star's retort [5] illustrated their group's "misfunctioning family" [6] dynamic, worse than the "Spanish household" [9] that Star lived in. Yet despite their arguments, their misfunctioning dynamic created a brain that may have been too small but was "fine" in the end [10]. GLAY emerged through human-MTH *and* human-human non-neutral powered relations. The poster enacted power in its relation with Mario by virtue of its dimensions rendering Mario's head a non-viable resource for creating the model. Rishi-youth relations (re)produced sedimented adult-youth power dynamics when they ratified the youth's intra-group (i.e., student-student) relations as desirable [1,3]. Furthermore, youths' cultural identities, histories, and family relations framed their dynamic as a family, "misfunctioning" and "worse" than a "Spanish household". This interaction illustrated the modeling task as not separate from their intra-group and teacher-student interactions, also involving human-MTH relations (i.e., Mario's head's-poster relation). GLAY emerged as a family through their powered relations with each other, the adults, and with the MTH (i.e., the poster) as well.

As the unit unfolded, meaning-making around GLAY as a Spanish family continued. Youth assumed roles shaping their individual relations with the MTH: Mario the artist, engaged in human-poster relations through which etchings on the paper emerged; Ren the "brain", who authored the messages on the model through human-curriculum relations, Batman the "getter'", who brought MTH resources (i.e., markers, etc.) into relation with the model, and Star the "heart", whose relations with the others brought decorative etchings of 'GLAY' into relation with the model. In this sense, the curriculum task, and expectations around what the model should be, the size of the poster, the quality of markers, and their intra-group and adult-youth relations, shaped who GLAY was as a family *and* the MTH entities that emerged (i.e., the models). Next, we illustrate how focusing on relations as the unit of analysis foregrounds youth-curriculum relations as shaping the emergence of models as MTH entities.

GLAY the original: A genderless, universal god and alien

As the short-term modeling activity unfolded, GLAY emerged not only as the group's team name, but the name the model they constructed – a genderless, universal GOD and alien (See Figure 2A).

Figure 2
Short-term (A) and long-term stress (B) models



'GLAY' first emerged on the poster when Batman suggested, "instead of writing our names, we can just put our team-name". Then, GLAY was shaped into a 'being' – first a human, then a ginger person (i.e., genderless ginger cookie), then an alien – through the youths' relations with the instruction slide (See Figure 1) and their negotiating how to represent the being. When beginning the modeling activity, the Jamboard slide was open on Ren's laptop and Mario began to "pre-draw" a sketch of their model on a small whiteboard. Ren clarified to Batman that their task was to "make a model" "based off of this ((the slide)) about how the body functions when we're stressed". Ren's attention then shifted towards Mario's sketch on the whiteboard:

> [11] Ren: ok Mario we're not gonna give him pants. We're just gonna
> [12] Mario: ok he's naked then.
> [13] Ren: yes he is naked
> [14] Mario: blurred
> [15] Ren: no we don't need to blur

With no pants [11], Mario's noting that the model would be "naked" [12] was ratified by Ren, indicating both youths were aligned in their authoring of the model as a 'naked' being. However, Mario's subsequent utterance that the model be "blurred" [14] indicated a disjuncture between how Mario and Ren had gendered the emerging model. To Mario the naked model – a gendered entity – would necessitate censoring to be appropriate for the classroom context. Ren however did not agree [15] as he later noted, "it's genderless, it's a cookie! You think you're gonna have private parts on a cookie?" That is, although Mario and Ren were aligned in their understanding of the model as a *being* of some sort, Ren drew on the representation on the slide (See Figure 1B) animated as a "gingerperson" by their teacher, to frame the model as a genderless cookie. Mario rejected this framing by voicing the disjuncture around the model's gender and personhood arguing, "I don't wanna do a cookie. I wanna do a person". The youth continued to argue until ultimately Ren resigned to Mario's persistence and the model was framed as a "person" (albeit still a "ginger person" [23] according to Ren) whose gender was under construction. Once the 'pre-drawing' of the model was complete, Mario held up the whiteboard to his groupmates and uttered:

> [16] Mario: I put in extra details
> [17] Ren: Why did you give him abs?
> [18] Mario: what?
> [19] Ren: Why did you give IT abs?
> [20] Mario: oh.. that's how you call them?
> [21] Ren: IT
> [22] Mario: I never knew…
> [23] Ren: it is genderless. It is a genderless ginger person. We call it a… IT. Them.
> [24] Mario: There..((shows Ren the whiteboard))
> [25] Ren: It's. it's non-binary.

When critiquing the 'pre-drawing', Ren authored the model as an "it" [19, 21] and "them" [23], building on his earlier positioning of the model as a "ginger person" who was now "genderless" [23] and "non-binary" [25]. Mario, less versed in pronoun use, expressed not knowing [22] and the interaction around the model's gender was driven though Ren's enacting power as a knower and author around gender, despite not having resolved the distinction between the model being 'genderless' [23] and/or 'non-binary' [25]. After this interaction, the group did not directly discuss the model's gender however the model emerged as 'genderless' through their negotiating the model's name. Star suggested "his name's gonna be GLAY", which Ren transformed to "GLAY the alien" because GLAY could be a "boy or girl" name, as noted by Batman. Therefore, GLAY the model emerged through the co-operative interaction between youths' relations with the curriculum slide, and their intra-group powered relations – Mario the artist insisting on the model's personhood, Ren authoring the model as genderless, and Star naming the model GLAY. GLAY the alien's identity was then ratified in the larger classroom space through the group and model's interactions with the adult facilitators the next day, when Rishi asked the group "what's gonna happen on this episode of the lives of GLAY?" Looking at their poster, Mario responded:

> [26] Mario: I mx. I like the shorts. And then he says he's genderless. While.. and he says.
> [27] Rishi: oh sorry I misgendered GLAY my bad
> [28] Mario: [No he. No but I]
> [29] Batman: [No it's GLAY is GLAY]
> [30] Ren: No. And he keeps saying he ((points to Mario))
> [31] Mario: Then. And then I'm saying that he's a boy and he's like [he's genderless.]
> [32] Batman: [GLAY is everything]
> [33] Ren: [GLAY is a. GLAY is an alien]
> [34] Mario: [So they put him shorts]
> [35] Rishi: ((looking at Mario)) GLAY is an alien!
> [36] Ren: GLAY is the alien
> [37] Mario: I know and then so then I put him like a blurred and then he's like. He's. Genderless.
> [38] Rishi: ((Rishi laughs)) So wait. Aliens don't have gender?
> [39] Batman: No. Just. He's everything.
> [40] Ren: No!
> [41] Rishi: I didn't hear you what? ((moves around in between Batman and Ren))
> [42] Batman: He's everything ((nods yes))
> [43] Ren: [he's eve. He's]
> [44] Rishi: [He's everything! Woah!]
> [45] Ren: He's at the ss.. GLAY is at the center of the universe
> [46] Batman: Nothing but everything at the same time..
> [47] Rishi: ((looks over to Batman with wide eyes)) Yo.. that's lit.

Mario's reanimation of the group's negotiations around gender [26] indicated the possibility of something unresolved for him, that he "never knew" [22] regarding gender and the emerging model. For Mario, the tension around the model's gender emerged in relation with representing the model's clothing [34] and Ren's authoring the model as genderless [31]. In the interaction, Batman and Ren positioned themselves as animators and knowers of GLAY's gender and identity and co-operatively constructed GLAY an alien [33], "everything" [32, 39, 42], the "center of the universe" [45], and "nothing but everything at the same time" [46], who was not to be referred to using 'he' pronouns [30]. Importantly, this interaction revealed how the youth's roles within the group and intra-group powered dynamics shaped how and who GLAY the MTH entity with personhood emerged. Batman and Ren were considered the 'smart people' of the group (animated – voiced – by Star the previous day) while Mario was the artist and, in this interaction, less of a 'knower' regarding GLAY's gender. Mario's concerns regarding GLAY's gender emerged through his role as the artist and shaped GLAY into assuming personhood through his decisions around the necessity to draw shorts [34], or whether to blur [37] certain regions of the entity. Ren and Batman built on these substrates through their powered authorship, co-operatively constructing GLAY's identity as an alien. GLAY the model's identity was also ratified through the adult's sociopolitical allyship towards youths' authoring their rights in the classroom space – through Rishi apologizing for having misgendered GLAY [27], re-animating GLAY as an alien [35], and legitimating their construction as "lit" [47].

The next day when youth continued modeling, GLAY emerged as an entity that didn't use pronouns, was just called "GLAY", and whose physical appearance was co-operatively constructed by gender and curricular expectations. For example, GLAY the model was shaped into being shoe-less, because as Mario noted "we can't put him shoes ms, because this is the part where the blood stream goes circle like you know?" as he traced his fingers along GLAY the model's extremities. Therefore, in addition to the youths' intra-group relations and adult-youth powered relations (human-human relations), the youths' relations with the curriculum (human-MTH relations) shaped how GLAY as an entity emerged. In this episode we build on recent scholarship on youths' social relations that shape modeling activities (Shim & Kim, 2018) by illustrating how youths' intra-group, adult-youth, and individual and group powered relations with the curricular materials shaped the emergent model entity. Their model represented the required biological systems (i.e., short-term stress). It was also a MTH entity with personhood (or alien-hood) that emerged through powered human-human and human-MTH relations. Next, we illustrate how youths' relations with macro sociopolitical powered dynamics also shaped the model that emerged.

Maria/GLAY jr.: GLAY the second, a universal goddess

In the next lesson set, the youth read a story about a character 'Maria', who was experiencing symptoms of long-term stress. The group's task was to create a model of long-term stress based on evidence pieces that the character Maria encountered in the story. This modeling activity and the model's identity emerged through the youth and model's relation with the previous lesson on short-term stress, evidenced by the youth negotiating the long-term stress model's name. Mario noted, "since we're gonna do another model, we can name him GLAY Jr.". However, Batman and Ren were not convinced, and the group debated whether the model's name would be GLAY Jr., or GLAY the second (who wore a top hat). Ultimately, the long-term stress model emerged as a MTH entity shaped through the youths' relations with the curriculum and the story character Maria (human-MTH relations), Star's relations with Batman, Ren, and Mario and larger sociopolitical powered dynamics (human-human relations), and the model's positioning as the 'second' of its kind following GLAY the original (MTH-MTH relations).

[48] Star: Like GLAY had a small brain that means he had no thing like..
[49] Mario: He had. He was dumb now
[50] Star: Exactly
[51] Ren: Its not a he. it's not a the.
[52] Star: It's not a he, they or she
[53] Ren: universal God give them some respect
[54] Star: we might as well. we might as well give him a gender because like..
[55] Ren: Give GLAY the universal God uh God respect
[56] Star: GLAY should be a female
[57] Mario: GLAY? a FEMALE? Excuse me? ((pauses drawing, leans back, and looks at Star))
[58] Star: GLAY should be a female. There's already three boys and there's only one girl. ((moves forward, points to Mario, Ren, and Batman and then herself))
[59] Mario: FINE
[60] Ren: It's women's history month. Ya gotta..

Star's initial relation with and meaning-making around the model's head being too small to draw in a brain [48] was reanimated by Mario as the model being dumb [49]. However, Ren took up this substrate and transformed it into a correction of Star's use of GLAY's gender [51], reanimated and expanded by Star from "he or "the." [51] to "he", "she" or "they" [52]. Ren, looking for the appropriate way to address GLAY, built on Star's animation from using "them" pronouns [53] to no pronouns [55]. Star however, transformed Ren's negotiation of GLAY's gender into an opportunity where they "might as well give him a gender" [54]. While Star's reasoning for gendering GLAY was not revealed, she re-asserted that GLAY should be female [56]. In response to Mario's dramatized surprise [57], Star drew on her position as a female in the group as consequential towards GLAY being gendered as female [58]. Building on this substrate, Ren's utterance entangled "women's history month" [60] and in doing so, larger sociopolitical powered dynamics around female representation, with the emerging 'gendering' of their model. The model emerged as a female through its relations with the gendered dynamics within the human family – GLAY – *and* the macro sociopolitical dynamics and histories informing the institution of women's history month. As such, GLAY emerged as a "universal Goddess", named by Ren moments later.

The model's physical shape emerged through the youths' relations with the evidence sets, when deciding how much clothing the model would need, and how to depict neural signaling loss due to long-term stress. At the end of the lesson, the teachers instructed the youth to "add a title" – a model criteria (Rinehart et al., 2016) agreed upon by the class. They decided that "her" name would be Maria since they were modeling the curriculum story character's experience. Being the second model their group created, the youth deemed it important to place a notecard indicating the model was "GLAY the second" inscribing her name as Maria/GLAY Jr. (See Figure 2B). Unlike the short-term stress model, they wrote their names on the poster sheet, a symbol of their pride in their work. The youth noted that Maria/Glay Jr. illustrated who the youth were (through their initials on the poster) and served as a window into their memories of struggles as a Spanish family learning to work with each other, a tv-drama unfolding daily. Maria/GLAY Jr. was not just a neutral epistemic product (model) representing youths' knowledge nor was it just a tool used to learn about stress. She was a MTH entity with personhood, a universal Goddess and the descendent of GLAY the original. Team GLAY's long-term stress model emerged through their intra-group and adult-youth (human-human) relations, their relations with macro sociopolitical powered dynamics, and youth-curriculum relations across this curricular unit (i.e., human-MTH relations across space and time).

Discussion

Centering a relational ontology in curriculum design and enactment supported the youth to continually engage in 'the right to reauthor rights', a Rightful Presence tenet (Calabrese Barton & Tan, 2020). While the science curricular learning task was to construct a model to first explain the biology of short-term stress and then long-term stress, the ways in which GLAY members engaged with their modeling suggested that they were probing for understandings beyond the biological phenomenon. They were simultaneously *modeling* – figuring out in real time – who they were, who they could be and wanted to be, in relation with whom and with what (i.e., configurations of human and MTH resources), as Spanish speaking youth in an urban classroom. Through a relational ontology, we suggest that the GLAY youth were engaging in *multi-scale onto-epistemological modeling*. That is, in their performing of the GLAY group, the youth entangled the following: a) their Hispanic identities with familial, playful repartee; b) their strength-based distributed expertise with the group work (Mario, friendly and tentative speaker but a recognized artist; Ren and Batman as the 'good science students' offering ideas, and Star as the friend-of-all leader who directs and oversees); c) their chosen spatial-material resources, including claiming the largest round table in the classroom on which they stuck a notecard with their name "GLAY" written on it, and preference for large poster paper and markers to draw a model (vs using Jamboard).

On another scale, the emerging creation of "GLAY the original as a genderless, universal God and alien" model of short-term stress suggested that the youth set much store on who and what GLAY the model represented, beyond the biological systems they were drawing inside the model. Here, GLAY further entangled and brought classroom epistemic discourse, issues of gender identity and (non)rightful presence as new arrivals. Their discussions of GLAY the model as "genderless", "non-binary", as "it", as "GLAY", is a continued thread that emerged from a prior lesson the youth grasped onto and elevated during this modeling activity. In the prior lesson, the class had discussed whether it would cause survey takers stress to disclose their gender, and whether the categories of "male, female, other" were marginalizing to people who identify as queer. Two members of GLAY also have same-sex parents. In these episodes, the youths' stance to depart from the normed heteropatriarchy of a default male Eurocentric scientific model was made starkly apparent. In addition, two of the GLAY youth were also recent arrivals to the school, suggesting an ontological thread in attending to tropes of power and alienation, rightful or non-rightful presence between the youth negotiating the identity of GLAY the model as a "universal GOD and alien" and their real-time, embodied experiences of figuring out how to fit in at the school.

Between short and long-term stress modeling, the youth explored stories as a part of the curriculum that fleshed out impacts of long-term stress on fictional characters one of whom was a Maria – a young Hispanic girl with younger-sibling care responsibilities. Long-term stress Maria/GLAY Jr. emerged from GLAY the original – a genderless, universal God and alien – held in dialogue with the Maria story, with whom the GLAY youth resonated. Star's decision to spotlight her lone female representation in the group with Ren's recognition that it was "women history month" led to a third scale of modeling as GLAY youth negotiated and collectively made sense of what it might mean for Maria/GLAY Jr. the model to be female, and Hispanic, instead of a genderless universal God and alien. The model was recognized as a MTH entity with personhood, and gendered and racial identities, both still a departure from the Eurocentric default white male model.

Implications

Struggles of gender identities and rightful presence are formidable sources of stress for youth in schools. The GLAY youth showed their wisdom in unabashedly making these embodied struggles (for some of them) central to a modeling activity on the biological phenomenon of stress. Their actions reflect their desire for authoring a Rightful Presence in middle school science, illustrated through centering a relational ontology. Who youth are, can be and want to be, with whom and what spatial-materials, are ineluctably bound up in the processes of epistemic meaning-making. In short, it is impossible to divorce ontology from epistemology, and it is imperative to attend to historical injustices and its contemporary reproductions through interrogating normalized science classroom practices and assumptions. With our study, rather than only considering scientific models as a tool for students to make sense of scientific phenomena, we argue for the need to understand models as deeply entangled with who and how youth are in and with this world. Furthermore, we advocate for acting as sociopolitical allies and ceding power to youth to reauthor both their and their models' rights in the classroom space as one way we can support this more expansive understanding of youths' learning and their world selves in classroom spaces.

Endnotes

(1) By examining human-MTH relations, we identify the many histories of coloniality (re)produced in science classrooms.
(2) Youth identified broadly as Hispanic, preferring more specific national identities (e.g., Dominican, Puerto Rican etc.).

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De/settling Powered Differentials and Disciplinary Practices Through Rightful Presence: Examining How Power, Emotions, and Resistance Shaped Emerging Epistemic Ideals in Middle School Science

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Abstract: There is a growing body of scholarship in science education that attends to the role of emotions and affect as shaping youths' negotiation of and experiences with disciplinary science practices towards more expansive understandings of how youth make-meaning around science phenomena. This study builds on this growing scholarship by examining how power and positionality shapes emerging emotional configurations in classroom spaces. Grounded in a larger study involving implementing a justice-oriented middle-school biology unit, we utilized interaction analysis methods to examine how care for the well-being of the 'other' co-operatively emerged as an epistemic ideal when creating a community ethnography and was shaped by de/settling powered differentials; disciplinary practices; and youth and facilitators' powered positionings in relation with macro sociopolitical worlds. This work contributes to our collective understanding of sense-making in science classrooms by nuancing the complex nature of engaging in allied sociopolitical struggles in explicitly justice-oriented learning spaces.

Introduction and motivation for the research

There is a growing body of scholarship in the learning sciences that attends to the role of emotions and affect as shaping youths' negotiation of and experiences with disciplinary science practices towards more expansive understandings of how youth make-meaning around science phenomena. For example, Jaber and Hammer (2016) document the importance of 'epistemic affect' in encouraging and sustaining youths' engagement in science practices, arguing for affect as entangled with conceptual and epistemological dimensions of science learning. Building on this and drawing on the relations between emotions - conceptualized as "the way that 'affect' becomes mediated, categorized, and meaningful to individuals and collectives as a matter of learning" (Vea, 2020, p. 236) Lanouette (2022) illustrated how children's science practices were shaped by place and emotion. That is, emotions and affective dimensions of lived experiences not only encourage and sustain engagement, but shape how youth engage in science practices, and the directions their investigations follow. Taken together, this growing body of literature illustrates the importance of emotions in science learning and has challenged how scholars understand the commitments and values that inform science practices, for example modeling science phenomena (Pierson et al., 2022). This study builds on this literature by attending to the role of emotions in shaping disciplinary practices, with a focus on how power and positionality shape emerging emotional configurations in classroom spaces. Grounded in a larger study examining the implementation of a justice-oriented middle school biology unit, we examine the role of 'care for the other' in shaping disciplinary science practices. Specifically, we ask: *how was care for the well-being of the 'other' when creating a community survey in an explicitly justice-oriented curriculum shaped by powered differentials; disciplinary practices; and youth and facilitators' powered positionings in relation with macro sociopolitical and cultural worlds and towards what ends?* Through interaction analysis of two lessons where adults and youth were constructing a community survey, we traced how different participants enacted their Rightful Presence (Calabrese Barton & Tan, 2019) in the classroom, through negotiating emotional configurations (Vea, 2020) towards co-operatively constructing (Goodwin, 2017) epistemic ideals (Chinn et al., 2014) as part of the survey design. Overall, this work contributes to more a critically nuanced understanding of how different powered differentials and emotional configurations shaped the emergence and sedimentation of disciplinary practices through an explicitly justice-oriented middle school science curriculum.

Theories informing this work

We drew on three distinct theoretical frameworks to inform our analyses of the community-survey episodes: a) Rightful Presence (RP; Calabrese Barton & Tan, 2019), b) Emotional Configurations (Vea, 2020) and c) Aims, Ideals, and Reliable Processes (AIR) model of epistemic cognition (Chinn et al., 2014). Together they illuminated how feelings and sense-making around care were shaped by powered relations, discipline-informed epistemic aims, and resistance and rightful presence.

The RP framework works towards making visible and disrupting settled powered differentials (e.g., teacher-student) that position youth as ‘guests’ and adults as more powered ‘hosts’ who extend rights to youth. Challenging this ‘inclusive’ approach requires adults working as sociopolitical allies ceding power to youth to re-author the “rules of the game” in these spaces (Calabrese Barton & Tan, 2019). Working towards RP is central to consequential learning and entails shifting powered relations such that students’ whole selves are legitimated and valued as central to learning (Tan et al., 2019). We drew on the RP framework towards identifying the ways in which youth re-authored their rights through disrupting powered hierarchies and disciplinary norms, along with tracing the adults’ moves towards allied political struggle in the negotiation of the community survey.

Learning from Tanner Vea’s (2020) work, we take up emotional configurations to analyze emotions as situated in and shaped by (and shaping of) social practice, and the meaning-making around that practice. We understand emotional configurations as embodying the relationships between feeling, sense-making, and practice, shaped by norms and powered relations. What feelings are permissible, by whom, and towards what ends are therefore determined and shaped through sociopolitical relations. Emotions and emotional configurations are thus political and can serve to guide sociopolitical action, shaped and guided in learning environments. That is, ‘guided emotional participation’ in learning spaces entails “cultivating arrangements between feelings, sense-making and practice” (Vea, 2020, p. 332) towards particular learning goals. In this view, emotion is both a condition for learning and a target of teaching that can drive sense-making. This framework provided a lens to analyze the ways in which feelings were entangled with sense-making around the practice of constructing a community survey and how differentially powered participants in the classroom guided and shaped these emotional configurations.

The AIR model posits that knowledge-building communities hold norms about what counts as worthy epistemic aims, reliable processes to achieve those aims, and ideals (criteria) used to evaluate the quality of the epistemic products and determine whether the aims have been achieved (Chinn et al., 2014). A community’s epistemic ideals and reliable processes may change over time as new ways of doing and knowing develop and may also be in tension with each other. We drew on the AIR framework to trace how aims, ideals, and processes were shaped by members of a classroom community within the disciplined (science) context of survey development.

Study context

This work is part of a larger grant-funded project to develop a middle-school science unit through critical participatory design research methods (Bang & Vossoughi, 2016) in collaboration with youth and teachers from the local area. After a year of collaborating online, the design team of middle-school youth, teachers, and university researchers developed a 7th grade science unit on stress in our bodies and community (Krishnamoorthy et al., 2022). The unit was piloted in Spring 2022, in one 7th grade science classroom at Oak elementary school, located in a sanctuary city in the NE-USA where 90.2% of the students in the district identify as Hispanic (1). While youth did not often openly discuss gender and sexuality, one youth identified as transgender. At the time of this study, the science teacher - a cis-female immigrant from a middle eastern country – had taught the youth for half a year in-person. The support teacher – a Black and African American cis-female – began working at the school a week prior to the unit enactment. Along with the teachers two university researchers – Rishi a genderqueer [they/them] South Asian immigrant, and Ravit a white cis-female Israeli immigrant – helped facilitate discussions.

The unit investigated stress as a non-neutral biological phenomenon shaped through various structural systems of oppression (racism, classism, sexism etc.), by supporting youths’ RP and epistemic agency in the classroom towards making consequential changes to inequitable and discriminatory issues in their local (classroom) community. The episodes analyzed occurred two weeks into the unit, when youth were tasked with creating a community survey to collect data on “what causes stress in the community”. Over two days, Rishi and Ravit co-facilitated the class’s creation of a pilot survey through a combination of small and whole-class group work. The initial survey was piloted with other 7th graders in the school, revised by the class, and sent out to community members across the city. The episodes analyzed include the pilot survey creation and revision lessons.

Methods

Data for this study includes field notes, material artifacts (PowerPoint slides), and audio and video recordings of whole class discussions and 2 focal youth (Batman and Ren). We analyzed episodes that involved whole group meaning-making around the creation and revision of the survey and used interaction analysis methods (Jordan & Henderson, 1995) to trace the emergence of care as an epistemic ideal in deciding reliable processes for learning about stress in the community. We traced how meaning-making around ‘care for survey takers’ feelings’ was cooperatively (Goodwin, 2017) constructed through utterances in the whole-class public space and focal youths' interactions with each other, across the lessons. Briefly, co-operative action refers to the co-operative construction of something (in this case an epistemic ideal) through joint-activity that involves humans "performing specific operations – most importantly decomposition and reuse with transformation – on materials provided by another" (Goodwin, 2017, p. 6). In the analysis, we identified how various youth and adults took up substrates – the "local public configuration of action that is operated on to build the next action" (Goodwin, 2013, p. 11), and transformed them towards the co-operative construction of 'care' as an epistemic ideal (AIR) through shifting emotional configurations. We then examined the participation frameworks (Goffman, 1981) of the adults and youth through shifting speaker roles (i.e., author and animator) to examine how power was enacted in (re)producing and de/settling powered differentials (e.g., teacher-student power dynamics, RP). Briefly, the 'animator' is a voice box through which an utterance is produced whereas the 'author' is the originator of the content of the utterance (Goffman, 1981). Furthermore, at any given moment a speaker can assume one or more speaker roles "based on their understanding of their own involvement and of others' involvement in an encounter" (Marks, 2012, p. 3). Analyzing speaker roles helped trace shifting participation formats towards the illustration of how participants negotiated powered dynamics through meaning-making as a joint-activity. The two hotspots analyzed illustrate how sense-making around care: 1) emerged through youths' resistance to extractive data collection practices by re-authoring teacher-student powered differentials and 2) was shaped by an adult's recruitment of their positionality as a minoritized person in relation with macro sociopolitical worlds.

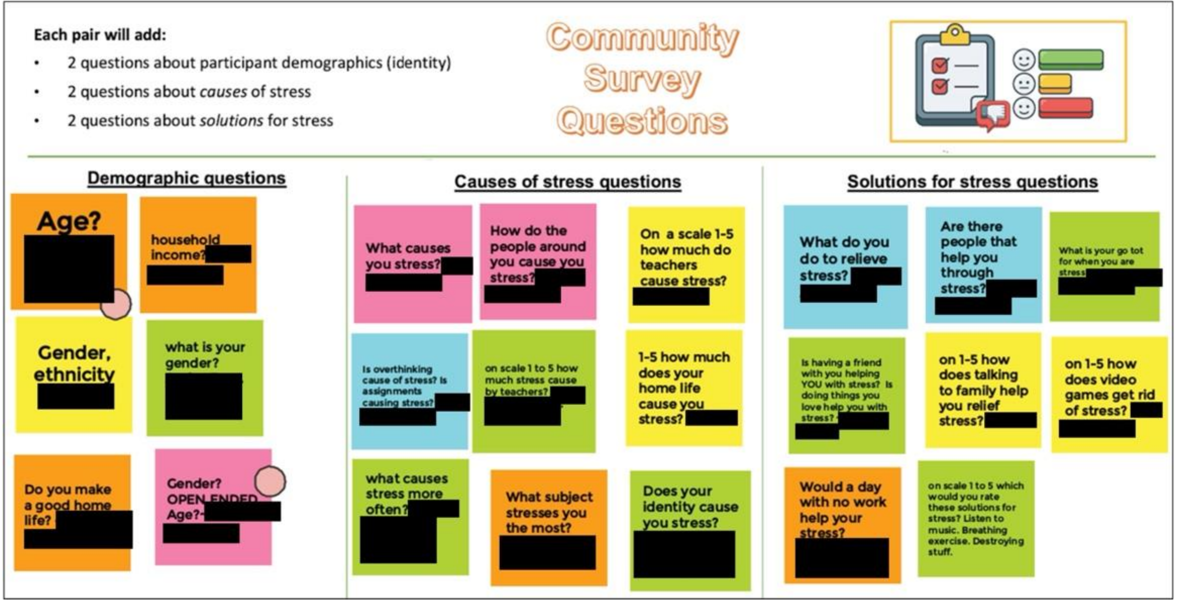
Data analysis and findings

"that's just gonna make them upset": Care for the 'other' as an epistemic ideal

When beginning the 'community ethnography' lesson, Ravit facilitated the activity set-up and explained "you already know what is causing stress for you. But remember yesterday […] there were differences and not everybody gets stressed about the thing, the same amount […] so we wanna find out what do other people in our community […] what is stressing them out" because "ultimately at the end what we wanna do is come up with some solutions" to issues that caused stress in the school. In this way, the adults' enacted power towards shaping the epistemic aims of the survey – to extract data regarding stress from the youths' communities that would help the youth create solutions to issues in their school. That lesson, youth worked in groups of four to propose questions for the survey. Then, Rishi and Ravit took up each group's proposed questions in a class discussion to select and finalize the pilot survey (See Figure 1).

Figure 1

Slide displayed in front of the class with each group's proposed questions



Each pair will add:

- 2 questions about participant demographics (identity)
- 2 questions about *causes* of stress
- 2 questions about *solutions* for stress

Community
Survey
Questions

Demographic questions

Age? [redacted]
household income? [redacted]
Gender, ethnicity [redacted]
what is your gender? [redacted]
Do you make a good home life? [redacted]
Gender? OPEN ENDED Age? [redacted]

Causes of stress questions

What causes you stress? [redacted]
How do the people around you cause you stress? [redacted]
On a scale 1-5 how much do teachers cause stress? [redacted]
Is overthinking cause of stress? Is assignments causing stress? [redacted]
on scale 1 to 5 how much stress cause by teachers? [redacted]
1-5 how much does your home life cause you stress? [redacted]
what causes stress more often? [redacted]
What subject stresses you the most? [redacted]
Does your identity cause you stress? [redacted]

Solutions for stress questions

What do you do to relieve stress? [redacted]
Are there people that help you through stress? [redacted]
What is your go tot for when you are stress [redacted]
Is having a friend with you helping YOU with stress? Is doing things you love help you with stress? [redacted]
on 1-5 how does talking to family help you relief stress? [redacted]
on 1-5 how does video games get rid of stress? [redacted]
Would a day with no work help your stress? [redacted]
on scale 1 to 5 which would you rate these solutions for stress? Listen to music. Breathing exercise. Destroying stuff.

The first hotspot episode began when Ravit oriented the class to a proposed question about survey takers' income (See Figure 1, under the 'demographic questions' column). Initially, the class spent a few moments sensemaking around the word 'income': "money" (2), transformed to "paycheque" and "how much" one earns, relating the ideas to data they explored the prior lesson that showed how income was related to stress. Then, for the remainder of the episode they discussed whether to ask survey takers about: 1) what their income was and 2) if so, how to ask the question. Through the discussion, youth were initially resistant to asking about income as it would be "weird" to ask middle schoolers who did not earn money about their income. However, as a whole class, they reasoned through this issue by adding the option of "teleporting" middle-schoolers to versions of the survey that did not ask about income. On the verge of a resolution in deciding whether to ask about income, Ravit called for the class to pause, and "trouble it a bit more". She asked, "do you think people will feel comfortable saying exactly how much they earn". Ravit's question leveraged the emotions of the 'other' (i.e., survey taker) to guide youths' sense-making in their negotiation of reliable processes regarding what and how to ask questions. The youth were quick to agree with Ravit, that a question on income could cause survey takers discomfort, raising issues about data surveillance and privacy so often abused by "companies" who ask for "too much information, bro". In taking up Ravit's bid to consider a survey taker's experience of discomfort, youths' sense-making around survey-takers imagined feelings were shaped through their (the youths') relations with macro sociopolitical powered dynamics concerning data surveillance and privacy and became consequential in shaping the group's epistemic ideals around care for survey takers' well-being. That is, youths' relations with extractive practices enacted through powered entities such as corporations shaped: 1) how they collectively made sense of Ravit's bid to care for the 'other' and 2) the epistemic ideals that emerged as a result.

In the next few moments, tensions emerged within the group, with some youth arguing to keep the question on income by asking it in a generalized way (e.g., income ranges) so that it could protect survey takers' privacy, while also meeting the task aims – to collect information from the community. Others however, argued that it "still won't work". Finally, Travisloot appealed to Ravit, who invited him to share his "reservation":

> Travisloot: Cause like don't like, most people like if they wanna like. Paycheque has to come like they're like stressed, and like you like ask like is your income like low high like then like if their income is like low that's just going to make them upset and they're not gonna want to continue to like.. because… they are not going to want to..

Travisloot's resistance animated the feelings of stress that a person might experience when their 'paycheque has to come', as being invoked when having to answer a question about whether their income was low. His argument not only took up the sedimenting epistemic ideal of considering survey takers' feelings of comfort when designing the questions, but also argued that not attending to this ideal would result in the survey epistemic aims not being met – that people would not continue in filling out the survey. Travisloot's resistance not only addressed consideration for the survey-takers' feelings but positioned it as necessary for the goals of the activity as determined by the facilitators (in positions of power). Eurocentric framings of data collection have procedures around not causing harm (e.g., IRB protocols), reasoned against what is 'necessary' for the research aims. Asking about income to ascertain whether it is a source of stress would classify as a 'necessary' process. Yet, when consideration of survey takers' feelings sedimented as an epistemic ideal, the boundaries of what counted as 'necessary' processes in data collection shifted - re-authored through youths' resistance. Positioning feelings (of the 'other') as integral to sense-making challenged ethical boundaries that shaped what was sensible to ask survey takers. Youth challenging ethical boundaries through resistance continued as the interaction unfolded.

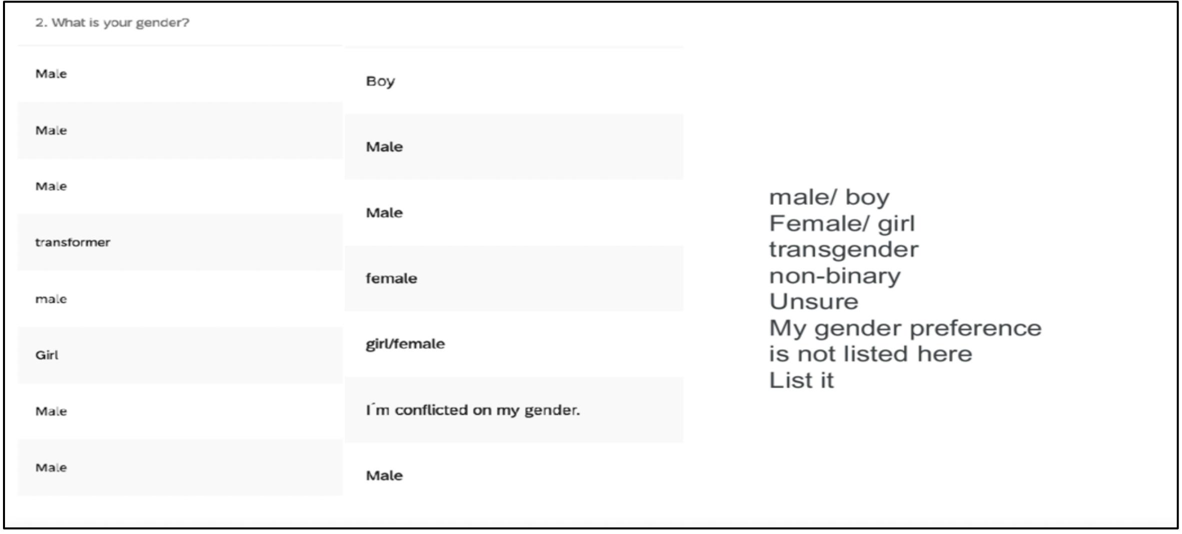
Initially, Ravit argued that "we can leave that question to the end", a practice she admitted was a "bit of a trick" to ensure participants would continue the survey despite the emotional cost. However, Travisloot's resistance persisted, arguing that "if we put it at the end then we're gonna run into the same problem. They might just like leave the quiz like unanswered and we'll never get their answer". Through his resistance, this youth's utterances desettled adult-youth power differentials – where many members of the class including the adults were pushing for the question to be included – by skillfully arguing for a consideration of survey takers' well-being as aligned with the aims of those in positions of power (and Eurocentric science ways of knowing). The epistemic ideal (care) was not only shaped through "how important [that] information [is] for us", as Ravit asked moments later, but also whether – as Travisloot argued – it would contribute to the data extraction aims of the survey. Ultimately, another student suggested the question be taken out, which the whole class agreed with. When framed as aligned with disciplinary goals by the youth, consideration of survey-takers' wellbeing was ratified by the adults in power as an ideal in developing reliable processes to learn about stress through the community survey.

"i don't wanna judge peoples' gender": Care for the minoritized survey taker 'other'

In the next episode ‘not causing stress’ emerged as a sedimented ideal in developing reliable processes and was recruited by Rishi towards advocating for the well-being of gender-minoritized community members. The hotspot occurred the next day when youth were analyzing the pilot survey results and refining their questions to make the final survey. The whole class was analyzing responses to the open-ended survey question “what is your gender”, where one responder wrote in “transformer” as their gender (See Figure 2).

Figure 2

Slide displayed to the whole class with pilot survey answers on the left, and the gender categories that emerged through the group discussion typed on the right in larger font



2. What is your gender?

Male
Male
Male
transformer
male
Girl
Male
Male

Boy
Male
Male
female
girl/female
I´m conflicted on my gender.
Male

male/ boy
Female/ girl
transgender
non-binary
Unsure
My gender preference
is not listed here
List it

Figure 3

Whole class (public space) and private conversation between Ren and Batman. Public space utterances listed with line numbers and private space utterances listed with alphabets.

Whole Class	Ren, Batman
[1] Rishi: Ok so with this question, what is your gender, who which groups had suggestions for this question. Who was not happy with it? **[2] Student**: me [3] **Rishi:** Ok lets start with you, Recorderboy. **[4] Recorderboy:** ((points to Juan white wall)) no, him **[5] Rishi:** No you say it! **[6] Recorderboy:** Him **[7] Rishi:** nods ok **[8] Juan White Wall:** Okay. Uh people fooled around and not putting a valid answer so uh I said we could just have three categories. Male/Boy. Female/Girl. And others, and have a text box of options. **[9] Rishi:** Ok so we have one option from Juan White Wall who says people start to fool around. I saw a transformers there I don’t wanna judge peoples gender, you can identify as a transformer if you want to, but maybe that’s not so helpful for our survey. That’s a suggestion here. So Juan White Wall is saying lets have three categories, lets have Boy/ (1.0) Male? Girl/Female, and then an Other. What do other folks think of this. Rose you had your hand up	**[A] Batman:** hmm ((sigh chuckle)) transformer ((looking up at board)) ((Ren raises his hand, Batman smirks and turns to Ren)) **[B] Batman:** [inaudible] **[C] Ren**: The [fact] that someone put transformer ((turned towards Batman, laptop in his lap)) **[D] Batman:** [nah] ((nods no)) **[E] Batman:** What do you mean? **[F] Batman:** ((taps left fist on table, looks at Ren)) ah Yeah. ((Grabs plexiglass and slides hand down)) I-I like that one **[G] Batman:** I’m a T-Rex. ((Ren giggles, fidgeting with his pen)) **[H] Ren:** I’m an attack helicopter **[I] Batman:** You’re an other? ((Whispered surprised tone, turns to Ren)) **[J] Ren:** Other? (2.0) Can you be like LGBTQ- **[K] Batman:** -((clicks teeth))No just do other ((points hand at board))

Initially, in both the whole class discussion and the private space with Batman and Ren (See Figure 3), the youth took up some of the utterances as not “valid” [8], where “the fact that someone put transformers” [C] was an illustration of survey takers having “fooled around” [8]. In their private space, Batman, and Ren – through humor – elaborated on transformers being an invalid option with Batman authoring himself as a T-Rex [G], and Ren, as an attack helicopter [H]. In the public space, Rishi re-animated Juan White Wall's utterance but re-authored him as "not wanting to judge peoples' gender" which positioned "transformers" as a potentially valid gender option [9]. That is, Rishi enacted power – as an insider who is trans and an adult in the room – by re-authoring the youths' meaning-making around transformers as him *not* wanting to enact a deficit positioning of survey takers' intentions. In this move, Rishi authored care for survey takers – that they are not judged by their choices – animated through their transformation of Juan White Wall's substrate. Yet while care for survey takers was framed as important, transformers remained an invalid option since it did not align with the goals of the lesson activity [9]. That is, while 'judgement' around survey takers' intentions were not ratified as a reason to discard transformers as a gender choice, 'helpfulness for the survey' was. Therefore, the unreliability of the process – asking an open-ended question about gender - shifted from survey takers' affordances for fooling around to being less helpful in attaining the survey designers' needs for information. In doing so, the boundaries around gender options that *would* be valid were defined by whether they or not they were 'helpful' for the survey.

What ensued thereafter was whole class – and informal small group chatter – around the categories that should be listed in the close ended question. Male/boy and female/girl were suggested as two options by Juan White Wall [8] and a few other students in subsequent utterances, and sedimented as the taken as accepted first and second options. Youth then struggled to decide on other options to propose. Some suggested 'other' as a category in both the private [K] and public spaces [8] (as examples), while others suggested "transgender", "unsure", "non-binary", "pronouns" and then "gay, lesbian, LGBT, asexual". As the youth broke out into dispersed chatter, Rishi raised their voice and appealed to the whole class (See Figure 4).

Figure 4

Whole class and private conversation between Ren and Batman. Public space utterances listed with line numbers and private space utterances listed with alphabets.

Whole Class	Ren, Batman
Students talking all at once, Micky raises his hand and Rishi walks up to him, bends down and listens **[10] Micky:** So I put like uh a bunch of options [[inaudible]]	**[L] Batman**: I sure, not sure and then you coulda ha- you should have other still [because what if] somebody wants to be a T rex? ((Gazing at Ren as he talks)) **[M] Ren:** [Because someone] ((Ren giggles)) **[N] Ren:** What if someone wants to be a T (.) rex (.) ((Batman leans into Ren)) **[O] Batman**: No but actually WHAT if someone wants to be som-
[11] Rishi: Ok so we have one more. Y'all this a really important question, right, and I am saying this as someone who is trans, like when I have to pick my gender on a on a survey, often the option I want is not there. cause I identify as genderqueer. That's actually like what I call my gender, and so this question is actually really important because we're asking about stress. We're asking about how people identify, and as Travisloot said last time we don't wanna ask questions in a way that may cause stress. Right? So we gotta think real carefully about how we phrase these questions. what options we give people so that we can consider how it might make them feel to answer them right? And So I like what you are saying we should have lots of options. We can have male, female. No sorry male or boy, girl or female, transgender, unsure, and then you said nonbinary, right? Are there any other, cause I don't know how y'all talk about gender right? how your generation talks about gender. Are there any other ways that people identify. that you know of?	**[P] Batman:** Just say other!

Across this [L-P]and their previous [A-K] private space interactions, both Batman and Ren reasoned through the options for gender through humor, taking up substrate from the whole class discussion towards a serious consideration of 'not judging' survey takers' intentions [9] when answering a question on gender. In this interaction, Batman built on the sedimenting options for the question, but argued for keeping an open option – "other" – because 'what if someone wants to be a T Rex?' [L]. Initially received as a humorous response – evidenced through Ren's giggling [M] – Batman then re-animated his question, 'what if someone wants to be' [O]. While his utterance was cut off by Rishi speaking into the whole class space, Batman built on the play he and Ren engaged in earlier [G, H] – where transformers could be a possible and valid option. If so, then providing an open space for survey takers to express an unlisted or unexpected gender would be necessary, as evidenced through his growing support to 'just say other' [K, P] as an option for gender.

In the public space, Rishi authored themselves as an explicit insider and knower of a specific survey taker's experience – a trans person who did not have their gender identity listed on a survey [11]. They framed this context and insider knowledge as important by shifting their positionality to that of a survey designer – with the youth ("we") – making a survey about stress. Considering non-cisgendered survey takers' feelings was important *because* the survey they were designing was about stress, informed by Rishi's previous experiences with answering questions about gender. Furthermore, Rishi framed meaning-making around how to ask about gender as important by recruiting Travisloot's resistance the previous day as the source for the epistemic ideal of care for survey takers' feelings as necessary for survey design. For the question on income (previous episode), consideration of participants' well-being was legitimated (by the adults) as an ideal in building reliable processes because it would not help the group meet the epistemic aims of the survey. In this turn of talk however, care for survey takers was positioned as important regardless of the aims of the survey through Rishi guiding youths' emotional participation (Vea, 2020) in considering how trans people – like Rishi – would feel not having their gender in the survey. It was no longer the emotions of a generalized 'other', but Rishi's feelings – an adult in a position of power– that the class needed to consider in designing reliable processes for their survey. This epistemic ideal also emerged as the hierarchy in gender categorizations was sedimenting.

While Rishi positioned the youth as the experts who knew how their "generation talks about gender" [11], neither of the gender binary categories were questioned (boy/male; girl/female). Instead, they emerged as obvious options, indicating an assumed acceptance and shared orientation around heteronormativity structured into their understandings of gender (Ahmed, 2006). This emergent gender hierarchy is also mirrored in broader data collection practices that often (re)produce harm towards and the invisibility of non-cis-gendered identifying communities through the powered heternormativity (and heterosexuality) that structures quantitative methods (Guyan, 2022). In this episode, reliable process for asking about gender necessitated youth recognize their power over survey takers' (like Rishi's) feelings, by carefully considering how to ask about non-cis-gendered identities. Batman and Ren's playful sensemaking around gender options, and Batman's growing insistence on 'other' being a more open and inclusive option (that would allow responses like transformers so as not to judge survey takers intentions) is indicative of the youths' careful consideration and care for the survey takers' feelings. Ultimately, Rishi proposed "my gender is not listed here" as an option that would "honor that we did not know" someone's gender identity, which the class agreed on.

Discussion and significance

Explicitly justice-oriented curricula necessitate adults work as sociopolitical allies towards youth reauthoring their rights in classroom spaces. In an activity such as designing a community survey, this involved youth and adults negotiating what and how to ask questions to survey takers. In this classroom, 'care for the other' emerged as an epistemic ideal through youths' increasing resistance to extractive data collection practices. That is, explicitly working to desettle adult-youth powered differentials resulted in emotions emerging as integral to sense-making around the ethics of knowledge creation towards more just ends. However, as evidenced in the first episode, this epistemic ideal was not ratified until the youth skillfully reasoned it as aligned with the aims set by the adults in positions of power. At the same time, when care for the 'other' sedimented as an ideal, aligned with disciplinary aims, it afforded the adult to advocate for the well-being of non-cis-gendered youth both within the classroom space and those taking the survey. That is, through the ideal of care, gender-alienation through the politics of data collection was elevated as an important consideration in survey design.

What 'care for the other' entailed, in nature and degree, was emergent and contingent on classroom interactions. First, survey-takers' assumed anonymity was reconsidered when youth focused on the locality of their survey catchment area – in their own community. They were not designing a survey to be sent into the void but asking salient questions about stress to their own community. Second, what it meant to care for the well-being of survey-takers gained deeper meaning when the issue was literally fleshed-out – embodied in the personhood of a classmate who identified and performed as queer (a transgender student in the class), and in Rishi- with whom students were relationally entangled. We suggest that a direct interaction of such relational nature solidified for youth the significance and importance of parsing how and why, and to what ends, gender questions ought to be asked in a survey. Third, the tensions between caring for the survey-taker because of its ethical imperative and caring that the survey yielded authentic data because the youth care about the phenomenon of stress in their community, was apparent and tricky to navigate. Across these three considerations, we see evidence of a braiding of emotional configurations with care for the other as an epistemic ideal, towards a more rightful presence for the local community of survey-takers and youth and adult as nested within said community.

Our analysis suggests that attuning to the youths' resistance through bids to re-author their rights in the classroom space along with the role of emotional guidance in shaping whole-group discussions was consequential towards illuminating the ways in which power and positionality shaped the direction of and sense-making around scientific practices. It also points to the complex nature of engaging in allied sociopolitical struggles. Even as student-adult power differentials were obvious, the kind and degree of power differentials made manifest along particular axes (e.g., conceptions of income, gender, the goals of a class survey instrument) were embodied and informed the actions of stakeholders in ways that gave texture to the overall student-adult power differentials. Thus, student-student power differentials; adult-adult power differentials and the potential myriad configurations of such are all productive towards unpacking the nature of allied political struggles towards rightful presence as well as the import of emotional configurations and de/settling epistemic ideals in and through these processes. How do we intentionally and systematically tease out power differentials that undergird such rightful presence authoring work? What are the significant roles that emotional configurations play, that designers of justice-oriented learning experiences need consider, and imbricated in what ways with epistemic ideals? Zooming out, how do we as a field continue to disrupt white Eurocentric scientific teaching and learning with these insights?

Endnotes

(1) None of the youth in the class identified as white, and a large portion of them identified broadly as Hispanic, though they preferred more specific country-based identities (e.g., Dominican, Puerto Rican, Ecuadorian etc.). While from the same school district, the design team youth were not in the same class or school where the curriculum was piloted.
(2) All quotes are from youths' utterances unless otherwise specified
(3) Rishi uses they/them pronouns

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Designing Classroom Space as an Extension of Pedagogical Judgment: A Case Study

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Abstract: For the past decade, learning scientists have come to understand the relationships between learning and space — usually outside of schools and classrooms. More recently, scholars in teaching and teacher education have called for research that considers how space and movement shape teaching and learning. In this paper, we integrate concepts and methods across the learning sciences and teacher education. We examine the relationship between classroom spatial design and the enactment of ambitious and equitable mathematics teaching. Specifically, we apply a case study approach to outline how an experienced teacher's use of space reflects her pedagogical judgment. Findings and discussion outline six key ways this teacher considers space in her classroom design and her facilitation of classroom interactions. We suggest this study has implications for future efforts to characterize classroom spaces in ways that integrate ideas in the learning sciences and teacher education.

Introduction

Over the past decade, learning scientists have come to understand the relationships between learning and space — usually outside of schools and classrooms. Some characterize diverse ways young children and families make places for learning as they move through built and natural environments such as urban settings, museums, or the natural world (e.g., Gutiérrez et al., 2019; Leander et al., 2010; Marin et al., 2020; Taylor, 2017). Others have begun to explore the connection between physical space, technologies, learners, and learning goals in designed learning experiences and the role physical space plays in a designs' distributed intelligence (Pea 2004; Tissenbaum et al., 2021). Still others are developing methodological approaches that better consider the relation between physical space and learning (Keifert & Stevens, 2019; Kelton, 2021; Shapiro et al., 2017).

Scholars in teaching and teacher education have called for research that considers how space and movement shape teaching and learning (e.g., Weiland & Poling, 2021; Shapiro & Garner, 2021). In particular, there is a need to understand how classroom spatial design can support the enactment of different pedagogies. In this paper, we integrate concepts and methods across the learning sciences and teacher education to examine the relationship between classroom spatial design and the enactment of ambitious and equitable mathematics teaching. Using an extreme case (Flyvbjerg, 2006) of an experienced teacher who is a former architect, we analyze how her use of space relates to her pedagogical judgment.

Theoretical perspectives

Our analysis integrates two theoretical perspectives. First, we take a situative perspective on teaching, with particular attention to teachers' pedagogical judgment. Second, we also draw on concepts and methods developed in the learning sciences and related fields that allow us to consider how the built environment shapes the interaction of people and things. By bridging these theoretical perspectives, we aim to add more nuanced understanding to each. Examining teachers' use of space sheds light on an undertheorized aspect of teacher learning, while bringing teachers' reasoning into studies of classroom spaces allows us to understand the practical implications of teachers' use of space and explore new avenues to understand teachers' sensemaking.

Teaching as a situative practice requiring pedagogical judgment

To understand teachers' sensemaking about their classroom space, we draw on situative theories of teacher learning. Importantly, we conceptualize teaching and learning as culturally, historically, and institutionally situated (Cazden, 2001; Lampert & Cobb, 2003; Lave & Wenger, 1991; Ma & Singer-Gabella, 2011) and as a social and interactional accomplishment (Cohen, 2011; Greeno, 1998). In this view, teaching is inherently complex and uncertain — particularly for teachers who aspire to ambitious and equitable instruction (Horn & Garner, 2022; Lampert et al., 2011). Ambitious and equitable instruction is that which supports all students — especially those who are often marginalized or minoritized — to engage in meaningful disciplinary practices. This vision of instruction requires teachers to be responsive to students' diverse needs as they implement rich tasks that support students' conceptual understanding. As a result, we do not seek to develop 'best practices' or 'ideal types' of spatial design for the classroom, but rather to connect teacher sensemaking to spatial pedagogy through pedagogical judgment (Horn & Garner, 2022).

Pedagogical judgment consists of three interrelated components: (1) *pedagogical action* (or what is visible in classroom activity), supported by (2) *pedagogical reasoning* (or teachers' rationales), and rooted in (3) *pedagogical responsibility* (teachers' sense of moral, ethical, and institutional obligations). Although these components are entangled, they are distinct enough to warrant separate analysis. For instance, teachers may enact the same pedagogical action — e.g., arranging students' desks in small groups — based on different pedagogical reasonings and responsibilities: One teacher may arrange groups because they use groupworthy tasks and expect students to collaborate in solving them, perhaps reflecting a pedagogical responsibility to support students' engagement in high-level mathematical thinking. Another teacher may arrange groups due to a school-wide expectation to do so, reflecting a pedagogical responsibility to follow institutional requirements. While this hypothetical example suggests such a connection, there is little empirical research that actually examines teachers' pedagogical judgment in relation to the spatial environments of their teaching contexts. We seek to address this gap by adding a spatial element to our analysis of a teacher's pedagogical judgment.

Toward more expansive understandings of classroom space

Historically, studies of classroom space that do exist have typically focused on physical arrangements of furniture, but with less attention to how teaching and learning unfolds in the built environment. A notable counterexample is Liljedahl's (2016) work on "thinking classrooms." Lijedahl offers strategies for designing classrooms to maximize student engagement and student thinking — e.g., by using "vertical non-permanent surfaces" for student collaboration. In response to recent calls for a spatial turn in teacher education (e.g., Weiland & Poling, 2022), we aim to expand an understanding of space in relation to pedagogical judgment.

To do this, we build on work in the learning sciences and related fields that use qualitative methods to foreground space and movement in studies of classroom contexts. Notably, we draw from work that characterizes learning spaces primarily in out of school settings as fluid entities comprised of assemblages of bodies, physical space, and movement over varying scales of time (e.g., Gutiérrez et al., 2019; Leander et al., 2010; Marin et al., 2020; Shapiro, Hall & Owens, 2017). Such characterizations, for example, lead us to consider how pedagogies are enacted across the physical classroom environment and enable or restrict movement in ways central to teacher sensemaking and student learning. We also draw from concepts that characterize how physical classroom spaces can (dis)empower students, such as *built pedagogy* (Monahan, 2005). Notably, this work focuses on characterizing physical spaces through photographs to show that classrooms are empowering when teachers and students are able to adapt, personalize, and move through them. Similarly, we draw from research arguing that *spatial pedagogies* — how teachers use space during instruction — shape the enactment of lessons, including students' learning opportunities (Lim et al., 2012). Yet, this research also shows that teachers may not be fully conscious of their own spatial pedagogies. Finally, we draw upon methods of interaction geography to conceptualize teachers' movement over space and time as an additional tool for reflection about space and movement (Shapiro & Garner, 2021). Together, this allowed us to examine our focal teacher's use of space alongside her pedagogical judgment, adding further insight to our understanding of each field.

Data and methods

This case study is part of a larger research project studying experienced secondary mathematics teachers' learning in a large urban US school district. Participating teachers are part of a professional development organization with an explicit commitment to ambitious and equitable math teaching. For this analysis, we selected one participating teacher, whom we call Linda Simmons, and observed her classroom in May 2022. We collected photographs, detailed fieldnotes, and used methods of interaction geography to manually transcribe and dynamically visualize her movement. We also conducted a two-hour interview with Linda to understand her use of space. During this interview, we asked questions pertaining to the history of the physical classroom space she worked in and how she approached supporting learning through designing physical space using a dynamic visualization tool called the Interaction Geography Slicer to further support reflection about these questions.

Focal case: Linda Simmons

We selected Linda Simmons as an extreme case (Flyvbjerg, 2006). She is atypical in two important ways: First, she is a veteran teacher, with over 20 years of experience teaching secondary mathematics; in that time, she has developed a strong commitment to ambitious and equitable pedagogy. Second, Linda was a professional architect for many years before she became a teacher. As a result, Linda is particularly attentive to the built environment, including the ways she uses classroom space to support her pedagogical goals. So, unlike many teachers (Lim et al., 2012), we anticipated that Linda would be keenly aware of her spatial pedagogy.

Previously, Linda participated in a year-long interview study of teachers' experiences during remote instruction at the start of the COVID-19 pandemic (Schneeberger McGugan et al., 2022). During this study, Linda described deep commitments to ambitious and equitable math teaching and collaborative learning. She also discussed the difficulty of remote teaching, largely because she and her students could not use the physical classroom space. This further underscored the relevance of spatial pedagogy for her pedagogical judgment.

Linda's pedagogical judgment

In previous interviews, we recognized that Linda's pedagogical judgment — including pedagogical action, pedagogical reasoning, and pedagogical responsibility — aligned with ambitious and equitable instruction.

Linda described her pedagogical responsibility, or her moral and ethical commitments, as twofold: 1) caring for students as full human beings, and 2) supporting students' authentic and meaningful mathematical engagement. Linda is committed to creating a safe classroom environment for all students, where they know that "[they are] welcome here, and [they] matter here" (May 2020 Interview). Her pedagogical responsibility to care for students by creating a welcoming classroom environment is deeply connected to her second responsibility of designing for and supporting deep mathematical learning. One aspect of her role as a caregiver to her students is a responsibility to foster rich student engagement with mathematics: "I really truly want to hold myself accountable to that idea of inviting every kid to engage meaningfully with what we're doing. And not just invite them, but actually have a way for them to do that" (November 2020 Interview).

Linda's pedagogical actions and pedagogical reasoning reflect these responsibilities. She prioritizes collaborative learning and is intentional about designing her lessons and classroom space to support groupwork: "All of their work is collaborative. All of their work, while they're sitting in tables — aside from when we're taking assessments — I expect them to be talking" (May 2020 Interview). In Linda's classroom, groupwork reflects both her commitments to a welcoming classroom environment and deep mathematical thinking, as she cultivates collaboration to build positive student-to-student interactions and to support their engagement with rich mathematical tasks. As Linda discussed how she tried to develop norms for collaboration online, she lamented the loss of her physical classroom during remote teaching: "I have built a very intentional learning space that has particular things on the walls. It has a particular arrangement of the tables" (November 2020 Interview) and "[My teaching is] very driven by the stuff on the tables" (August 2020 Interview). In sum, analyses of Linda's pedagogical judgment revealed her understanding of her teaching practice is rooted in her classroom space, making her an ideal case for analyzing our phenomenon of interest.

Analytic methods

To understand the relationship between Linda's use of space and her teaching practice, we conducted several lines of analysis and in this paper, report on a thematic analysis in the grounded theory tradition (Charmaz, 2006; Glaser & Strauss, 1967). Specifically, we transcribed and iteratively analyzed video recordings of our interview with her, as well as photographs and fieldnotes from our observation. We conducted an open coding process, identifying themes relevant to Linda's use of space and her pedagogical judgment. We then iteratively discussed and refined these themes to produce the findings presented in this paper.

Findings

In our analysis of Linda's teaching practice, we found that her pedagogical judgment influenced both her intentional design of classroom space (i.e., the spatial organization of her classroom) and her subsequent facilitation of classroom interactions (i.e., the enactment of instruction within that space).

Designing classroom space for ambitious and equitable instruction

We identified three key features of Linda's classroom design: *reorienting* the classroom, *de-fronting* the classroom, and *valuing* diverse mathematical identities and ways of thinking. Each of these design choices reflects Linda's pedagogical judgment, as she organized her classroom for ambitious and equitable instruction.

Reorienting the classroom

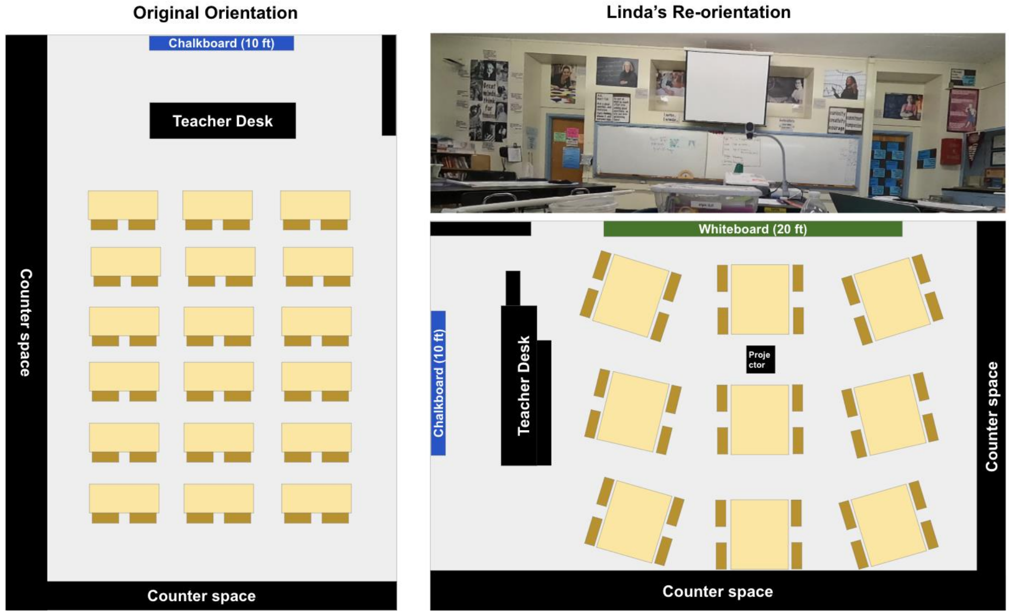
When Linda's school was first built in the 1950s, classrooms were planned as a long rectangle, with students facing a chalkboard on the shorter side of the room (Figure 1a). Students were separated from the chalkboard by a large built-in desk, which teachers could use for demonstrations. This combination of a smaller, distant chalkboard and an authoritative, imposing teacher desk conflicted with Linda's pedagogical responsibility:

namely, a commitment to creating a safe space where students feel comfortable and invited to participate. Indeed, she described the teacher desk as feeling like “a wall” that “divides” her from her students.

To better align with her pedagogical responsibility, Linda reoriented the classroom as a wide rectangle (Figure 1b). She installed a whiteboard on the longer wall which she uses to display important information — e.g., when giving instructions or showing a task from the projector at the center of the room. The chalkboard still exists, but is no longer the focal point of the room; Linda instead uses it to hang student work. Notably, Linda is the only teacher in her building to reorient the classroom in this way.

By reorienting the classroom, Linda is able to enact her pedagogical responsibilities. As she teaches, she is physically closer to students — no longer separated by a 10-foot barrier — which allows her to develop a sense of social closeness as she attends to and cares for her students. Furthermore, it brings students closer to the mathematics: In her re-orientation, students’ desks are never more than 20 feet from the whiteboard, in contrast to 30 or more feet from the old chalkboard. While Linda has worked to de-emphasize the importance of the front of the classroom, the whiteboard can serve as a place to record students’ findings — e.g., when students “generate the entire trig table from scratch” — or display important information. Bringing students physically closer to her and to the whiteboard allows Linda to better enact her pedagogical commitments to cultivating an inclusive classroom community and supporting students’ engagement with rich mathematics.

Figure 1
Original orientation of Linda’s classroom (a), with chalkboard (blue) at the top of the floorplan and student desks (yellow) in rows. Linda’s re-oriented classroom (b), with a large whiteboard (green) at the top of the floorplan and students’ desks (yellow) in groups.



(a) (b)

De-fronting the classroom

In addition to reorienting her classroom, Linda has worked to “de-front” the room — that is, to diminish the importance of the front of the classroom as a source of authority and a focal point for students’ attention. Instead of turning to her or to the whiteboard for information or correct answers, Linda has arranged students’ tables so they can turn toward each other for most of their mathematical activity.

Linda’s students are seated in groups of four, with some tables angled slightly (Figure 1b) so that “there’s not a single kid facing the front of the room.” Linda described this as a way to help students “value the conversations in their group more than they focus on [her] delivery from ‘on high’.” While each student can turn to see what is on the whiteboard, they face one another in their default position. Moreover, each table has a dry-erase surface, which students can use to work out ideas together. Linda referred to the dry-erase surfaces as students’ “shared thinking space.” When we observed Linda’s class, many students wrote on the dry-erase surfaces as they collaborated — and they were well-worn, suggesting this was a frequent occurrence.

De-fronting the room further reflects Linda’s pedagogical judgment, demonstrating her pedagogical responsibility to supporting students’ authentic and meaningful mathematical engagement. Linda’s reasoning suggests that, for her, delegating authority — that is, allowing students to recognize their own and their peers' strengths and ideas — is central to mathematical engagement. Linda's classroom design — specifically the arrangement of desks, with shared writing surfaces — encourages students to turn toward one another as they collaborate, rather than relying on Linda or the textbook as the primary source of information.

Valuing diverse mathematical identities and ways of thinking

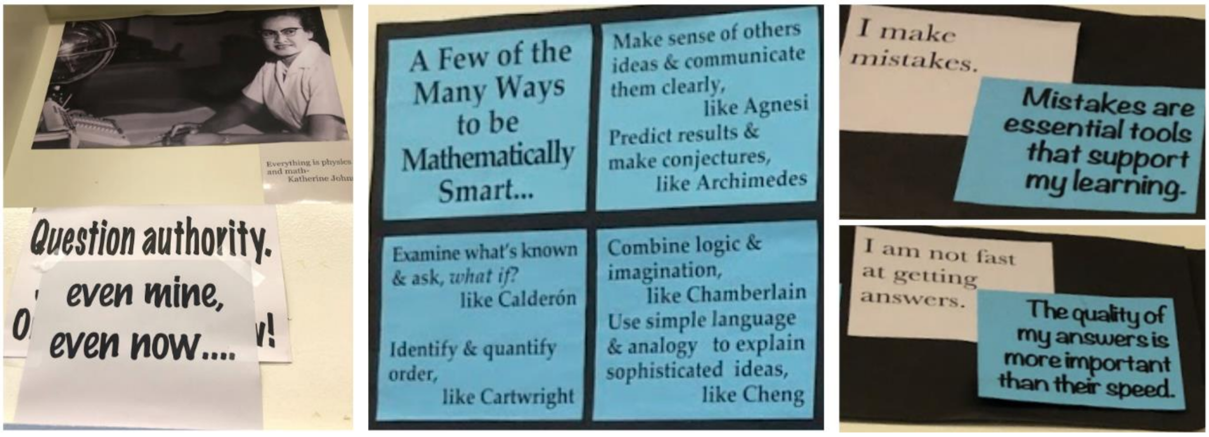
In addition to the thoughtful arrangement of furniture, Linda designed the walls of her classroom to reflect her pedagogical commitments. Linda emphasized her desire for students to feel comfortable, welcome, and represented in her classroom; she wants them "to see this as our space." In this endeavor to support students' sense of belonging, Linda has decorated the walls with posters of diverse mathematicians and scientists, particularly highlighting people of color and women in STEM — including Katherine Johnson (Figure 2a), Emmy Noether, and Benjamin Banneker — as well as people in fields tangentially related to STEM. Linda displayed her intentionality in this endeavor by describing it as "a place to start, not a place to end;" she said she regularly adds posters, seeking out mathematicians who share her students' identities.

Linda also represents diverse ways of participating in mathematics. One large poster highlights ways people can be mathematically smart, including: "Make sense of others' ideas and communicate them clearly (like Agnesi)," and "Examine what's known and ask *what if*? (like Calderón)" (Figure 2b). The suggestions reference specific contributions from a diverse set of mathematicians. Another poster offers ways to reframe negative self-talk, e.g. "I make mistakes" to "Mistakes are essential tools that support my learning" (Figure 2c).

Another important sign in Linda's classroom says "Question authority. Even mine, even now" (Figure 2a). Linda uses the poster to highlight her goal of supporting students' critical thinking; telling students each year: "Every single day, I want you to walk out of here being a more critically thoughtful person, and that includes the fact that just because somebody says, 'This is the way it is' — How dare you let somebody else describe for you what your world is?" Originally, though, the second line on the sign said, "Except mine, or at least not now." After the tumultuous summer of 2020 — and the violent murder of George Floyd — Linda reflected on what it meant to "hold [herself] accountable" to encouraging students' critical thinking. She decided that asking students to not question her authority conflicted with her pedagogical responsibility, so she revised the sign. She intentionally chose to leave the revision visible, so students can clearly see the change.

The wall hangings in Linda's room are not merely decorative; she regularly refers to the posters and reinforces their ideas through her pedagogical actions. For example, in addition to encouraging students to question authority, Linda described referring to the mathematical smartnesses poster when she assigns competence — noticing and naming when students do interesting things. When she does not invoke the poster, Linda said that students do not take her compliments seriously: "Somehow they think, 'Oh, you're just blowing smoke. You've just made up a reason to tell me I'm doing something [good].'" But when she can refer to a specific mathematician who shares that skill, Linda "can tell them who those people are and what they've done and whatever, then all of a sudden it's like, 'Whoa, I'm just like whoever!'"

Figure 2
Wall hangings in Linda's classroom: A photo of Katherine Johnson above the "Question Authority" sign (a), a portion of the Mathematical Smartnesses poster (b), and a portion of the positive self-talk poster (c). This is just a small portion of the posters in (b) and (c); they each contain many more examples.



(a) (b) (c)

Ultimately, these wall hangings support Linda's pedagogical responsibility to create an inclusive and welcoming classroom where students' various and intersecting identities and academic strengths are valued. By displaying images of a diverse collection of mathematicians, Linda shows that all students — regardless of their identities — can be successful in mathematics. Perhaps even more importantly, Linda's classroom design communicates that she values students' ways of thinking, helping them recognize that their strengths are valuable in mathematics. Linda also regularly reflects on her classroom decor, ensuring that the ideas her posters communicate still reflect her pedagogical judgment, and making adjustments or revisions when they do not.

Facilitating ambitious and equitable instruction within the built environment

We found that, in addition to designing her classroom space to support ambitious and equitable instruction, Linda facilitates movement and interaction within the built environment in ways that reflect her pedagogical judgment. She does this through three pedagogical actions: providing students' *access* to materials, encouraging their *unrestricted movement* around the room, and inviting students to contribute to *classroom decor*.

Providing students' access to materials

Linda has organized her classroom space so that students have ready access to whatever materials they might want for mathematical exploration. In addition to dry-erase surfaces, tables have boxes with mathematical tools, including straight-edges, compasses, markers, glue sticks, and so on. Having these materials readily available allows students to decide what tools they need and when they need them. Indeed, when we observed Linda's class, students frequently used these materials — and other resources around the room — to engage in the task.

Linda described this pedagogical choice as a way to empower students: "I don't want it to be, 'I'm going to hand you protractors, but I'm not going to hand you compasses,' or, 'I'm going to hand you rulers, but you aren't going to get tape measures.' I want all of it in there, because that way, it's their decision what's the best tool for them to use for a particular thing." She went on to argue that directing students to use specific tools tells "them so much that they should have to figure out for themselves." By giving students access to a variety of materials — and encouraging them to use whatever tools they see fit — Linda's pedagogical actions support her pedagogical responsibility to facilitating students' engagement in meaningful and authentic mathematics. She helps students exercise their agency and authority to determine what they need for mathematical sensemaking.

Encouraging students' unrestricted movement around the room

In Linda's class, students are able to move about the room as they wish. They are free to get replacement materials or consult with other groups; Linda even keeps a cabinet of snacks in case students are hungry. Students are not expected to interrupt the flow of the lesson to ask to get tissues, a new marker, or even more expensive materials like graphing calculators. In our interview, Linda described being "neurotic" about assigning calculators earlier in her career. But now, she trusts her students to get materials and return them when they are finished. Especially by the end of the year, "they should feel very comfortable just getting what they need and not having to ask permission constantly to get what they need." These norms were apparent during our observation, as students moved freely about the room, with a constant hum of cheerful mathematical activity. Each group worked on building different three-dimensional geometric figures, so students frequently checked with other groups to see what they had done with their shapes.

Linda also allows students to come to her classroom at any time, even during other class periods. Earlier in the year, the boys' restroom had been out of soap for weeks. Linda has a sink in her room, and she said that students "would come over just to wash their hands, and I told them that it's totally fine. They just come in, they wash their hands, they leave, and it's just in the middle of class, just doing their stuff — totally fine. I'm delighted that they're washing their hands." During our interview, a student stopped by Linda's room to get a snack and to borrow some knitting needles, which Linda had for an after-school knitting club that she runs.

Linda described students' unrestricted movement as a way to cultivate a welcoming and inclusive environment. She wants students to see her classroom as "*our* space," rather than *her* space. By recognizing students' autonomy and giving them opportunities to exercise it, she invites them to participate in classroom activities — whether social or mathematical — as they choose. Moreover, Linda's attention to students' needs — whether hygienic, nutritional, or extracurricular — demonstrates her care for students as full human beings. Linda's students know that they are welcome in her classroom at any time of day, and for any reason.

Inviting students to contribute to classroom decor

Finally, Linda invites students to decorate the room with things they care about. Though she has cultivated representations of diverse mathematical identities and experiences, she also asks students to contribute. She has a designated bulletin board titled, "We hold these truths" and invites students to post things important to them

(Figure 3). As Linda described, “that bulletin board is not *my* bulletin board — that’s *our* bulletin board.” During our observation, we saw that students had contributed artwork, images, and quotes.

By inviting students to publicly share and connect over what they each find important, Linda fosters a socially collaborative environment. This pedagogical action highlights her commitment to cultivating an inclusive classroom community, as students take ownership over the space. While some students shared things that are somewhat related to math — e.g., geometric art and origami — additional items, like a signed photo of a football player and a flier for an extracurricular organization — show students’ interests in other areas. This reflects Linda’s pedagogical responsibility to care for students as full human beings. In addition to supporting students’ mathematical identities, Linda encourages them to share other aspects of their lives, as well.

Figure 3
“We hold these truths” bulletin board, with contributions from students, including origami, graphical designs, and an athlete.

Discussion

In this case study, we found that Linda’s use of classroom space is intimately tied to her pedagogical judgment, including her conceptualization and implementation of ambitious and equitable mathematics teaching. We identified six key features of how Linda uses space and movement in her pedagogy, which fall into two groups: design of classroom space (i.e., the spatial organization of her classroom) and facilitation of classroom interactions (i.e., the enactment of instruction within that space). Taken together, these findings underscore the importance of considering the built environment in planning and implementing instruction and more generally, how we conceptualize teaching and teacher sensemaking.

While Linda is an extreme case, with unique experiences in spatial design and ambitious and equitable pedagogy, we argue this analysis has important implications for research on teaching and teacher education. Most studies of ambitious and equitable pedagogy — even those accounting for teachers’ contextual sensemaking — overlook the physical environments where teaching and learning take place. By understanding how built environments intersect with pedagogical judgment, researchers can better understand the embodied and situated nature of teaching. Moreover, our analysis demonstrates the value of integrating concepts and methods in the learning sciences with teacher education to foreground the role of physical space in classroom teaching and learning. In particular, our analysis highlights implications for how theories and methods in the learning sciences expand how we conceptualize concepts such as pedagogical judgment and support teachers’ reflective professional practice. Notably, theories in the learning sciences informed our approach to supporting teachers’ reflective practice during interviews and our use of the Interaction Geography Slicer served as a facilitation tool to further support the kinds of conversations about space and movement with one teacher. Likewise, our findings expand an understanding of concepts such as built pedagogy, which focus on the design of physical classroom spaces without an emphasis on how teachers adapt those spaces during classroom lessons.

This study has several important limitations. While we sought to supplement Linda’s descriptions of her use of space with our own observations of her instruction, we only observed one class period. Additional observations of different lessons and classes may reveal new themes that we did not uncover. Moreover, such data may highlight elements of Linda’s spatial pedagogy that even she is not fully conscious of — or, perhaps, ways that her spatial pedagogy does not have the intended impact on her students. And while the single-case nature of our study design is not a limitation, *per se*, we note the need for additional research in this area. Other teachers — especially those in different settings and with divergent goals — may use space very differently. To address some of these limitations, our current work is expanding diverse methods and analyses, including cross-case analyses and exploratory visualization methods, in collaboration with more teachers and classrooms.

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Increasing Preservice Teachers' Computational Thinking Lesson Design Capacity Within a Research-Practice Partnership

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Abstract: This study examines efforts by a research practice partnership (RPP) in the western US to develop preservice teachers' (PSTs) capacity to design computational thinking (CT) instruction for K-5 students. Using a sociocultural perspective, we analyzed interview and survey data to examine 6 preservice teachers' enculturation into a future community of practice where teachers value and can adeptly design CT instruction. RPP supports, such as co-design opportunities with RPP members and an accessible CT summary chart, mediated PSTs' successful planning and implementation of a CT lesson, although conflicts between their coursework and RPP activities proved a significant barrier to deeper engagement. PSTs also demonstrated a working definition of CT and beliefs around their own sense of efficacy and understanding of coherent CT instruction. This study provides evidence of a scalable approach to teacher education in CT instruction for RPPs and highlights areas where additional supports would further scaffold teacher learning.

Introduction and motivation

Despite widespread recognition of the importance of computing to students' futures (NASEM, 2018; Wang et al., 2016), and despite policy reforms intended to galvanize the development of more inclusive opportunities (e.g., ACM et al., 2016), many communities remain underrepresented in computer science (CS). In the US, frustratingly little progress has occurred in terms of increasing the diversity of those seeking and attaining careers involving computing (Google/Gallup, 2016). Understanding how to create meaningful trajectories for learners in computing – from K-12 to careers – has long remained an urgent need (NASEM, 2021; Wilson et al, 2010). CS learning opportunities at the K-12 level in the US remain particularly sparse for underrepresented students (CtE, 2016), with efforts all too often faltering due to schools prioritizing other academic goals and the lack of teachers prepared to teach CS (Wang et al., 2016). Visions of equity in CS will remain empty aspirations until K-12 school systems have sustainable and scalable materials and approaches to create meaningful CS learning experiences for their students (Tissenbaum & Ottenbreit-Leftwich., 2020).

Increasing the capacity of K-12 school systems to engage their students in meaningful CS learning will require overcoming systemic barriers, particularly in terms of teacher preparation and curriculum design and implementation. Research-practice partnerships (RPPs; Coburn & Penuel, 2016) focused on design work hold particular promise for attending to barriers holding back innovation within school systems. In this paper, our context centers on a RPP in the western US focused on creating equitable learning opportunities in CS for their K-5 students, particularly multilingual students from Latinx backgrounds. To overcome limited resources and instructional time, members of this RPP envisioned K-5 students engaging in computational thinking (CT; Grover & Pea, 2013) – the sort of thinking a computer scientist would use – not within a separate CS class but productively integrated within existing subjects and over time (e.g., science, math). Similar design approaches that embed CS into core subjects at the K-12 level have shown promising outcomes (Century et al., 2020). Indeed, a major science education reform in the US, the Next Generation Science Standards (NGSS Lead States, 2013), identifies engaging in computational thinking as part of a core set of science and engineering practices students should engage with in science. In terms of capacity-building, the RPP sought to position teachers to collaboratively design CT into core subject lessons with support from RPP members. Practicing teachers, however, proved too overburdened with competing initiatives to engage in new design work.

Aware of the potential upside of having *student* or pre-service teachers (PSTs) receive training on CT (Yadav et al., 2017), the RPP approached PSTs in partner schools to engage in co-design work. RPP members hypothesized that PSTs may not only have more flexibility to test out the utility of the RPP's co-design approach versus practicing teachers but that this experience could prove particularly impactful in developing student teachers' design capacity for integrating CT into curricula and in shaping their beliefs and self-efficacy for CT instruction. This paper asks: (RQ1) *What aspects of the design space facilitated (or hindered) student teachers' engagement in productive CT lesson design?* and (RQ2) *How did student teachers' understandings and beliefs about CT instruction change over time?*

Theoretical framework

Our study focuses on PSTs' learning as they engage in design work within the context of a RPP and during their teacher credentialing program. Drawing on sociocultural conceptions of learning, notably the situated learning notion of communities of practice (Lave & Wenger, 1991), members of the RPP envisioned the formation of a community of K-5 teachers with the capacity to adeptly integrate CS and CT into their classroom in meaningful ways for all students, notably multilingual learners. Included in the RPPs' conception of a community of practice are the students, multilingual learners and English speakers, who are active participants within the community (Téllez, 2007).

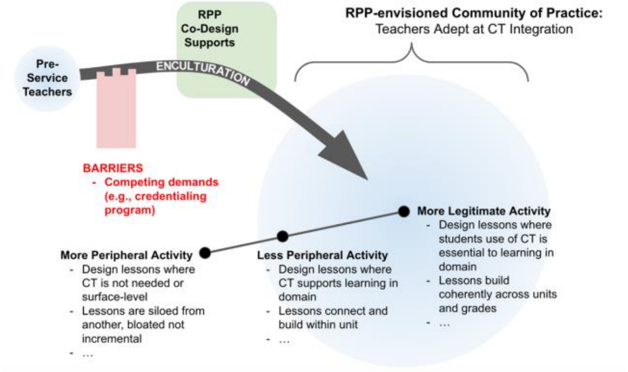
In line with situated learning, in terms of both our design and analysis, we view learning as changes in activity and participation of participants – such as teachers demonstrating an increased sophistication in their professional language (Little, 2002) – where they move from the peripheral position of an envisioned community towards one of increased participation where they more expertly engage with the skills and cultural practices of a particular community (Lave & Wenger, 1991). Members of the RPP organized design opportunities for PSTs to become increasingly immersed, or enculturated, into the community of practice envisioned by the RPP through participating in lesson design and implementation with support from RPP members.

We also utilize Vygotsky's (1978) conceptions of tools and mediation to frame the design and analysis of activities that supported PST participation and movement within a community of practice. According to Vygotsky (1978), people utilize tools (e.g., symbolic representations including speech, drawing, and number systems but also physical tools with cultural knowledge embedded within them) to mediate their learning and activity. Prior work has shown the promise of focusing on mediation and tool use in examining teacher learning (Orland-Barak, 2014). We see supports and structures within the RPP – namely elements in our design process and aspects of CT – as tools to mediate PSTs learning and support their movement from peripheral participation to deeper and more complex participation within the community of practice envisioned within the RPP.

Methodology

Approach to design activities

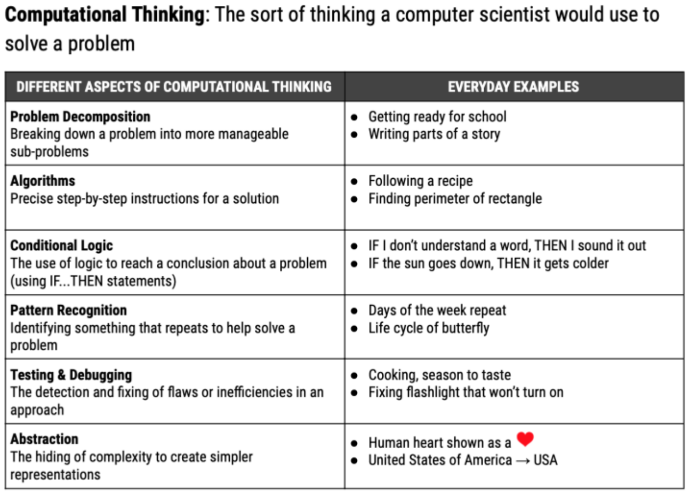
Figure 1
Theorized movement of PSTs towards becoming teachers integrating CT



The RPP that serves as the context of this design study is composed of K-5 teachers, district and school administrators, and researchers from local universities and not-for-profit institutions. For the past several years, members of the RPP have sought out ways to develop district teachers' capacity to integrate CS/CT into their instruction with the ultimate aim of forming a professional community of teachers adept at designing meaningful and inclusive CS/CT learning experiences. With PSTs, the RPP saw an opportunity to design and test ways to support novice teachers' "enculturation" (Russ et al., 2016) into this future community (see Figure 1). Following prior work on the benefits to teachers via collaborative design (Severance et al., 2016), members of the RPP developed tools and structures that positioned PSTs as lead co-designers of lessons that integrate CT with support from researchers and district personnel. The RPP wanted to see how this approach helped (or hindered) PSTs' capacity for designing CT learning opportunities, which echoes recent professional development models centered around CT integration through joint work (Love et al., 2022).

The support PSTs received over the course of three months ranged in form but all sought to spur PSTs development towards becoming teachers adept at CT integration. At the outset of their involvement, PSTs participated in a three-hour researcher facilitated workshop introducing them to the idea of computational thinking along with design ideas and tools. One notable tool researchers introduced – a one-page summary CT chart defining CT with everyday examples – purposefully built off of an activity where PSTs used their own knowledge and experience to recognize different facets of CT in their everyday lives and educational experiences (see Figure 2). This workshop also introduced PSTs to the notion of "coherence" in learning, that is a progression for learning where learning builds and becomes more complex over time (Fortus & Krajcik, 2012), by having PSTs analyze CT lessons across a primary grades science unit. After the workshop, PSTs worked closely with cooperating teacher mentors the credentialing program placed them with to plan how to integrate CT into an upcoming lesson. An additional support structure included hour-long one-on-one design sessions between PSTs and researchers and district personnel from the RPP. In these sessions, members of the RPP offered ideas, suggestions and instructional tools that PSTs could incorporate into their lessons.

Figure 2
Introduction to computational thinking summary chart handout for pre-service teachers



Computational Thinking: The sort of thinking a computer scientist would use to solve a problem

DIFFERENT ASPECTS OF COMPUTATIONAL THINKING	EVERYDAY EXAMPLES
Problem Decomposition Breaking down a problem into more manageable sub-problems	• Getting ready for school • Writing parts of a story
Algorithms Precise step-by-step instructions for a solution	• Following a recipe • Finding perimeter of rectangle
Conditional Logic The use of logic to reach a conclusion about a problem (using IF...THEN statements)	• IF I don't understand a word, THEN I sound it out • IF the sun goes down, THEN it gets colder
Pattern Recognition Identifying something that repeats to help solve a problem	• Days of the week repeat • Life cycle of butterfly
Testing & Debugging The detection and fixing of flaws or inefficiencies in an approach	• Cooking, season to taste • Fixing flashlight that won't turn on
Abstraction The hiding of complexity to create simpler representations	• Human heart shown as a ❤ • United States of America → USA

Approach to data collection and analysis

This is a multiple case study designed to explore a single phenomenon through the exploration of several cases (Creswell, 2007). Six PSTs (five at the primary level, one at the secondary level) participated in this research study. In terms of participant selection, the RPP was interested in working with PSTs who were engaged with students in the classroom and who could teach a lesson to their students. Working directly with students was an important feature in participant selection because of the emphasis on students as members and collaborators within a community of practice (Téllez, 2007).

Primary sources of data include 30-minute semi-structured interviews with participants after their enactment of the CT lesson, transcripts and artifacts from the 3-hour workshop, and PSTs' responses on surveys given pre and post participation in design activities. All six PSTs participated in the support activities organized by the RPP (i.e., PSTs participated in the initial workshop, worked with a collaborator within the RPP, and received support from the cooperating teacher mentor their credentialing program placed them with).

In terms of data analysis, we coded transcripts from the initial workshop and semi-structured interviews as well as pre and post survey responses for each participant. This coding process involved rounds of inductive and deductive coding of available data (Emerson et al., 2011), leading to the development of a codebook. Examples of codes include aspects of CT ("algorithms", "conditional logic") as well as codes that identify how PSTs talked about CT integration and instruction ("explicit", "implicit"). To ensure the reliability of our codebook, we used a set of our codes and Dedoose's interrater reliability test to achieve a pooled kappa score of 0.85, demonstrating a high consistency of our code application across various excerpts (De Vries et al., 2008). Throughout the data analysis process, we engaged in the creation of written analytic memos to discern potentially key data for further analysis. After discerning patterns of data triangulated across all sources of data, researchers engaged in the co-reconstruction of meaning from these data patterns.

Data and results/findings

We found that the mediating supports organized by the RPP supported the PSTs' capacity to engage in CT design work over time. While enabling in some capacities, the RPP and other programmatic structures were constraining in other aspects. We also found that PSTs demonstrated learning through their movement towards a future community of practice and the development of CT specific beliefs and definitions.

Claim: Design supports enabled productive CT lesson design but competing program demands across the RPP inhibited design in some ways

We found that (1) the structure of the RPP supported PSTs' capacity for engaging in CT design work, scaffolding their movement towards the center of the community of practice; however, (2) certain aspects such as PSTs Masters/Credential program requirements, number of meetings with RPP mentors and sustained support throughout the process acted as possible constraints on the design space.

Supports organized by RPP greatly promoted PST design

At the outset of the project, PSTs' pre-survey responses revealed very little to no capacity for designing quality lessons that integrate CT. The PSTs had simple ideas about what CT instruction should look like only saying, "*using technology integrated into the curriculum meaningfully (PST 4, Pre survey)*" but showing little capacity for designing lessons. Indeed, three of the six PSTs reported having virtually no knowledge of CT let alone knowledge of how to design lessons supporting CT learning. By the end of their participation three months later, however, each participant credited several aspects of RPP's program of support as key to increasing their design capacity for working with CT. Notably, PSTs acknowledged the utility of the workshop and tools introduced there like the CT chart and the benefits of co-designing with members of the RPP and their cooperating teacher mentors.

During the initial workshop, PSTs were supported by RPP mentors facilitating the workshop. PSTs were presented with information about CT and asked to think about the ways CT is already integrated into aspects of life and schooling. With these supports in place, PSTs were able to articulate ideas about CT integration, One PST was asked to focus on algorithms and shared that algorithms are universal:

> *Are most things that they do… they're actually writing How-To books and learning to be very clear with their step by step instructions in their writing…it's kind of meta, but I had to teach them the steps to writing their How-To books, which needed to include step-by-step instructions on teaching someone how to do something (PST 1, Workshop transcript).*

The structure of the workshop, including opportunities to think about current practices in relation to the new information about CT, supported all PSTs thinking about the ways CT was already integrated or embedded in the daily things they do in the classroom. This demonstrated the efficacy of the workshop as a support for PST learning. Three participants discussed the usefulness of the CT summary chart in supporting their ability to integrate CT into a lesson, saying "*there's a PDF that was provided that was really helpful for me in breaking down what each of the terms meant and then the practical application*" (PST 3, Interview transcript), which demonstrates the utility of the CT chart as a tool to mediate learning and lesson design.

After the workshop, PSTs were expected to plan and teach a lesson integrating aspects of CT. In their interviews, all PSTs talked about working with at least one person involved in the RPP to develop the lesson. Members of the RPP were available to support PSTs with lesson development and design as needed. During the semi-structured interview, one PST shared how a researcher from the RPP supported their design process:

> *I was glad that I reached out to [name redacted] and kind of got a little bit more support with what to do. I'd ask 'what should this look like?', 'what should some of my goals be?', 'what would be a good thing to use?' So I guess just kind of having someone more on the inside who could be like a soundboard to run ideas off with (PST 2, Interview transcript)*

During another interview, a PST explained the ways their cooperating teacher mentor (i.e., the teacher PSTs were placed with as part of their credential program) supported their enculturation into a future community of practice where CT integration is expected. While their cooperating teacher mentor was unfamiliar with CS and how to integrate CT, they supported the PST in learning and developing understanding in that area:

> *My cooperating teacher offered a lot of help because she was the one that thought we should try it out. She was there to tell me we should do it and learn something new. She helped me with the broad ideas of what we could do and how we could go about doing it (PST 4, Interview transcript).*

Across five of the six PST learning trajectories, PSTs reported the same pattern: RPP mentors supported CT integration and cooperating teacher mentors supported lesson planning and implementation. The PSTs reference to RPP members and cooperating teacher mentors in a supportive role highlights the ways that members of the RPP may have functioned collectively as something of an "old timer," someone established in a community of practice supporting the enculturation of "newcomers" (Lave & Wenger, 1991).

With these supports in place, PSTs successfully developed and taught a CT lesson, something that they previously admitted having little capacity for doing. The supports organized by the RPP functioned as mediating tools and means (Vygostky, 1978). These supports greatly aided PSTs in developing an increased design capacity to integrate CT into their instruction, which supported their movement towards the center of an envisioned community of practice (Lave & Wenger, 1991) – a community of teachers in the RPP where a focus on inclusive and meaningful CT instruction would be the norm.

Certain RPP structures inhibited PSTs capacity for inclusive CT design

Despite the successes of the structures of the mediating supports, there were aspects of the organization of the RPP's program of support that made reconnecting with the PSTs after the workshop and supporting them in additional ways a challenge. One PST noted the difficulty of moving forward immediately after the workshop:

> *I think that my cooperating teacher and I were having a hard time at the beginning thinking about what it meant to incorporate computational thinking into a lesson, I think we were just overthinking it. We were just unsure of where to start, even after we had been to the intro meeting and gone through that meeting, We were just so confused (PST 4, Interview transcript).*

Three other PSTs reported feeling similarly, saying that having more examples of lessons that integrated CT would have been helpful. The RPP team had planned to connect with PSTs after the initial meeting to build on the introduction of CT and support the integration process but faced scheduling conflicts due to the work expectations of the credentialing program (e.g. classes, student teaching and completing credentialing tasks).

Notably, even though the RPP had a vision for providing inclusive CT learning opportunities for all students – particularly for multilingual learners – PSTs did not attend to providing those opportunities in the same depth they thought about CT integration. During interviews, PSTs were asked what English Language Development (ELD) strategies they integrated into their lesson plan and they provided examples like using visual representations or aids as well as examples of shapes or directions. One PST shared, "I went around and talked with students about shapes. Talking with their groups and peers just helps them be able to engage with the vocab." Given the focus of the RPP on providing language opportunities for multilingual students in the CT learning context, we expected to see more evidence of planning for rich opportunities to engage in talk.

Claim: PSTs 'experiences increased their understanding of certain aspects of CT and coherent instruction, and shaped self-efficacy beliefs about CT instruction

Beyond examining how the supports organized by the RPP supported (or not) PSTs' capacity to engage in CT design work, we also saw patterns indicating the sort of knowledge the PSTs acquired and how their experiences shaped beliefs about CT instruction. Five of the six PSTs reported not knowing much about CT and what integration would look like, saying "*I couldn't explain this to anyone*" (PST 3, Pre survey). By looking at participants' engagement with the RPP structures and supports, we can trace PSTs development of understanding as they moved from the periphery of a community more towards the center. We argue that PSTs (1) demonstrated an increase in understanding of CT instruction, (2) developed beliefs around the feasibility of CT integration, and (3) began to grasp the concept of coherence.

Developing a definition of CT and knowledge about CT integration

The pre-survey responses served to document PSTs' baseline knowledge of CT integration. One question asked what experience they had with CS or CT with one PST reporting a dearth of experience in working with CS:

> *Not very much! I took a digital media course in my undergrad and learned a bit about binary and such, but my knowledge about CS is fairly limited overall. I have taken about 3 statistics courses, two in my undergrad at [redacted] and feel rather comfortable with stats (PST 2, Pre-survey).*

This was a characteristic response across five of the six participants. In response to the pre-survey question asking what it would look like to have students use and learn about computational thinking in the classroom, one PST shared, "*My best guess is working with data/computers/potentially coding*" (PST 2, Pre-survey), which demonstrates a general idea about what CT integration and instruction might look like without any specific grounding knowledge about CT. We argue that PSTs' ability to design and enact a lesson by the end of the program shows the movement within a community of practice as well as increased understanding of CT.

By the end of their participation, all PSTs articulated a working definition of CT and aspects of CT, which they had developed as they moved through supports organized by the RPP. One PST defined CT as:

> *The ways that people of any age are able to think about the technical parts and steps of any sort of task or activity. Just the ways that we think in strategic, step-by-step ways. It's not just computer science thinking, but it's any way that people engage in thoughtful thinking (PST 2, Interview transcript).*

This particular definition describes the algorithmic aspect of computational thinking. It demonstrates the development of a conceptual understanding of CT that was missing in PSTs' pre-survey responses.

Even though PSTs articulated accurate definitions of CT and successfully planned and taught a CT lesson which demonstrates an understanding of CT, one PST expressed that the most challenging part was making sure the CT was apparent and clear to students. They said, "*I think the computational thinking could have come across as more of a language scaffold so I think I need to make sure to include the computational thinking in a way that's purposeful*" (PST 4, Interview transcript). This response demonstrates areas where PST thinking and understanding of CT integration may need to be supported more throughout the RPPs' program of supports.

Developing PSTs' self-efficacy beliefs about CT instruction

At the end of their participation, all six PSTs expressed a desire to implement CT into their future classrooms, citing their beliefs that CT integration is important for their students. This following response was characteristic of the other PSTs beliefs about the integration of CT into their future classrooms:

> *I think that it's definitely doable and worthwhile to do. I think it's fun to get students to think in these kinds of ways and to see their abilities to try new things. And just knowing that [CT] happens naturally in so many ways (PST 2, Interview transcript).*

In this response, the PST says that CT is happening "naturally in so many ways" which is characteristic of how CT was discussed in the initial workshop. Flowing from PSTs understanding of aspects of CT and a recognition of the ways that they may already be teaching CT, PSTs' developed beliefs about their own ability to implement CT in their future classrooms. This PST noted the importance of CT to students' futures:

> *I would be really excited to implement CT into my future classroom. I think that it's really important, especially for minorities like women and people of color to have these skill sets and to help them get ahead in life. Especially when it's so male dominated (PST 6, Interview transcript).*

This response not only reflects the PSTs' belief in the importance of teaching CT to younger students but the feeling of excitement illuminates the "mastery" experience this PST had in teaching a CT lesson, increasing their sense of efficacy (Bandura, 1994). Research on self-efficacy points to a link between self-efficacy and classroom practice (Washburn, 2006 cited in Téllez & Manthey, 2015), therefore the expressed feelings of self-efficacy are a positive outcome of the RPP structure. Given the evidence that experiences can shape beliefs (Pajares, 1992), the development of PSTs' efficacy beliefs about CT instruction highlight how supporting structures in the RPP mediate PSTs' learning and experiences within structured co-design work.

PSTs develop a basic understanding of coherence in curriculum

In addition to developing a definition of CT and increased feelings of self-efficacy, PSTs also developed a basic understanding of the importance of teaching CT coherently. One PST said that CT instruction should happen over time, across different content areas, so that it can "*build up to a project at the end of the year*" (PST 6, Interview transcript). Another PST equated teaching CT to painting, saying, "*you would start always on the back layer, and then you would work your way up creating the frontal layers*" (PST 5, Interview transcript). The other PSTs had similar responses, articulating that CT is built over time. While all PSTs articulated that CT should not be taught in just one lesson and needs to develop over time, PSTs did not specifically talk about the slow increase in complexity of concepts nor the ability to develop more complex models (Fortus & Krajcik, 2012).

Discussion and conclusion

This study examined the efforts of a RPP to overcome challenges in providing all students with CT instruction, namely a lack of CT curriculum and teachers underprepared to facilitate CT instruction, and offers promising evidence for approaches that can begin to attend to these challenges. Specifically, this study provides evidence for how PSTs can be included in RPP work focused on CT instruction and support the aims of RPPs. Notably, our study showed how working with PSTs can provide a RPP with additional capacity and maneuverability – particularly when in-service teachers lack the time and space to participate fully – and also allow for the development and refinement of approaches that may support all teachers in designing CT instruction. This systems-level thinking and unorthodox arrangement of a RPP's resources echoes calls for 'infrastructuring' (Penuel, 2019), or the redesigning of existing elements within an educational system into new forms that can better support ambitious educational initiatives.

The approaches to support PST learning in CT highlighted in this study serve as a response to calls to redesign how PSTs learn CT (Yadav et al., 2017). Unlike past approaches in teacher education which present CT in a module-like manner largely separated from practice (Yadav et al., 2015), this study provides a tangible program centered on developing PSTs' capacity for engaging in authentic complex CT lesson design and implementation over time. The results corroborate the history of research examining teachers' pedagogical design capacity (Brown, 2009); however, the examination of PSTs' learning of not just CT ideas but design principles for CT instruction is new. In particular, this study builds on previous work in science on the topic of curricular coherence (Fortus & Krajcik, 2012), and shows how PSTs can fruitfully engage with this principle within the context of CT integration (though new additional supports are needed). Aligning with previous work on teachers' beliefs around CT integration (Love et al., 2022), this study also offers evidence that the supports PSTs engaged in to integrate CT led to positive outcomes not only in terms of their learning but their beliefs' and self-efficacy about CT integration.

The co-design features of this study were crucial for PSTs in developing their design capacity for CT integration. Co-design between teachers and other experts like researchers has recognized benefits for in-service teacher learning and building the capacity of educational systems to implement reforms (Severance et al., 2016). This study strongly indicates that a well-scoped co-design approach can provide a rich professional learning experience for PSTs in the area of CT and CS instruction. Future research on how best to engage PSTs in design work in ways that does not prove too time-consuming would prove beneficial. PSTs engagement in intensive design activity, such as co-design, proved somewhat burdensome and reflects a larger pattern. While in-service teachers had virtually no chance of participating in the RPP activities completed by PSTs, the competing demands and responsibilities on PSTs from their routine program coursework and student teaching was substantial.

This study shows that tangible design supports are likely needed to support design work around equity in terms of CT (Google/Gallup, 2016). We surmise that the RPP's heavy focus on CT integration may have overshadowed the importance of designing for language development, resulting in PSTs focusing more intently on CT integration than a pressing issue of equity for multilingual learners. Bringing language learning and opportunities for meaningful engagement with language front and center to the design space and principles would prove an important step moving forward to ensure that lessons are designed with more intentional focus on the language opportunities students engage in.

The goal of the RPP was to test certain supports and structures providing guidance for future work with specific attention to areas of the RPP that can be strengthened. We encourage other RPPs with visions of CT or CS instruction similar to the RPP here to engage in similar explorations, particularly with regard for the scaling up to support a larger group of teachers or PSTs in learning about CT integration. Such efforts will provide additional evidence for approaches that can move RPPs closer to having a robust community of teachers capable of creating meaningful CT and CS learning opportunities for all students.

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Vector Addition in Stories: Exploring Knowledge Application After a Concreteness Fading Intervention

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Abstract: Concreteness fading, as an instructional approach, can enable students to develop grounded understandings of new concepts, yet the effects of a concreteness fading intervention have been rarely researched. In this study, we designed a concreteness fading intervention to teach middle schoolers vector addition and added an extra task to allow students to demonstrate their understanding through a storytelling activity. As a result, we discovered that students could develop some understanding of the topic. The stories they created served as a medium to provide them with a context to apply their newly gained knowledge.

Introduction

Among all the secondary-level mathematics topics, vector addition is a challenging but essential mathematical skill because of its vital role in postsecondary STEM education. Current secondary mathematics educators, however, often rely on formal notations in their classroom, which is criticized as "formalism first" (Nathan, 2012). Supposing students' understanding goes beyond those symbols of vector arithmetic during their middle or high school math class, they will likely have fewer difficulties with college-level vector arithmetic (see Knight, 1995). Therefore, developing an intervention that empowers students to gain a deep understanding of vector addition that they can demonstrate to the instructor is critical to secondary-level vector addition teaching and learning. In this study, we designed an intervention by incorporating an instructional approach, concreteness fading, and added an extra task in which students apply their newly gained knowledge to construct artifacts. By paying particular attention to the extra task, this study aims to examine how students demonstrate their knowledge gained from a concreteness fading intervention and contribute to the concreteness fading literature.

This study has a potential contribution to the domain of vector addition learning, both theoretically and practically. The potential theoretical contribution is that we explored a new way to examine how students can demonstrate their mathematical understanding gained from a concreteness fading intervention, which has not been studies before. As for the potential practical contribution, this study depicts a new approach to teaching vector addition and understanding students' vector addition learning for secondary mathematics educators.

Theoretical framework

When introducing vector addition to students, this topic can be complex for them to start since it is highly conceptual and inaccessible in their daily lives. Bruner (1966) proposes three stages –enactive, iconic, and symbolic–for learners to perceive new concepts. Inspired by these three stages, there is an instructional approach called concreteness fading (CF) that refers to a learning process in which students start learning a new concept or skill with concrete learning materials related to their previous knowledge, and gradually transition to abstract learning materials (Fyfe et al., 2014). In a CF intervention, students will first encounter something they are familiar with. Then the same learning content will be presented to them with its concreteness level gradually fading. When they are familiar enough with different forms of the notion, formal notations can be introduced without making them feel intimidated. With a learning process that gradually fades concreteness, students can develop their understanding in the intervention. A CF intervention can strengthen the advantages and avoid the disadvantages of both concrete and abstract learning (Fyfe & Nathan, 2019). As no previous studies researched how to implement CF to teach vector addition, it can be promising to implement a CF intervention to teach vector addition.

Since previous CF studies seldom examine the knowledge application after a CF intervention and the assessment of learning from a CF intervention often replies on a worksheet with formal questions (e.g., the knowledge assessment questionnaire in Jaakkola & Veermans, 2018), we believe an activity that incorporates constructionism can be promising because it allows students to demonstrate their grounded understanding in a personally meaningful way. Constructionism, proposed by Papert (1980), is a learning theory that states deep learning emerges when students explore and play with ideas by creating personal self-driven projects in which students make their own object-to-think-with (Ackermann, 2001), a physical representation of their understanding of the learned content. When designing a constructionist learning activity, the learning environment should ensure that learners can start with something easy (low-floor) , have space for them to increase the complexity of their construction (high-ceiling), and support their building of various types of projects that fit their interests and learning types (wide-walls) (Resnick et al., 2009). Therefore, by combining "concreteness fading" and constructionism, our research question is how students demonstrate their understanding of vector addition from a CF intervention in a constructionist story creation activity.

Methods

Participants

This study had nine 8th graders from a charter school in a large Midwestern city in the U.S. The participants had learned the coordinate plane in 7th grade and never learned vectors in math class. They were evenly divided into three random groups to participate in this study.

Study design

The participants formed a group of three to complete three CF learning tasks (see Table 1). First, the task Enactive Physicality provided participants with cardboard tiles and a football to experience vector addition through physical activities (see Figure 1). Next, the same problem was presented in the task Iconic Depiction through a football simulation game (see Figure 2). Finally, in the task Abstract Representation, participants had similar problems on a worksheet (see Figure 3).

Table 1

CF Learning Tasks

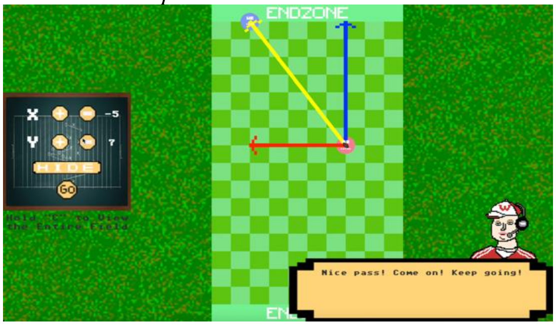
Task	Activity	Duration
Enactive Physicality	The participants tiled the floor with light and dark green cardboard tiles and randomly selected two tile's vertices to stand on and figure out a way to describe their position. Then they played a game in which they passed a football to experience informal vector addition.	20 mins
Iconic Depiction	The participants played a video game built on similar concepts that introduced some formal representations, such as axis and unit vectors.	20 mins
Abstract Representation	The participants worked on a question sheet with similar settings and more formal notation and symbols.	20 mins

Figure 1

Task Enactive Physicality

Figure 2

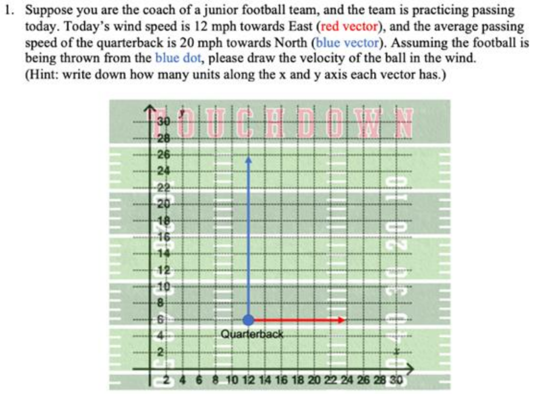
Task Iconic Depiction



Hold "C" to View the Entire Field

Nice pass! Come on! Keep going!

Figure 3
Task Abstract Representation



1. Suppose you are the coach of a junior football team, and the team is practicing passing today. Today's wind speed is 12 mph towards East (red vector), and the average passing speed of the quarterback is 20 mph towards North (blue vector). Assuming the football is being thrown from the blue dot, please draw the velocity of the ball in the wind. (Hint: write down how many units along the x and y axis each vector has.)

After the CF learning tasks, there was an extra 30-minute "constructionist problem design" (CPD), in which participants built a story together to demonstrate what they learned today. We designed the learning activity following the constructionist design principles of "low-floor," "high-ceiling," and "wide-walls." The participants were asked to start with any rough ideas by considering one of the learning objectives in the conceptual story design sheet we provided (see Table 2) and use the materials–crafting sticks, IKEA artist's figures, color markers, and blank paper–we provided to build up their story. This fit the idea of creating a "low-floor" for the participants because they could start designing their story with any ideas in mind. When the participants first made up a story and built it with materials, we asked some prompt questions (e.g., how to describe the positions of your characters?) to enable them to iterate their story by adding more mathematical concepts (high-ceiling). Here, we are constrained by the study time that the task had to be finished within 30 minutes. Catering to that, we designed five contexts for them to choose from, and engage them with freestyle storytelling (wide-walls). By providing predefined contexts, the participants could start their story constructing quickly rather than spending time figuring out a context for their story. After they completed their iterative story building, the researcher asked every participant to retell the story and inform what kind of mathematical concepts they added into their story.

Table 2
Conceptual Design Tool

Item	Option	
Learning objectives	a.	How to describe the movement (resultant) in terms of x and y?
	b.	What are the most important things about vectors?
	c.	(We can describe any location in space using a coordinate system.) What does your friend need to know about the coordinate system?
Contexts	a.	Robotics
	b.	Fashion
	c.	Bicycling
	d.	Soccer
	e.	Basketball

Data collection and analysis

Three two-hour study sessions were conducted from February to March 2022 after regular school hours. For each study session, we obtained consent from the participants' parents and the participants themselves before the study. Then we followed the procedure mentioned above to let participants work on the CF learning tasks. Before the CPD task, they had a 10-minute break. After the break, they were provided materials and worked on the CPD task together. During the study session, video cameras and audio recorders were used to capture the video and audio data produced by the participants.

After the data was collected, audio tracks were transcribed. In this study, we concentrated on the addition task–CPD. We conducted a qualitative analysis of all the transcripts of the CPD task. By applying a bottom-up method, we first reviewed the videos and selected clips that included conversations related to this task. Then, we did a round of open coding, identified codes with similar themes, and categorized our open codes into more focused codes. The below coding scheme (see Table 3) was then developed and used to recode the data. The unit of our analysis was the entire group, who built up their artifact together. To ensure the validity of our analysis, two researchers with an educational research background coded the same set of data separately, and the coding results were cross-validated.

Table 3
Coding Scheme

Codes	Definition	Example
Link to Prev. Activity	The participant mentions an activity or an element from the previous CF tasks.	P3: And we can use the sticks, like **make the tiles again**.
Link Context to Math	The participant says something that contains explicit mathematical terms or concepts.	P1: Looks more **like an exponential function**.
Coordinates-related	The participant says something related to coordinates or the coordinate plane.	P3: We should place him at **the origin** and then we'll say like something like **five, seven (5,7).**
Vec Components	The participant says something related to distance and directionality	P1: Mane's vector is **five x plus seven y**. And Salah's vector is **zero x and**…
Vec Addition	The participant says something related to vector addition either explicitly (e.g., 5x plus 6y) or implicitly (e.g., eight units along that direction).	P1: You were standing here and then your vectors, like four X plus seven Y. You're not going to do like four X, seven Y. You're going to **start from this position and move four times horizontally and seven Y vertically**.
Link to Sports	The participant says something that includes sports elements, such as teams, athletes, scores without mathematical context.	P1: Let's do **Liverpool vs. Arsenal**.
Contextual Explanation	The participant attempts to use something specific in the context to explain a mathematical concept.	P2: We are basically using distance. So, we have to **measure how far and how soft or hard he has to throw the ball for P3, so he's able to catch it and shoot the ball in**. So, he has to throw the ball over his head so that P3 can catch it.

Results

We segmented the transcripts by identifying the end of a meaningful conversation and coded 23, 22, and 15 excerpts for three study sessions (Group 0218, Group 0222, and Group 0325). All the groups picked learning objective *a. How to describe the movement (resultant) in terms of x and y?* as the learning objective of their story. The below table (Table 4) shows the counts of each code in every group. In addition, two groups (0222 and 0325) selected basketball as their context, and one group (0218) chose soccer. One of the stories (Group 0218) is like this:

> P1: So this is Mane and this is Salah. This guy passes ball to this guy and then this guy kicks it and then they hit P2's head.
> P1: And then this guy, and then these two are Liverpool. And then P2 is the goalkeeper of Man United. And then like this guy made a vector. It was five x plus seven y.
> P1: And this guy he scored it. He gets...
> P3: 4, 14?
> P1: The vector was like eight blocks and then P2's position was 4,14. And Mane's position is...
> P3: 6,7.

Table 4
Code Counts

	Link to Prev. Activity	**Link Context to Math**	**Coordinates-related**	**Vec Components**	**Vec Addition**	**Link to Sports**	**Contextual Explanation**	**Total**
Group 0218	2 (4.3%)	13 (28.3%)	6 (13.0%)	7 (15.2%)	3 (6.5%)	10 (21.7%)	5 (10.9%)	46

Group 0222	7 (19.4%)	10 (27.8%)	2 (2.8%)	0 (0.0%)	0 (0.0%)	3 (8.3%)	14 (38.9%)	36
Group 0325	5 (11.6%)	12 (27.9%)	11 (25.6%)	4 (9.3%)	0 (0.0%)	0 (0.00%)	11 (25.6%)	43

Group 0218 was the only group that incorporated the concept of vector addition into their story. They drew a grided coordinate plane and placed the figures in two positions on the plane as two soccer players on a soccer field. Then they explained that they had a vector for one player to pass the ball to the other player and the other player had a vector to score a goal. Therefore, at the beginning of their design, a couple of codes–*Link to Prev. Activity*, *Link to Context to Math*, *Coordinates-related*, and *Vec Components*–emerged. There were a lot of *Link to Sports* coded when the participants enriched their story by adding more details. At the end of this activity, they had several codes of *Vec Addition* when they explained how a character in the story kicked a ball from its position to another position on the coordinate plane by adding a new vector to the current position of that character. The below excerpt shows how they embrace their understanding of vector addition in their story.

> **0218P1**: You were standing here and then your vectors, like four X plus seven Y. You're not going to do like four X, seven Y. You're going to start from this position and move four times horizontally and seven Y vertically, like seven.

Group 0222's story was different from group 0218's. They barely used the mathematical language in their story. Their story had a scenario in which a figure represented Kobe Bryant, and another figure was one of the participants. In their story, Kobe passed to the participant, and the participant shot a game-winning three-pointer. The dominating code in their transcript was *Contextual Explanation*. The participants knew that reaching another position relies on appropriate angle and distance, but they relied on the context in their story to elucidate their understanding. The below excerpt is a good example.

> **0222P3:** Oh, the distance. Since it's five to eight meters, he's gonna have to throw it really, really, really hard and really, really with the amount of power. So it can get to me. Because if he doesn't, if he throws you a light, it's not gonna get to where he needs it to go. If he throws it to really, really hard, then it's gonna go out of bounds. He has to throw it with medium strength, so it can get to me because it's like five to eight meters and a little bit more than this.

Although a couple of *Link Context to Math* codes were from the conversations of the participants in Group 0222, they referred to mathematical concepts for adding numerical details to their story, such as counting the sticks placed between two figures and stating the distance was 11 inches. They also made connections to previous tasks when constructing the story, as the below except shows, to make their story similar to the physical activity they had done.

> **0222P2**: So like when we did the tiles, he had to measure the distance and how far it was and the way that we are facing. Kobe had to pass the ball to him. So he had to throw it, he had to know how far he had to throw it for P3 to be able to catch the ball and stuff like that.

Group 0325's basketball story differed from the previous groups'. Their two-part story had a lot of *Coordinates-related* codes that densify their use of coordinates in the story. For instance, in the below excerpt, they were able to embed the coordinate plane and units on the coordinate plane well in their story.

> **0325P3**: So Brad and Bob are trying to play basketball at the park, but there is trafficking in the way. Brad has to throw the ball 10 units, 10 units on the coordinate plane.

Their use of *Vec Components* is restricted to a single way of describing the distance along a direction. For example, the below excerpt illustrates that P2 knows that the movement along a direction on the coordinate plane relies on the units along that direction, but she needs the story context to help her explain this idea.

> **0325P2:** They're playing basketball. Bob jumping up to dunk on Brad. So it shows how far he has to go. Like the distance, how many units he has to go to reach the basket to dunk.

Discussion

The story the participants created revealed that they had different understandings of how to describe movement in terms of x and y on a coordinate plane. All the groups drew a grid coordinate plane which they were familiar with and had been exposed to in the previous CF tasks. They also placed the figures on the coordinate plane like what they had done physically in the first task *Enactive Physicality* and had seen in the second task *Iconic Depiction*, but Group 0222 did not include coordinates for their figures in their final story because they focused more on the plot of their story and simply ignored this part. Utilizing a coordinate plane to describe positions is the first thing they learned from the CF intervention. Some may argue that they have learned the coordinate plane in their 7th-grade math class, but facing such an open design task, using the coordinate plane to describe positions is more likely from the intervention as all three groups made connections to previous CF tasks in the process of their story creation.

Vector addition with formal notations seems hard to all the groups. Group 0218 seemed more comfortable with vector-related mathematical vocabulary, so they used vector components to describe the ball-passing distance between the figures on their coordinate plane. Although they did not explicitly state that adding a vector to a point could get to another position, what they embedded in the story indicated they knew this addition would work. On the other hand, Group 0222 and Group 0325's understanding was not apparent. Group 0222 focused on the story's details and showed their understanding of reaching another position on a coordinate plane through their rich story details about how to pass the ball with the right strength and angle. They used a lot of general mathematical terms, such as five to eight meters or six squares, but they did not show the clear idea of the effect of traveling a distance along a direction. Group 0318 had a similar story but differed because they concentrated on using units on their coordinate plane to describe the distance. They also pointed out that they needed a distance of several units along a direction to pass the ball to the other figure, demonstrating they understood the vector's directionality. Thus, on the one hand, the physical activity in the first CF task Enactive Physicality impressed the participants most and made all three groups create a story of passing a ball. On the other hand, although the third CF task Abstract Representation was temporally closest to the CPD task, there might be too many unfamiliar symbols, so the formal notation of vector was not in any of their stories.

Another point worth noting is the affordance of the story they designed. Unlike the context of a word problem, the contexts in their stories are crucial to their mathematical understanding demonstration. As mentioned above, Group 0222 rarely used mathematical language to tell their story, but the contextual explanation in their story revealed how they understood the ball passing between two players (with the right strength and angle) and reflected what they had experienced in the previous activities (football passing on the tiles and in the simulation game). Although Group 0218's story manifests that they know the effect of adding a vector to a certain point on the coordinate plane, they still enjoyed the story creation process by adding real soccer players and real soccer game details to their story. Group 0325 had two very similar parts in their story. Both parts included passing a ball to a target with certain units on the coordinate plane, showing they qualitatively understand how vector addition works. Thus, in such a constructionist activity, the story context allows them to start with something they are familiar with and interested in and then iterate the story by adding mathematical ideas.

There are also limitations in this study. First, due to the time limit of the entire study session, the participants had to use one of the predefined contexts to build up their story. For more personally meaningful story creation, future studies should consider allowing students to choose their own contexts to increase their engagement level during story creation. Second, the facilitator should have more prompt questions to encourage participants to use more mathematical language to build their stories. For example, when group 0222 said Kobe needed the right height and speed to pass the ball, the facilitator could ask a follow-up question–could you use x and y to describe the right height and speed? By asking follow-up questions, students will likely involve more mathematical language in their stories and present their mathematical thoughts in a more straightforward way. Third, it is worth exploring how exactly the process of concreteness fading influences the participant’s story-making and storytelling. This study primarily examines the understanding of vector addition from students’ storytelling and does not explore how the progressive vector addition learning–from physical activities to abstract mathematical symbols contributes to the following story-making. Future studies may further investigate the relationship between the concreteness fading intervention and the constructionist storytelling.

Concluding from our findings, the theoretical contribution of this study resides in the creation of an approach to examine the potential knowledge gained from a CF intervention. 1) This study incorporates an innovative story-creation activity that encompasses constructionism to assess learning from a CF intervention. Previous CF studies only include two or three stages (Suh et al., 2020), and most of those studies rely on a worksheet with symbolic questions and statistical tests between the pretest and posttest to assess the knowledge development from a CF intervention (e.g., Jaakkola & Veermans, 2020). 2) Our qualitative analysis supports a better understanding of the learning process through students’ iterative story creation instead of examining the learning outcome from a knowledge test. 3) While constructionism is often used as a theoretical framework to design a learning activity, our study shows constructionism could be used in learning assessment as well. From a practical perspective, a constructionist story creation activity establishes a safe and comfortable environment in which students are able to demonstrate their learning with the-object-to-think-with. Compared to using a worksheet to measure the learning outcome, implementing a design activity is likely to create a more engaging and authentic learning assessment process.

Conclusion

In this study, we added an extra task to a traditional three-stage CF intervention that teaches vector addition. The additional task incorporates constructionism and assesses students' learning from the CF intervention. By scrutinizing the stories students created, we discover that students still have difficulty with formal mathematical notations even after a thorough CF intervention, but they can embed the mathematical concepts that they are familiar with deeply into their story. In addition, the story creation activity enables them to use their own knowledge to show what they gained from previous activities. Future studies can also consider adding an extra part to a typical CF intervention for learners to exhibit their learning.

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Gestural Replays Support Mathematical Reasoning by Simulating Geometric Transformations

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Abstract: Actions relevant to conceptual ideas can promote thinking and learning, whether *internally generated* when spontaneously produced by learners (i.e., gestures), or *externally generated* when prompted to perform directed actions. Few studies have explored how prompting students to predict their future actions influences their thinking. This study compared the effects of internally generated predicted actions versus externally generated directed actions on undergraduate students' (N = 67) geometry proof performance. We investigated the role of *gestural replays* as physical re-enactments of one's prior actions involved in mathematical transformations. Gestural replays provide evidence of mental simulation processes of past actions. Quantitative models revealed significant benefits of gestural replays that depict students' prior mathematical transformations on proof performance, which extended to both externally generated directed actions and internally generated predicted actions. Qualitative analysis further illustrates ways gestural replays support embodied simulations that can bridge concrete actions and generalizations needed for mathematically valid proofs.

Introduction

Theories of grounded and embodied cognition (GEC) propose that cognitive processes are rooted in perceptual and motor systems (Wilson, 2002). One way mathematical ideas are grounded and embodied is through gestures. Teachers and students spontaneously use hand gestures to formulate their thoughts (Alibali & Nathan, 2012) and express their current and emerging understanding (Church & Goldin-Meadow, 1986). Gesture production generates new ideas (Novack & Goldin-Meadow, 2015), creates cohesion (Walkington et al., 2014), and promotes learning for a range of mathematical ideas (Goldin-Meadow et al., 2001; Smith, 2018).

Another line of evidence in support of GEC comes from studies showing that physical movements can be used intentionally to influence learning (Nathan, 2017). For example, students directed to move their eyes or arms (i.e., directed actions) in patterns that are compatible with the strategy for solving insight problems were more successful at generating correct solutions (Thomas & Lleras, 2007). Moreover, directing students to perform specific bodily actions tied to conceptual ideas but unrelated to a specific solution strategy can also facilitate the learning of abstract concepts in statistics (Zhang et al., 2021). However, Walkington and colleagues (2022) found that relevant directed actions by themselves did not directly improve high school students' (n=85) mathematical proof performance. Only when students' explanations included gestures of previous directed actions did the relevance of those actions become beneficial. These mixed results raise an important question: **How do *specific* body-based processes influence *specific* mathematical reasoning**?

We explore this question in the context of geometry proof, where participants were asked to either *perform* directed actions or *predict* actions that simulate geometric transformations as they reason about universal claims regarding the nature of space and shape. This study investigates the effect on proofs of students' spontaneous *gestural replays* -- physical re-enactments made during their explanations of one's prior actions of mathematical transformations (Beilock & Goldin-Meadow, 2010; Walkington et al., 2022). We report quantitative and qualitative analyses that examine the role of gestural replays and illustrate the ways that gestural replays can support participants' geometric reasoning and broader aspects of mathematical cognition.

Theoretical framework

Assumptions about cognitive processes

This work builds upon some assumptions about cognitive processes. First, cognitive processes operate within a predictive architecture. Rather than passively waiting for input to think, people continually anticipate what is to come in streams of sensory input and are poised to proactively respond (Clark, 2015). This predictive stance orients people to engage in sensorimotor simulations that project how one's behaviors will change the world and how the world will change in response to these behaviors.

Second, cognition is grounded and embodied. Barsalou (2008) proposed that meaning derives from perceptual and motor experiences from interactions with the world. This model also holds for *offline cognition,* when task-relevant inputs and outputs are no longer physically present (Barsalou, 2008; Wilson, 2002). Many of these cognitive tasks are accomplished through mental *simulations* of actions. For example, in language comprehension, reading action words (e.g., *kick*) activates neural pathways of the relevant sensorimotor systems (e.g., leg); readers automatically simulate these actions stated in words and ground arbitrary symbols and sounds to their cultural meaning (Glenberg & Gallese, 2012). Similarly, during mathematical reasoning, many mathematical concepts and symbolic systems of notation gain meaning by being grounded in perceptual systems and actions, including gestures and movement (Abrahamson & Sánchez-García, 2016; Alibali & Nathan, 2012).

Gestures as simulated actions for fostering mathematical reasoning

Spontaneous gestures have been shown to predict conceptual reasoning and learning by contributing to different types of mathematical reasoning (e.g., Cook & Goldin-Meadow, 2006; Ottmar & Landy, 2017; Smith et al., 2014). For example, children encouraged to gesture while explaining their solutions to mathematics equivalence problems were more likely to express new and correct problem-solving strategies compared to those told not to gesture and those told to explain their solutions with no mention of gestures (Broaders et al., 2007). Restricting gestures impairs model-based inference-making but not fact retrieval (Nathan & Martinez, 2015).

Some gestures arise from mental simulations of actions or perceptual states (Hostetter & Alibali, 2008). As simulated actions, gestures can highlight the spatial-temporal information from actions (Beilock & Goldin-Meadow, 2010) and help schematize relevant information to facilitate encoding (e.g., So et al., 2014) and generalization (e.g., Novack et al., 2014) of cognitive processes. Specifically, *dynamic depictive gesture*s (Garcia & Infante, 2012) enact spatial-temporal transformations of mathematical entities. For example, merely tracing a triangle highlights its static properties, whereas a dynamic depictive gesture can portray the invariance of the sum of its interior angles by re-scaling (transforming) its size, thus supporting generalization and abstraction. By simulating geometric objects and transformations, dynamic depictive gesture production predicts the formation of generalized mathematical proofs (e.g., Nathan et al., 2021; Pier et al., 2019).

Directed actions affect gesture production and non-verbal cognition

While people's movements can reveal their thinking, directing them to perform directed actions as part of an intervention also affects thinking and learning. Some studies have shown that directed actions from earlier training leave a legacy in gesture production in subsequent performance (Donovan et al., 2014). Cook and Goldin-Meadow (2006) found that children were more likely to produce gestures when given instructions that included actions about a solution strategy. Moreover, children's gestures were "picking up on, and reproducing, the content of the instructor's gesture" (p. 217). Performing gestures, in turn, led to better problem-solving performance on a post-test compared to children who expressed a solution strategy in speech only.

When relevant to conceptual ideas, performing directed actions, even without conscious awareness of their relevance, can facilitate learners' performance (e.g., Thomas & Lleras, 2007; Zhang et al., 2021). For example, Nathan and colleagues (2014) experimentally investigated the influence of performing directed actions on undergraduate students' proof performances. All participants were directed to perform either *task-relevant* actions or *task-irrelevant* actions prior to tasks. Task-relevant actions embodied the conceptual relations that underlay the proof tasks, while task-irrelevant actions were matched using the same number of steps and touch points but did not embody the same conceptual relations. Participants who performed task-relevant actions were more likely to generate correct intuitions (i.e., snap judgments) and key mathematical insights for subsequent tasks than those who performed task-irrelevant actions. This finding suggests that relevant directed actions facilitate intuitive and nonverbal processes. However, performing directed actions alone was ineffective for generating valid proofs that required students to consciously describe their chain of reasoning.

Gestural replays moderate cognitive relevance of directed actions

Walkington and colleagues (2022) also examined the influence of performing relevant directed actions on geometric reasoning in the context of an embodied video game that tracked high school students' movements. They observed that some of the explanatory gestures made by players were actually "replays" of the directed actions that were elicited during game play. These replays could be exact copies -- as when players' crossed arms matched the crossed arm movements they performed in the game -- or recreations of the same relations using different body parts, such as crossed hands or fingers. The investigators found that although performing relevant directed actions did not *directly* cause learners to produce more gestures or improve their performances, participants who produced gesture replays of previous cognitively relevant actions during their explanations showed significantly better insight and higher proof performance. Moreover, this effect was most consistent for insight and proof when those replays were dynamic depictive gestures. These findings suggest that the presence of gestural replays derived from relevant directed actions *moderated* the effect of those actions on proof performance. These gestural replays appeared to support embodied simulation by bridging the concrete actions performed in gameplay to the generalized reasoning used to establish mathematically valid geometry proofs. Walkington and colleagues concluded “that engaging in these ‘gestural replays’ of their actions during explanations--even when those replays were not identical recreations of the original actions--changed participants’ encoding for the mathematical principles of the task and subsequent task performance” (p.27).

Research question

In prior research (Xia et al., 2022), we found that prompting participants to predict possible actions for geometry conjectures produced a marginally significant effect on the generation of valid proofs (Cohen’s *d* = .25, p = 0.07) compared to actually performing the relevant directed actions. Moreover, neither condition led to more gestures, suggesting that gesture is not a mediator. We and others (e.g., Walkington et al., 2022) also observed the prevalence of gestural replays during students’ explanations. In light of these findings, we revisit the data post hoc to investigate: **How do specific body-based processes influence specific mathematical reasoning**? We hypothesize that gestural replays of directed or predicted actions made during students’ explanations provide a bridge between these actions and generalized mathematical reasoning that can enhance proof performance. We explore this hypothesis using both quantitative and qualitative analyses.

Methods

Participants & procedure

Participants were undergraduate students from a large university in the Midwestern US who participated in a 2X2 design comparing Directed Action Yes (DA) or No (DA') and Predicted Action Yes (PA) or No (PA'). For this secondary analysis, we focus on the two diagonal cells: DA+PA' (directed actions without predicted actions; n = 30) and DA'+PA (predicted actions without directed actions; n = 37) because it would be impossible to tell the source of the gestural replays in the DA+PA group, and there are no replays in the DA'+PA' group.

All participants were prompted to individually read each of the eight geometry conjectures, statements that are false or always true, with order varied by a Latin Square. DA+PA' participants were directed to mimic relevant actions comprised of a sequence of three animated poses without any prompt to make predictions (see an example in Figure 1). DA'+PA participants saw no directed actions and were prompted to predict the pose sequence for each conjecture (see an example in Figure 2). Participants completed each conjecture task by judging the conjecture's veracity (i.e., false or always true) and providing a verbal justification. Finally, each participant was asked to complete surveys about demographics, math history, and spatial skills.

Coding

Proof validity

Video recordings of participants’ explanations for each conjecture were transcribed and coded (0/1) for mathematically valid proofs (reliability κ = .96) based on Harel and Sowder’s (2005) characteristics of valid deductive proofs that must be simultaneously logical, operational, and generalizable.

Gestural replays

Spontaneous gestures made during mathematical explanations were first coded as *gestural replays* or not (1/0). Gestural replays were further coded at two levels: (1) exact replays exactly matched the directed (DA) or predicted actions (PA); (2) corresponding replays matched DA or PA to different body parts (e.g., DA crossed arms could match crossed hands in the explanation). Gestural replays coded were further classified as either *non-dynamic* or *dynamic* depictive gestures (0/1), as described earlier. Inter-rater reliability is forthcoming.

Results

Quantitative analysis

We ran mixed-effects logistic regression models (Snijders & Bosker, 2011) to predict participants’ proof performance. Our earlier analyses showed that *dynamic gestural replays*, either of DA or PA, were significantly associated with proof performance; while performing DA or PA did not cause more dynamic gestural replays, suggesting that dynamic gestural replay is not a mediator. Our current analysis explores how gestural replays influence the effects that DA and PA have on proof performance, using a model with an interaction between *dynamic gestural replay* and *experimental condition* (Walkington et al., 2022). *Participant ID* and *conjecture* were included as random effects. *Students' most advanced previous math course* and *spatial thinking* were retained in the model as covariates that significantly reduced the deviance of our model. We report odds ratios that are exponentiated raw coefficients and effect sizes using d-type measures (Chinn, 2000).

$$
\begin{aligned}
&logit(P_{ij}) = \gamma_{00} + \gamma_1 \times (experimental\ condition) + \gamma_2 \times (dynamic\ gestural\ replay) \\
&+ \gamma_3 \times (experimental\ condition) \times (dynamic\ gestural\ replay) + \gamma_4 \times (math\ course) + \\
&\gamma_5 \times (spatial\ thinking) + U_{0j\ participant} + T_{0j\ conjecture} + \boldsymbol{\varepsilon}_{ij}
\end{aligned}
$$

The results show that for DA+PA' trials, making dynamic gestural replays had a significant effect on generating mathematically valid proofs (*OR* = 2.76; *d* = 0.56, *p* = .006). For DA'+PA participants, making dynamic gestural replays also had a significant effect on proof performance (*OR* = 8.59, *d* = 1.19, *p* < .001). In contrast, for trials where students did not produce gestural replays, performing DA or PA was not significantly associated with proof performance. In trials where participants did perform dynamic gestural replays, DA'+PA participants significantly outperformed DA+PA' (*OR* = 3.11, *d* = .63, *p* = .019), even when controlling for math education and spatial ability. Gestural replays appear to strongly influence proof performance.

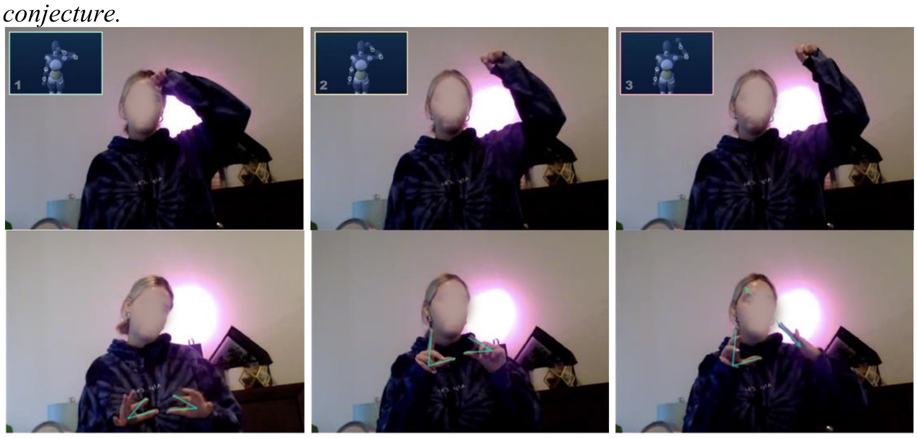
Qualitative analysis

To gain additional insight into how gestural replays might bridge actions to generalized mathematical reasoning, we qualitatively examined two cases. One participant produced gestural replays of directed actions that were *externally generated* (i.e., designed by researchers); the other produced gestural replays of predicted actions that were *internally generated* by the participant.

Case 1: Student's gestural replays from externally generated directed actions

We focus on this student's (S1; Figure 1) reasoning process after they have mimicked the relevant directed actions designed for the conjecture, *In triangle ABC, if Angle A is larger than Angle B, then the side opposite Angle A is longer than the side opposite Angle B*.

Figure 1
(Top Row) *Student performing externally generated directed actions shown in the picture inset.* (Bottom Row) *Student replaying modified versions of directed actions while evaluating the conjecture.*



(a) **(b)** **(c)**

Transcript #1 of S1:

[1] ((*Reading the on screen text*)) In triangle ABC, if Angle A is larger than Angle B, then the opposite side, the side opposite Angle A is longer than the side opposite Angle B, um, ((*performing movements for 27 sec*)), true.
[2] ((*Reading the on screen text*)) Explain why the statement is always true or false.
[3] Because if Angle A is opened up more than Angle B and it's bigger, doesn't even matter what side, then that line opposite would span a longer distance than would the line of Angle B.

Figure 1 (Top Row) includes an inset (upper left corner) that shows how participants were directed to mimic the on-screen avatar by raising their left forearm, bent at the elbow, to open up the angle created by the upper and lower portions of their arm. This sequence of motions was designed to highlight a key relation: as one angle of a triangle opens up, the side opposite the angle necessarily becomes larger.

After performing the directed actions, S1 contemplated aloud "if Angle A is larger than Angle B" (Line 1) while gesturing with the thumb and index finger of her right hand to form Angle A. Next, she compared this angle to a smaller Angle B that she formed using the thumb and index finger of her left hand (Figure 1a; Bottom Row). Juxtapositioning these two angles, the student moved the thumb and index of the right hand to open (increase) and close (decrease) Angle A while gazing at the changing angles. This illustrates a transformation of directed actions by juxtaposing the actions (i.e., angles) that originally occurred sequentially (Nemirovsky & Ferrara, 2009) and changing an angle by expanding and contracting. This process helps the student ascertain that the mathematical conjecture is true.

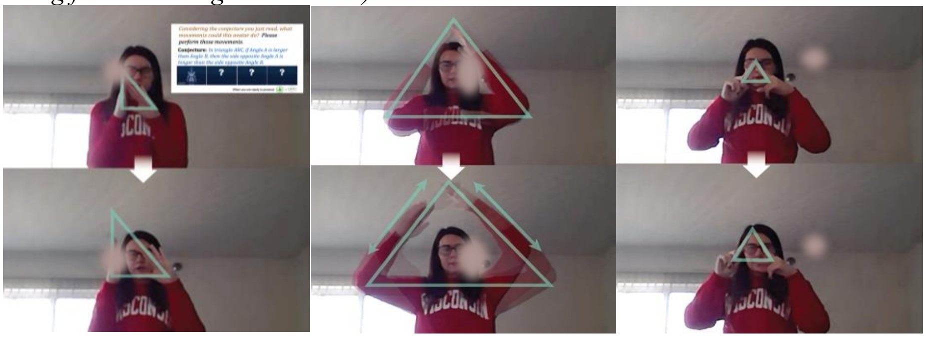
In her follow-up explanation (Line 2), S1 continued to justify that the conjecture is true: "... if Angle A is opened up more than Angle B and it's bigger" while holding the pose of Angle B and moving her right index finger up to make Angle A bigger (Figure 1b). Although the student performed a modified version of the original directed actions (i.e., switching from arms to hands and fingers), her *dynamic depictive gestures* constitute "corresponding gestural replays" that glean the relevant perceptual-motor information from the directed actions, which embody the key mathematical relation. She continued that it "doesn't even matter what side," suggesting that she was generalizing the mathematical relationship between angle size and side length for all triangles -- not just this particular example. In this way, the gestural replay may serve as a bridge between directed actions and generalized reasoning. In a second dynamic depictive gesture (Figure 1c), S1 moved her left hand back and forth to depict a "line opposing" the angle (Line 3), reinforcing that a larger angle always produces a longer opposing side length.

Case 2: Gestural replays from internally generated predicted actions

In this case, S2 read the following conjecture: "*For a triangle that is similar to triangle ABC, the side opposite to angle B must have the same length*" (a false conjecture). Then, S2 was prompted to predict possible actions for the conjecture but given no instructions on what movements to predict (see the inset in Figure 2a). Thus, unlike the DA condition, the movements in the PA condition were internally generated.

Figure 2

*Starting (*top*) and ending (*bottom*) poses of three different sets of predictions using (a) hands, (b) arms, and (c) fingers (with graphic overlays of the geometric objects being formed through movements).*



(a) (b) (c)

When asked to predict a series of movements for the conjecture, the student created a few different options, each building off the previous ones. For the first sequence (Figure 2a, Top), S2 created a triangle with her left palm and the fingers of her right hand. Then (Figure 2a, Bottom), S2 created a second, similar triangle by spreading her hands apart horizontally and using a pointing gesture as she described, "extend[ing] my fingers out" to complete the triangle. For the second set of predicted actions (Figure 2b, Top & Bottom), S2 made a set of similar triangles using her arms and moved both arms outward to make the triangle bigger with the same angles. In her third and final sequence (Figure 2c, Top), S2 used three fingers to first represent a triangle and then (Figure 2c, Bottom) made the triangle sides longer by moving her fingers outward while trying to keep the angles the same. Across all three predicted action sequences (Figure 2a, 2b, 2c), S2 made *dynamic depictive gestures* to demonstrate geometric transformations of geometric objects that explored general properties of triangles. We also noticed S2's representations ultimately refined to smaller body movements (i.e., fingers).

The reasoning also progressed to a generalized proof. After correctly identifying the conjecture as false (Transcript #2, Line 7), S2 explained "because although the angles will stay the same, the side lengths will change…" (Line 8). She then added that "the side length has to get bigger" (Line 9) while her gestures quickly shifted from gross-motor usage of the forearms to using three fingers to represent all three sides of the triangle. She then shifted from a self-oriented process of ascertaining, to a social-oriented process of persuasion directed at the researcher, saying that "if you're extending it out but want to keep the angles the same, the side lengths have to change" (Line 9). While speaking, S2 spread out her fingers to make the side lengths longer. This *dynamic depictive gesture* sequence is an "exact gestural replay" that exactly resembles the third representation of S2's internally generated predicted actions (compare Figure 2c to Bottom Row of Figure 3). Upon analysis, we see that S2's verbal explanations explicitly said, "side lengths [can] change" while replaying the predicted actions. However, her speech in the prediction phase focused on "similar triangles" and "same angles," though her movements embodied the idea that the side lengths can change. This suggests that the gestural replay helps bring the nonverbal forms of knowledge into verbally coded awareness, and that the combination of nonverbal, intuitive forms and verbal forms of knowledge leads to a valid, generalized mathematical proof (Nathan, 2017).

Figure 3
(Top Row) *Starting, Intermediate, and Ending poses of the third set of predicted actions from Figure 2(c).* (Bottom Row) *Student replayed the predicted actions during verbal justifications.*

Transcript #2:

[1-6] … ((*S2 first reads the conjecture and then predicts actions while speaking rationale*))
[7] This statement is false.
[8] This statement is false because although the angles will stay the same, the side lengths will change, that's what makes triangles similar.
[9] The side length has to get bigger because if you're extending it out but want to keep the angles the same, the side lengths have to change.

Discussion

Embodied interactions offer promising pathways for improving mathematical thinking and learning. As these approaches proliferate (Abrahamson & Trninic, 2015; Nathan & Walkington, 2017; Ottmar & Landy, 2017; Smith, 2018) -- in classroom curricula, video games, for example -- scholars in the learning sciences need to move beyond assertions that embodiment either *does* or *does not* improve learning and address a theoretical need to identify *how* these interactions recruit body-based resources as part of a broader understanding of embodied learning, and a practical need to identify *when* embodied interactions benefit mathematical reasoning. In answer to the research question, we found evidence supporting the claim that gestural replays provide a kind of "bridge" between actions and verbalizable conceptual reasoning that is critical for articulating mathematically valid proofs in geometry. This applied to both externally generated directed actions (DA+PA') and to internally generated predicted actions (DA'+PA). This investigation contributes to a growing body of empirical research showing that it is not mere *movement* but the type of movement and its conceptual meaning that is most consequential (e.g., Walkington et al., 2022; Zhang et al., 2021).

In geometry proofs, students must offer arguments that are logical, operational, and generalizable in order to defend universal claims about properties of space and shape. To achieve this, interlocutors rely upon physically enacted simulations of transformations of imagined objects in the form of *dynamic gesture replays*. Each term in this phrase has a theoretical import. That they are *gestures* indicates that students' conceptualizations of the relevant ideas are body-based, challenging traditional notions that privilege symbolic and verbal accounts of knowledge and abstractions and offering instead a more distributed account that extends notions of cognition to encompass non-symbolic body movements and the sensorimotor processes associated with these nonverbal behaviors. That they are *dynamic* indicates the power of enacting transformations on imagined mathematical objects to support the type of generalized thinking that is often attributed to abstract formalisms (and often regarded in contrast to concrete experiences). That they are *replays* indicates that students reinvoke these behaviors as a valuable cognitive resource, often preserving the original relational information even as they are gesturally "revoiced" using different body parts.

This study also explored the influences on embodied mathematical reasoning in terms of the history of these movements. Many embodied curricula and game-based interventions use externally generated movements to bring about the desired behaviors, prompting students to mimic the actions of another, touch certain locations, or follow certain patterns (e.g., Cook et al., 2006; Nathan et al., 2014; Thomas & Lleras, 2007). The present study is one of the very few that compare the effects of performing externally generated directed actions to performing internally generated predicted actions. The results are notable: When producing dynamic gestural replays, participants who predicted actions showed superior proof performance compared to those who mimicked cognitively relevant directed actions that had previously been shown to be advantageous to proof performance. Enactivist theoretical accounts (e.g., Abrahamson & Sánchez-García, 2016; O'Regan, & Noë, 2001) are likely involved, as these hypothesize the ways that sensorimotor behaviors such as dynamic gestures emerge as a solution to an interaction problem, influenced by feedback from the environment (including one's own actions) that guide future actions (including gestural replays). For example, students may come to experience an appropriate geometric transformation because of the actions they perform (e.g., expanding one's hands away from one another while they each form the shape of a vertex between the thumb and fingers) rather than acting on a priori images of geometric objects (e.g., dilating a triangle).

The qualitative analyses illustrate how gestural replays can bridge concrete actions and generalized geometric reasoning. For example, S1 replayed the externally generated directed actions, thus re-enacting the movements into personally meaningful gestures. S2's internally generated predicted actions engaged body-based resources to simulate the possible solutions and operationalize her own geometric thinking, which may have also helped to bring S2's nonverbal ways of reasoning into conscious awareness (Aleven & Koedinger, 2002), leading to a multimodal explanation that served as a mathematically valid proof of her claim. In each case, gestural replays simulate and schematize generalizable mathematical relations embodied by the relevant actions to enact mathematical transformations supporting generalizable geometric reasoning.

These findings need to be replicated across different populations and tasks. Still, this study offers two insights for the design of embodied learning interventions. First, there is value in directing students to perform relevant actions, but explicit prompting for them to replay those directed actions through personally meaningful gestures that enact mathematical transformations strengthens the influences of directed actions for proof. Second, simply encouraging students to predict actions for corresponding tasks may benefit learning, expanding the forms of embodied interventions that can benefit thinking and learning.

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Tracing a Path Toward Social Empathy: The Development of the Multicultural Awareness and Empathy Orientations Model

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Abstract: This paper describes the process of developing the Multicultural Awareness and Empathy Orientations Model (MAEO) to support the analysis of pre-service teachers' uptake of human-centered design practices and multicultural awareness as part of an education and social justice course. This conceptual model is informed by Segal's (2018) theory of social empathy. It is also informed by sociopolitical theories associated with anti-racism, identity, and multicultural and culturally responsive education, with an emphasis on identity and difference within educational systems. This conceptual model theorizes the intertwine between cultural empathy and an emerging critical multicultural awareness of historically excluded communities. The model provides a potential tool to aid in the design of multicultural or social justice-oriented courses at all educational levels. It also serves as an assessment tool to track one's progress toward social empathy that is guided by macro perspective taking of those who have lived experiences in historically excluded communities.

Introduction

Preparing preservice teachers (PSTs) to teach in increasingly diverse communities calls for PSTs to understand and empathize with the social worlds of their students, particularly those from historically excluded communities. This is particularly important since the majority entering the teaching profession continue to identify as white and female (Reyes &Aronson, 2022). As a response to this need, many teacher preparation programs (TPPs) have required PSTs to take courses in multicultural education, social justice, and equity. Anti-racist education scholars also recommend ongoing training in culturally sustaining pedagogy (e.g., Basile et al., 2019; Blake et al., 2011). However, some questions regarding these courses still need answers. For example, how might their effectiveness be assessed? How might empathic growth be measured during courses that seek to prime PSTs to empathize with students from historically excluded backgrounds? These questions drove us to develop an evidence-based conceptual model – the Multicultural Awareness and Empathy Orientations Model (MAEO). This model, we argue helps to assess both an individual's progress toward social empathy and the effectiveness of these courses to promote social empathy.

As part of a partnership with the instructors of a course focused on identity and difference in education, we designed a digitally interactive instructional booklet (James, Shehab, & Rost, 2021) that is currently in its third iteration. It engaged undergraduate students - the majority of whom are PSTs - in human-centered design (HCD) practices and course concepts centered on multicultural awareness of historically excluded communities. The booklet engaged the undergraduates in weekly activities that blended empathic practices with their emerging understandings of marginalized communities. In Fall 2021, we began a study to analyze the impact of this intervention on PSTs' development of social empathy and empathic techniques (Hess & Fila, 2016; Segal, 2018), which includes multicultural awareness of people who have vastly different lived experiences from their own.

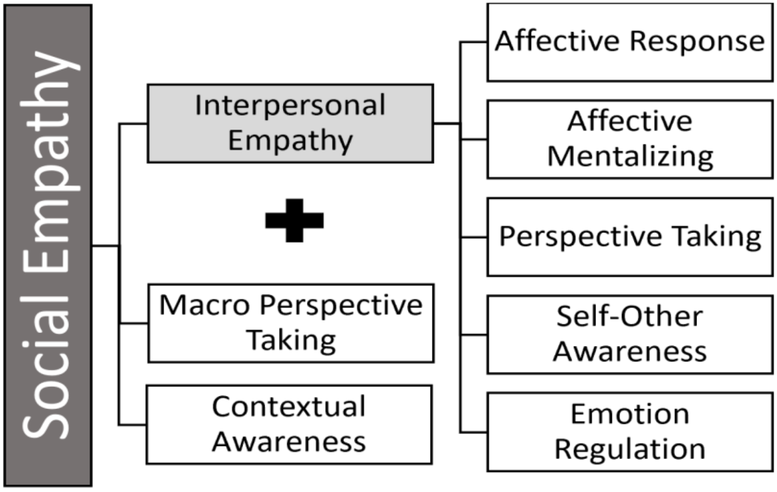
As part of this work, we designed a conceptual framework to help us understand and trace the undergraduates' trajectories as they navigated the course and this instructional booklet. This paper outlines the design of this conceptual model, grounded in theories of social empathy (Segal, 2011, 2018; Segal et al., 2017) and sociopolitical theoretical frameworks centered on anti-racism (Dunn et al., 2021; Kendi, 2019; Love, 2019), critical race theory (CRT; Delgado & Stefancic, 2001; Ladson-Billings, 2009; Stovall, 2016), social justice (Davis, 2003; Gewirtz, 2006; Kumashiro, 2001), desire-based theory (Tuck, 2009) and culturally sustaining education (Ladson-Billings, 1995; Paris, 2012). This work is also grounded in conceptualizations of HCD that describe it as an empathetic and human-centered problem-solving approach that embraces an iterative and collaborative process with all stakeholders (Brown, 2009; Lawrence et al, 2021). Below, we outline the process of analyzing the current literature and how that analysis informed the creation of the MAEO model that foregrounds the relationship between sociopolitical, multicultural awareness and social empathy. We believe that this evidence-based conceptual model has potential to map PSTs' multicultural awareness and empathic orientation toward historically excluded communities and trace their growth.

Literature review

Defining (social) empathy

Many scholars have explored the concept of empathy and its role in both teacher education and enacting culturally sustaining teaching (e.g., Arghode et al., 2013; Dolby, 2012; Dunn & Wallace, 2004; Warren, 2014, 2018). These scholars focus on what can generally be described as cultural empathy, and what Segal (2011) defines as social empathy. She built her conceptual model of social empathy on the theoretical framings of empathy, or interpersonal empathy, developed by scholars in the fields of psychology, cognitive neuroscience, and social work (e.g., Coplan, deWaal, Singer, and Lamm). In her conceptualization of interpersonal empathy, Segal describes a cognitive-affective model made up of five processes. She asserts that empathy includes two affective components: affective response and affective mentalizing. Affective response describes the initial emotional response we have to something we have observed (such as feeling sad when we see someone else crying). Affective mentalizing describes being able to have those same feelings when we visualize it in our heads (such as hearing about someone crying over the death of their parent and, after visualizing it, having an affective response). Her interpersonal empathy model also includes three cognitive processes: self-other awareness, emotion regulation, and perspective taking. Effectively engaging in these cognitive processes allows someone to put themselves in the perspective of someone else while regulating their own emotional response and being aware of themselves in relation to the person(s) they are trying to empathize with. In her conceptualization of social empathy, Segal (2018) adds two additional components: contextual understanding and macro perspective-taking (see Figure 1). These two components act in concert, allowing someone to be able to consider and understand the perspectives of those outside their own sociocultural spheres. They can do this best, Segal argues, by developing contextual understanding of others' lived experiences, including "the historical events that shaped the group and contributed to its members' identities today" (p. 19). This includes awareness and acknowledgement of the systemic barriers those from historically excluded and marginalized communities face. Segal's conceptualization of (social) empathy distinguishes itself from responses frequently mistaken for empathy such as sympathy and judgment.

Figure 1
Visual Representation of Segal's (2018) conceptualization of social empathy.



Many fields outside of psychology and social work have explored the ways that social (cultural) empathy figures into the work they do. For example, Hess and Fila (2016), engineering educators, conducted a study where they observed the empathetic practices of engineering students as they engaged in a service-learning project to develop an accessible zipline for campers with disabilities. They identified 12 different empathic techniques: direct observation, interaction, empathy by proxy, projection, simulation, empathic concern, synthesizing empathic knowledge, designing for user-centered criteria, integration, refining user suggestion, checking with users, and imagined use. Five of these techniques played a role in the design of the instructional booklet we designed for the course (see Table 1). Each week of the semester, PSTs engaged in activities that centered one or more of these techniques. These activities were initially scaffolded to build confidence in their ability to engage in HCD on their own. For example, one week they practiced interacting with peers in the class before interacting with someone that could be identified as an educator in the field. In reflections, they might have been asked to engage in projection (i.e., perspective taking) and they would then get feedback from their instructors. By engaging in these practices and techniques explicitly, we believed it would help orient the PSTs toward empathy across diverse communities.

Design sciences scholars also embrace conceptualizations of empathy in their work. Brown (2008) initially conceptualized design thinking and human-centered design as an empathy-based approach for problem solving. “[Designers] can imagine the world from multiple perspectives—those of colleagues, clients, end users, and customers (current and prospective). By taking a “people first” approach” (p. 3). Going further, Lawrence and colleagues (2021) conceptualized an HCD taxonomy that consists of five spaces: Understand, Synthesize, Ideate, Prototype, and Implement. The Understand Space centers designers’ practice of understanding their stakeholders and includes exploration, observation, empathy, and reflection processes. By engaging in these processes and adopting the empathy techniques (Hess & Fila, 2016), designers make it easier to take the perspectives of those who are part of the design process in empathetic ways.

Table 1

The empathic techniques adopted from Hess and Fila (2016) in the design of the HCD booklet.

Empathic Technique	Definition	Examples of Activities
Direct Observation	Observe a specific context and those within that context	Observe the context of your community placement
Interaction	Engage in conversations with those who have a direct stake to learn about their perspectives	Interact with participants at a community placement
Empathy by Proxy	Engage in conversations with intermediaries who have knowledge of primary stakeholders	Interact with administrators or volunteers at community placement
Projection	Mental perspective-taking where we try to imagine ourselves in others’ shoes	Put yourself in the shoes of the participants at your placement
Synthesize Empathic Knowledge	Making sense of information gathered and identify patterns that lead to user insights	Identify patterns in what you learned at your community placement

A sociopolitical framing of multicultural awareness

Over the past several decades, teacher preparation programs have attempted to address the issue that arises when an increasingly diverse student population is taught by predominantly white, middle-class females (Reyes & Aronson, 2022). Requiring PSTs to take multicultural education, minority studies, or social justice courses is one way that TPPs have addressed this need to better support all teachers, particularly those from dominant cultures, in working with racially, ethnically, and linguistically diverse communities (Kretchmar & Zeichner, 2016). These courses adopt one or more critical theories to help support PSTs develop social empathy and multicultural awareness. As such, we considered the need for a focus on the following sociopolitical theories: social justice education, culturally sustaining pedagogy, and critical race theory (CRT) – including critical whiteness studies and anti-racist pedagogy – as we made sense of the PSTs’ work.

Multicultural social justice education, for example, is often grounded in “guiding students in critical self-reflection of their socialization” into hegemonic constructs such as those based on race, class, gender, and ability (Sensoy & DiAngelo, 2009, p. 350). Courses that adopt a social justice frame to multicultural awareness might consider Gewirtz’s (2006) aspects of social (in)justice: distributive, recognitional, and associational justice. Distributive justice can best be described as equitable distribution of resources. It is also “defined as the absence of exploitation, marginalization, and material deprivation” (p. 74). In taking up distributive justice, PSTs could investigate whether state funds are distributed to schools across a state. Recognitional justice would be defined as “the absence of cultural domination, non-recognition and disrespect” (p. 74). Culturally sustaining pedagogy would be an example of recognitional justice. Finally, associational justice centers on fostering democratic and equitable participation within a community in such a way that everyone can fully participate in decision making, particularly those that have been historically excluded from participation and decision making.

Many multicultural education courses are also grounded in critical race theory (CRT), which embodies important pedagogical frames including anti-racist pedagogy, intersectionality, and critical whiteness studies (CWS). CRT, which had its beginning in legal studies, has long been a part of educational research. “Many in the field of education … use CRT's ideas to understand issues of school discipline and hierarchy, tracking, controversies over curriculum and history, and IQ and achievement testing" (Delgado & Stefancic, 2001, p. 3). CRT brings to the forefront issues of racism and oppression that exist in U.S. educational systems. One of the tenets of CRT is intersectionality (Crenshaw, 1989), which defines the multiple and intersecting ways in which people from historically excluded communities are discriminated against, both legally and socially. Since separate laws for the protection of race, ability, gender, sexual identity, and other historically excluded groups exist in the U.S., and levels of protection vary by state, an understanding of this inconsistency is important for educators. A gay, Black, disabled woman cannot split her identity into individual facets of herself; she embodies all these identities at once, and therefore the laws are not currently designed to recognize her wholeness (Crenshaw. 1989).

Work in both anti-racist pedagogy and critical whiteness studies is also situated within the umbrella of CRT. Both incorporate framings for what it means to develop multicultural awareness and include knowledge and active disruption of systems of oppression, particularly in educational spaces (Blakeney, 2011; Dunn et al., 2021; Kendi, 2019; Love, 2019). Anti-racist educators decenter hegemonic practices in educational spaces while at the same time fully addressing the "historical constructs that facilitate inequalities and seeking to create an antiracist paradigm that in time will serve to historically condition a new antiracist society" (Blakeney, 2011, p. 120). CWS brings to the forefront a theoretical lens for making sense of white people's discomfort with exploring white privilege, white saviorism, and the ways that they implicitly (and explicitly) support systemic racism and oppression (Matias et al., 2014; Reyes & Aronson, 2022). Within education, CWS interrogates the complacency and complicity of teachers, the majority of whom are white, middle-class women, in maintaining structures of systemic racism and oppression (Reyes & Aronson, 2022).

Finally, we draw attention to what Tuck (2009) calls the suspension of damage-based thinking. Tuck encourages researchers and educators to focus on the desires and goals - "the hope, the visions, the wisdom of lives and communities" (p. 417) and not just focus on people's "pain and brokenness" (p. 409). In doing so, scholars move beyond the damage of historically excluded individuals and communities and look for the counter-narratives and the realization of imagined worlds. When research is damage-centered, it "simultaneously reinforces and reinscribes a one-dimensional notion of these people as depleted, ruined, and hopeless" (Tuck, 2009, p. 409). Taking up Tuck's framework gave us a way of theorizing the impact of developing multicultural awareness when PSTs demonstrate sympathy rather than empathy.

Building the multicultural awareness and empathy orientations model

In the Fall of 2021, we began a study of the intervention we collaboratively designed with instructors of a social justice in education course that is required as part of the TPP at a large land-grant university located in the Midwest. As part of that study, we collected participants' instructional booklets and their four cumulative assessments, which were critical reflective essays. In the spring of 2022, we began to examine the PSTs' work in the booklets and assessments. Adopting Tracy's (2020) phronetic iterative analysis approach to qualitative coding, we did a first read-through to see what emerged in the data. Then we moved onto the second stage by returning to the research literature, as described above, to help flesh out potential codes. In doing this, a conceptual model that would assist us in tracking PSTs' progress toward social empathy throughout the course as well as determine where they ended up at the end of the semester started emerging.

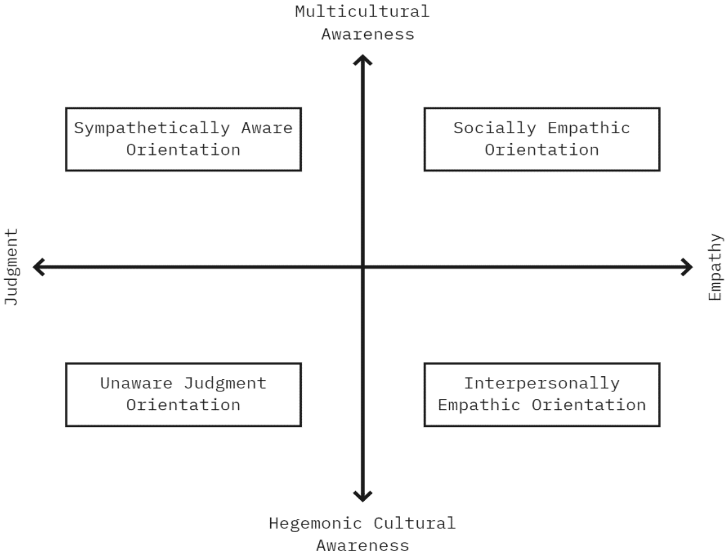
In developing the Multicultural Awareness and Empathy Orientations Model (MAEO), we considered what we knew about empathy and multicultural awareness from the literature and sought ways to integrate them into our data analysis to assess both white PSTs and those of color. Our goal was to create a framework to help us assess PSTs' progress toward developing social empathy. Segal and colleagues (2017) clearly outline interpersonal empathy and the cognitive-affective components that make up empathy generally. Segal and colleagues also offered a solid reference for responses that frequently get confused for empathy (e.g., sympathy, pity) and those responses that are antithetical to empathy such as judgment and manipulation).

However, in defining the components of social empathy – macro perspective-taking and contextual understanding – we added to Segal's (2018) conceptualization of social empathy based on the sociopolitical research described above. Segal (2018) argues these two components work in concert with each other. For one to enact social empathy it requires them to have "both the desire and the interest to learn about people who are different" (p. 20). This contextual understanding, she argues, sets one up to be able to consider the "large-scale view of situations" (e.g., historic and systemic barriers) when taking on the perspectives of those from historically excluded communities. The sociopolitical theories we describe above would argue it is not enough to have a desire and interest to learn, but that one needs to confront and resist and disrupt to truly have contextual understanding, which we refer to as multicultural awareness. In this way, we add to Segal's (2018) conceptualization of social empathy, which is reflected in the model we describe below.

Out of this analysis approach, our model started to emerge with two variables – empathy and multicultural awareness, which we viewed as two continua that intersect, creating four orientations. As visualized in Figure 2 below, the MAEO model consists of both a horizontal and vertical axis. We began by mapping out the terrain of the empathy spectrum as defined by the research literature. Many affective responses are confused for empathy, as Segal and peers (2017) described - sympathy and pity, for example. An inability to empathize, the authors argue, often manifests as judgment, which occurs when one cannot put themselves in another's shoes. This represents the left side of the continuum, with judgment situated furthest. We take up Segal and peers' (2017) conceptualization of interpersonal empathy, represented by all five traits described above, as the embodiment of the right side of the spectrum. While responses such as pity and judgment would reside on the left side, practices such as perspective taking and self-other awareness would situate further to the right.

Conceptualizing the vertical axis required further consideration of Segal's definition of contextual understanding, which focuses on a developed awareness of others' lived experiences and systems of oppression that impact them. As stated above, we considered the sociopolitical theories of critical scholars and their work in multicultural education, social justice, and antiracist pedagogy as well as CRT and its sub-theories (e.g., CWS). Initially, we conceptualized the two end points. At the bottom, we have situated hegemonic (e.g., white, patriarchal, heteronormative, ableist) cultural awareness. It is characterized by a lack of multicultural awareness, and instead predominantly aligns with a hegemonic understanding of the world. Basing this on critical theories, the lower half of the spectrum includes avoidance, which CWS describes as white people's unwillingness to discuss racial issues (Matias, et al., 2014, Reyes & Aronson, 2022). Tied to a lack of recognitional justice (Gewirtz, 2006), this end of the spectrum would reflect those who perhaps had limited exposure to the lived experiences of those from historically excluded groups. The top of the spectrum would account for high levels of multicultural awareness grounded in a deep understanding of systems of oppression (Delgado & Stefancic, 2001), the willingness to act to disrupt these systems (Blakeney, 2011), and the ability to engage in macro-perspective taking (Segal, 2018). As a person develops their multicultural awareness, they move along the spectrum, perhaps enacting a white savior mindset, demonstrating an awareness of hegemonic systems and ways of being or even confronting and resisting these systems. This is one way that this work has added to Segal's (2018) conceptualization of "contextual understanding." Sociopolitical theories make it clear that it is not enough to be aware of systems of oppression. Instead, one must act and disrupt based on that awareness in order for it to be considered a true demonstration of social empathy.

Figure 2
Multicultural Awareness and Empathy Orientations Model



As Figure 2 demonstrates, each quadrant of the conceptual model defines an orientation. This orientation, within the context of our study, described the orientation that a PST demonstrated in a particular moment of their work throughout the course. However, these orientations can describe more than just where an individual is situated (e.g., it could map where a particular course or program is oriented on the axes). Table 2 (below) describes each of the four orientations.

Table 2
A description of the four orientations in the Multicultural Awareness and Empathy Orientations Model

Orientation	Description
Unaware Judgment Orientation (Bottom left)	This orientation is characterized by a narrow-world view and exhibits deficit thinking. There is little evidence of critical reflection. It also reflects avoidance of or distancing of self in conversations on systemic oppression and white privilege.
Sympathetically Aware Orientation (Top left)	This orientation views historically excluded communities as victims. While there is an increase in multicultural knowledge, there is a focus on feelings of sympathy and pity for these communities because of the oppression they face. This may result in a white savior mindset while orienting themselves as social justice allies or advocates.
Interpersonally Empathic Orientation (Bottom right)	This orientation, due to a lack of multicultural awareness, focuses on in-group perspective taking. This orientation demonstrates a willingness to see systems of oppression but through a limited, hegemonic lens. Likewise, this mindset focuses on achievement (or lack thereof) as individual and merit-based rather than framed within systems of oppression.
Socially Empathic Orientation (Top right)	This orientation embraces macro perspective-taking fueled by an ability to not only grasp systemic oppression but also act to disrupt it and imagine anti-oppressive systems. People within this orientation decenter whiteness and asset and desire-based framing.

The conceptual model in action

Sydney (a pseudonym) is one participant from our study on the social justice in education course that we described above. She identifies as a white female seeking licensure in early childhood education. She took the social justice in education course we studied during the fall of 2021 as part of a prerequisite to entering the major in her junior year. Using the MAEO model described above, we were able to trace Sydney's path throughout the course as she navigated course concepts on identity and difference. We used her work both in the interactive instructional booklet and the four cumulative reflective assessments to map her orientations throughout the course.

Initially, Sydney demonstrated many aspects of the interpersonally empathic orientation, which situated her close to the intersection of both axes. She frequently described herself as a social justice advocate in the early reflections within the instructional booklet but lacked awareness of what it means to enact social justice. This manifested in her frequently describing things through hegemonic lenses. "Being caucasian in this education system, as well as being english [sic] speaking and of a well-known religion [Catholic], gives me a spot in the 'social norm' category" (Sydney HCD Book 1, p.13). So, while she demonstrates awareness of hegemonic systems, she also frames them in ways that signal a hegemonic mindset, particularly when she uses the phrase "social norm."

As Sydney continued through the course, her multicultural awareness increased, particularly demonstrated through her ability to talk about the oppressions that people with disabilities and women of color face. However, rather than confronting these systems, she demonstrated awareness of them and showed signs of sympathy in how she spoke of those experiencing this oppression. "Whether the discrimination is intentional or not, there are groups of people who are judged, fall silent, and face inequality because of who they are; these are underrepresented groups" (Sydney Assessment 2, p. 1) This framing demonstrated the ways that she both othered them and felt sorry for their situation, which placed her more in the orientation of sympathetically aware. At times, Sydney did show a glimmer of the socially empathic orientation, particularly when she spoke of challenging dominant discourses by bringing in multicultural literature, but this was hampered by her frequent centering of herself as the person who could help children of color see their value (an example of white saviorism).

In practice, this conceptual model allowed us to trace Sydney's journey toward a socially empathic orientation. Each instance of grappling with social justice and multicultural concepts signals an orientation, and using this model made space for us to trace her journey and pinpoint moments of growth. This can help make visually clear the complexity of these journeys, as learning is not a linear process, but one that shows wobble (Fecho et al., 2005) as people take up new concepts and orient them in their understandings of the world.

Implications for practice and research

Despite evidence that the majority of TPPs have adapted their programs to include at least some multicultural education as part of a teacher's preparation, many scholars have pointed out the variance across programs in terms of breadth and depth in multicultural education (e.g., Cochran-Smith & Zeichner, 2005; Kretchmar & Zeichner, 2016). "Many teacher preparation programs attempt to infuse multicultural perspectives by simply adding one or two courses in multicultural education and/or requiring teacher candidates to complete assignments that explore surface-level differences in culture and language" (Assaf, Garza, & Battle, 2010, p. 116). This conceptual model provides a useful tool for creating and assessing multicultural education courses and programs. In essence, this model could be used as a guide for designing courses based on the features of a social empathy orientation as well as act as an assessment tool to determine where courses and programs are oriented in practice. For example, we adopted this model to help us evaluate the course once we realized that many of the participants were oriented more toward Sympathetically Aware on the map. This allowed us to identify aspects of the course (e.g., course readings) that shifted students toward damage thinking (Tuck, 2009) and encouraged othering. We were also able to use this model to make recommendations to the course instructors that might help shift the PSTs' trajectories toward the Social Empathy Orientation.

Secondly, there is a continued need to assess PSTs' abilities to be able to support and provide equitable, culturally sustaining teaching practices once they enter the teaching profession as in-service teachers (Paris, 2012, Reyes & Aronson, 2022). This model could be a helpful tool to track a PST's progress as they navigate a course or program. By using this model, teacher educators could help adjust a PST's trajectory before they enter the field. For example, a teacher educator could have encouraged Sydney to critically reflect on her work, helping her to reflect on those moments she painted people from historically excluded communities as victims. In this way, she would have adopted the critical lenses advocated by critical scholars. It can also act as a self-reflection tool as well for PSTs as they could consider their own positionality in the world and their emerging abilities in macro perspective-taking and contextual understanding.

In terms of research, this conceptual model adds to our understanding of social empathy, particularly what it means to have contextual understanding – what we call multicultural awareness. By synthesizing social empathy with theories from CRT, social justice education, critical whiteness studies, and antiracist pedagogy, we can recognize the importance of action and disruption, which is a vital aspect of truly enacting social empathy in teacher education and learning sciences more broadly. For instance, this model opens many avenues for learning sciences scholars interested in sociopolitical work to study the ways that learners explicitly or implicitly develop particular orientations on the model. For example, CWS scholars might explore what learning processes and experiences shape youths' orientation within the model. It could also inform the design of interventions that might alter that trajectory, allowing scholars to use the model as a program evaluation and data analysis framework (as we used it). This model might support participant recruitment by giving researchers a frame for participant selection across all four orientations. Finally, this conceptual model is still in flux and leaves the door open for additional research with multicultural education courses and programs to help refine both the model and the ways in which each orientation is conceptualized.

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Supporting Alignments in Scientific Activity: Moving Across Question, Evidence, and Explanation

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Abstract: A core practice of science is planning and conducting investigations. This practice needs reconceptualizing, to account for where work happens between identifying a phenomenon and designing an investigation, and between gathering and analyzing data to support developing an explanation of that phenomenon (Manz et al., 2020). Teachers, supported by curriculum materials, need to engage students in becoming more involved in the decisions related to what data to choose as evidence, how to represent data to answer specific questions, and what conclusions can be drawn from data. We present results of a design study in which students investigated a dataset to answer a question about a major change to an ecosystem, using a technology tool, CODAP. We explore how the curriculum and teacher supported students in taking up different facets of data practices that support figuring out a phenomenon while moving between investigating and developing explanatory models.

Subject/problem

Historically, students' experience of science investigations follows a "cookbook" lab approach that involves following procedures given to them by teachers, with little opportunities for grappling with issues that scientists do of choosing measures and kinds of analyses to perform, or taking up questions of how to handle missing data (Banilower et al., 2018). That is, school science investigations give students little opportunity to gain a "grasp of scientific practice" (Ford, 2008) or gain a feeling for the work of science (Jaber & Hammer, 2016). This is a problem because recent reforms in science education reflect a "practice turn" (Ford & Forman, 2006), which views science learning as bringing students into the community of scientific practices through experiencing for themselves how and when to use such practices to understand a compelling, natural phenomenon. Engaging in disciplinary practices is intended to support students to see science as an enterprise concerned with improving understanding of the natural world through mutually supporting practices.

One of the core practices emphasized in *A Framework for K-12 Science Education* (NRC, 2012) is planning and carrying out investigations. Manz et al. (2020) argue that this particular practice needs reconceptualizing in science education, to account for where real work happens in identifying a phenomenon, designing an investigation, and gathering and analyzing data to support developing an explanation of that phenomenon (Figure 1). Aligning work across the elements in Figure 1 represent areas of uncertainty but also opportunities for students to be more involved in the decisions that occur in authentic scientific investigations which in procedural lab activities remain largely unseen. For instance, before analyzing data, students need to decide what data are relevant to answering questions.

In this paper, we explore how a curriculum and teacher supported students in engaging in data modeling (red box in Figure 1) within an investigation, where students define measures and articulate how such measures can help them make progress in understanding a phenomenon, and where they draw conclusions from data they represent. In this design study, students were given opportunities to consider how data could answer a question they had, represent data using a technological tool, and draw conclusions from it. We sought to understand how a curriculum, teacher, and students can work together to take up different facets of data modeling for making sense of a phenomenon while investigating and developing explanatory models.

Conceptual framing

In drawing upon a vision of science education that sees the importance of bringing students into the practices of science, we build on Manz et al.'s (2020) work towards conceptualizing the investigation as "developing alignments between phenomena, empirical models, data models, and explanatory models" (p. 1166-7; Figure 1). Much scientific practice unfolds in moving between these elements, and since the decisions and assumptions around methodology are often obscured from view, this 'alignment' work is needed to highlight the interconnected, interdependent, and iterative nature of moving between these elements as new questions arise and explanatory models get refined. Accordingly, there is a need for helping students engage with scientific practice in moving across these spaces, characterizing the facets of practices occurring there, and subsequently learning how to support teachers and students through curriculum and professional development.

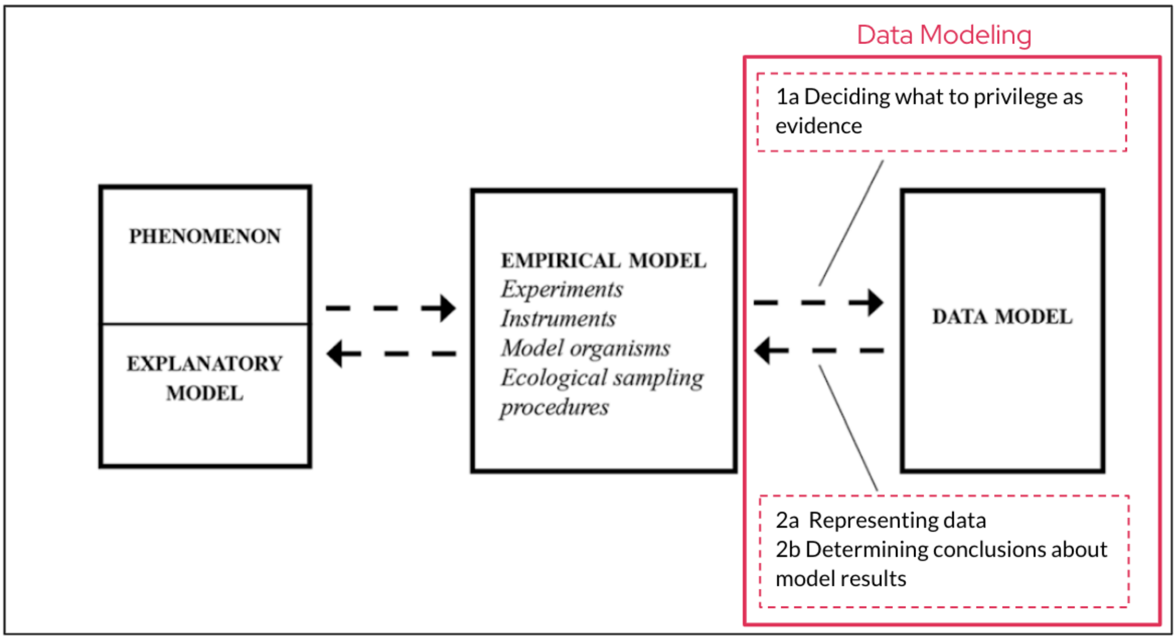
As we are concerned with supporting students in developing data practices, we focus on data model*ing* as occurring across the act of developing a data model. In our context, the data model is where students coordinate different artifacts from the lesson and try out different data presentations in the Common Online Data Analysis Platform (CODAP), a free, web-based data visualization tool developed by Concord Consortium (2019) that functions as a 'sandbox,' where students can explore and make sense of data. The alignment work taking place during data modeling serves to support students in developing a data model in the context of understanding a phenomenon, that is, engaging in such acts as defining measures, visualizing data, and constructing explanations with data. Of particular importance are data modeling activities that help students with moving from an initial, empirical model of a phenomenon towards specifying and then interpreting evidence from data models to draw conclusions that help students update their explanatory model of a phenomenon.

Teacher moves and curricular supports for specifying a data model

We are particularly concerned with studying how students are supported to engage with real world, messy data sets in the context of a curriculum that supports figuring out an ecological phenomenon. The data students engage with were collected by scientists to answer different questions, so one practice we focus on in specifying the data model is deciding what to privilege as evidence (1a in Figure 1) in response to *students'* questions.

Both curriculum materials and the teacher play crucial roles in supporting students' alignment work. Curricular tasks that engage students in determining, defining, and operationalizing data as evidence and help them grapple with decisions about what data to consider as evidence are important for facilitating students' scientific work in this alignment work (Manz et al., 2020). Teacher moves to problematize or make clear what is at stake in these decisions can help students see how the work is meaningful (Reiser, 2004). Talk moves that re-voice students' ideas about appropriate measures can also help students to narrow in on evidence needed to answer a given question (Watkins & Manz, 2022).

Figure 1
Investigations Framework; in red, we highlight the data-related practices occurring during data modeling. Adapted from Manz et al., (2020)



Teacher moves and curricular supports for interpreting evidence implied by the data model

Another key alignment involves investigating ways to represent data (2a) and drawing conclusions about data (2b), particularly to be able to communicate to themselves and to others how their data model helps explain part of a larger phenomenon (see Figure 1). The need to focus on these moves arises from both the opportunities to give students a feeling for the challenges scientists face in doing so and from prior research, which suggests interpreting and communicating data model results is difficult for students (Zangori et al., 2013).

There are a number of strategies for organizing curriculum activities and teaching that can facilitate this move from data model to explanatory model. In deciding how to represent data, students can be supported in grouping or “binning” cases in the dataset in various ways in order to surface different relationships (Erickson et al., 2019). Other strategies include inviting students to consider how the results of an investigation bear on the phenomenon at hand and addressing the gaps between their investigation models, evidence, and focal phenomenon (Manz et al., 2020). Talk moves can support students in expanding their initial thoughts towards pointing to the evidence that supports their claim (Michaels & O’Connor, 2017; Windschitl et al, 2020). We aim to better understand how curriculum tasks and teacher facilitation can work synergistically and with students to align an updated data model with the empirical model.

Methods

This embedded, single case study as part of a larger, multiple case study design (Yin, 2009) focused on one enactment of a lesson as part of a unit of study on ecosystems in which students engaged with real-world data about rainfall and large herbivore populations in the Serengeti between 1960 and 1975. The case is a paradigmatic one, chosen to illustrate what rich data modeling opportunities can look like in a classroom.

We address three primary questions based on the areas of alignment surrounding the data model: How did the teacher, curriculum, technology tools, and students work together to: (1) Decide what to privilege as evidence to answer the question? (2) Represent the data?, and (3) Generate tentative conclusions about what the data model reveals about the phenomenon?

Participants

The focal participants in the study were a teacher and students in a single classroom. The teacher was one of seven teachers who participated in a field test of materials as part of a larger initiative to develop open access (OER) materials aligned to the Next Generation Science Standards (NGSS Lead States, 2013).

The teacher in the study, Melissa, taught in an urban high school serving primarily Latinx students in a large school district in the Mountain West of the United States. At the time of the study, she had been teaching for 13 years, 12 as a high school science teacher. Melissa identifies as white and female. There were a total of 23 students in Melissa’s ninth grade biology class. Of these, 11 identified as female, 11 as male, and one as gender nonbinary. Nearly all identified as Latinx (20), with one Black student, one Asian American student, and one white student. She had three students with identified learning disabilities and one gifted student.

We chose this teacher for two key reasons. First, we had multiple sources of data available from her enactment: a video recording of the full lesson and multiple student work artifacts from her classroom. Second, her own teaching to us embodied a general approach of opening up investigations for students, where students were asked to make key decisions about data with her support, rather than simply follow her directions.

Intervention

We took a design-based approach to developing and co-designing with teachers a set of *data excursions* and accompanying tools and routines for supporting students’ data literacy skills within two lessons of a widely used, open access, storyline-based high school biology curriculum. These data excursions were intended to allow students to interact with existing datasets to query their contexts, change the way they are aggregated and represented, and explore their properties, in order to explain changes to the Serengeti ecosystem that led to a dramatic increase in the populations of two large herbivores, buffalo and wildebeest, between 1960 and 1975. Rather than present students with cleaned up data, we sought out the original data for students to engage with to more closely approximate how scientists think about and use data (see Figure 2).

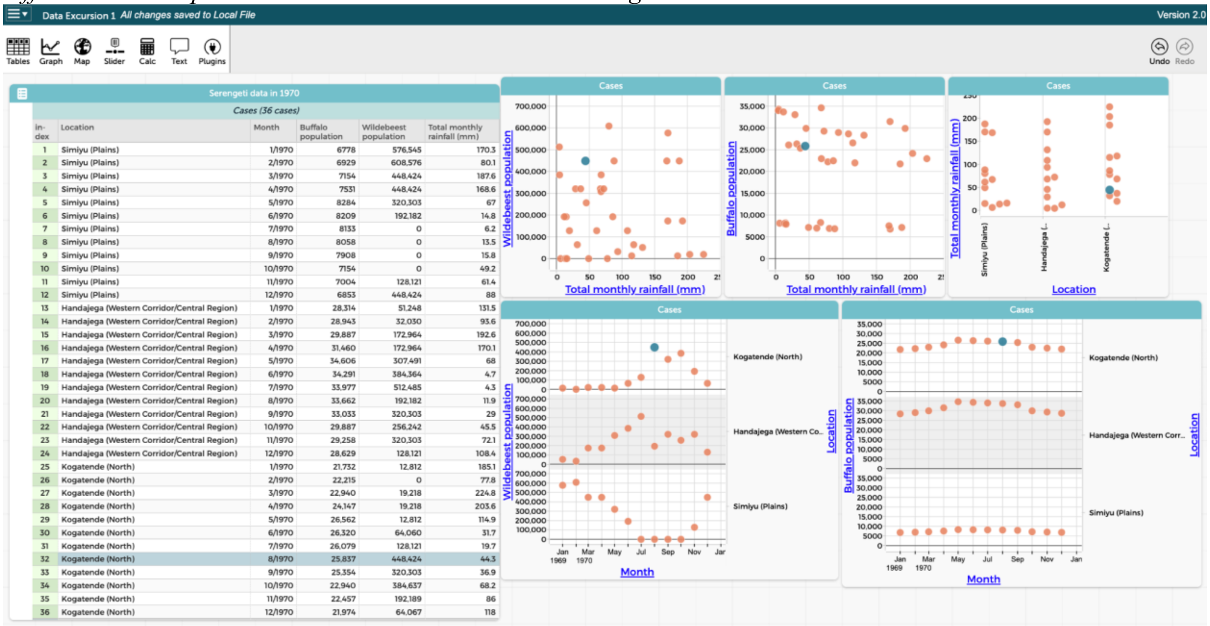
In the focal lesson, students addressed the question: “Was the increase in population of wildebeest and buffalo caused by an increase in the availability of food?” After an initial discussion to consider what data they might need to answer the question, students watched a video from an ecologist who studied the Serengeti during that time period, who said they did not have data on food from 1960-75, so they had to estimate food availability by looking at data on rainfall.

Students were then introduced to CODAP, which features a drag-and-drop interface that simplifies creating and modifying graphs of the dataset. All representations in a document—tables and graphs—are linked so that any data points highlighted in one representation are simultaneously highlighted in the others. Both the software’s ease of use and this “linked representation” feature is intended to help keep students focused on the meaning of the data and support their ability to see and interpret patterns in the data (see Figure 2).

The curriculum included a handout for student groups, to specify what data they planned to analyze, what patterns they noticed in the data, and their explanations of the lesson-level question in a “claim-evidence-reasoning” format (McNeill & Krajcik, 2012). After collaborating in small groups, the whole class discussed the groups’ ideas to arrive at a consensus explanation.

Figure 2

CODAP platform with dataset for the lesson 2 data excursion, and student work examples demonstrating the different visual representations that students created during lesson 2.



Serengeti data in 1970

Cases (36 cases)

index	Location	Month	Buffalo population	Wildebeest population	Total monthly rainfall (mm)
1	Simiyu (Plains)	1/1970	6778	576,545	170.3
2	Simiyu (Plains)	2/1970	6929	608,576	80.1
3	Simiyu (Plains)	3/1970	7154	448,424	187.6
4	Simiyu (Plains)	4/1970	7531	448,424	168.6
5	Simiyu (Plains)	5/1970	8284	320,303	67
6	Simiyu (Plains)	6/1970	8209	192,182	14.8
7	Simiyu (Plains)	7/1970	8133	0	6.2
8	Simiyu (Plains)	8/1970	8058	0	13.5
9	Simiyu (Plains)	9/1970	7908	0	15.8
10	Simiyu (Plains)	10/1970	7154	0	49.2
11	Simiyu (Plains)	11/1970	7004	128,121	61.4
12	Simiyu (Plains)	12/1970	6853	448,424	88
13	Handajega (Western Corridor/Central Region)	1/1970	28,314	51,248	131.5
14	Handajega (Western Corridor/Central Region)	2/1970	28,943	32,030	93.6
15	Handajega (Western Corridor/Central Region)	3/1970	29,887	172,964	192.6
16	Handajega (Western Corridor/Central Region)	4/1970	31,460	172,964	170.1
17	Handajega (Western Corridor/Central Region)	5/1970	34,606	307,491	68
18	Handajega (Western Corridor/Central Region)	6/1970	34,291	384,364	4.7
19	Handajega (Western Corridor/Central Region)	7/1970	33,977	512,485	4.3
20	Handajega (Western Corridor/Central Region)	8/1970	33,662	192,182	11.9
21	Handajega (Western Corridor/Central Region)	9/1970	33,033	320,303	29
22	Handajega (Western Corridor/Central Region)	10/1970	29,887	256,242	45.5
23	Handajega (Western Corridor/Central Region)	11/1970	29,258	320,303	72.1
24	Handajega (Western Corridor/Central Region)	12/1970	28,629	128,121	108.4
25	Kogatende (North)	1/1970	21,732	12,812	185.1
26	Kogatende (North)	2/1970	22,215	0	77.8
27	Kogatende (North)	3/1970	22,940	19,218	224.8
28	Kogatende (North)	4/1970	24,147	19,218	203.6
29	Kogatende (North)	5/1970	26,562	12,812	114.9
30	Kogatende (North)	6/1970	26,320	64,060	31.7
31	Kogatende (North)	7/1970	26,079	128,121	19.7
32	Kogatende (North)	8/1970	25,837	448,424	44.3
33	Kogatende (North)	9/1970	25,354	320,303	36.9
34	Kogatende (North)	10/1970	22,940	384,637	68.2
35	Kogatende (North)	11/1970	22,457	192,189	86
36	Kogatende (North)	12/1970	21,974	64,067	118

Data sources

This case study relied on multiple sources of data, stemming from the enactment of lesson 2 in Melissa’s class. Prior to the first author entering her classroom, Melissa underwent consenting procedures with her students. The first author captured video recordings of the lesson, which spanned two fifty-minute periods of instruction over two consecutive days. The camera was set up towards the front of the room and focused on Melissa to protect the privacy of students who had not consented. The first author created activity logs while observing the lesson over the two days. We made transcripts of the video recordings to support analysis through the Vosaic video analysis software. Melissa provided graphs from nine different student groups, each of which had between 2-3 students, and student notebooks from 11 students in the class which captured their responses from the handout described above. Lastly, we also drew on the curriculum materials as a data source.

Approach to analysis

The first two authors undertook an interaction analysis (Jordan & Henderson, 1995) to help us identify key moves made by the teacher and students to decide on what data to privilege as evidence and also to develop conclusions from the data, focusing especially on the moves made by the teacher to support student sensemaking related to data modeling. We relied on both inductive and theoretically-driven coding, guided by the Manz et al. (2020) framework. We also looked to Lehrer and English’s (2018) data modeling framework for explicit data modeling moves - posing questions that can be answered with data, grappling with decisions about the design of investigations, and building understanding of the available attributes.

We began with an initial viewing of the lesson 2 videos to develop ideas about the teacher moves supporting data modeling. We then undertook an iterative process of developing a coding scheme and segmenting the video, resulting in a refined coding scheme allowing us to identify moments of moving across question, evidence, and explanation. Identifying moments moving across these elements highlight where students can be involved in scientific activity. The decisions around investigating support alignment - where students identify the relevant part of the larger phenomenon to investigate, decide how a dataset can help answer this part of the phenomenon, and develop an explanation based on data representations and conclusions. Table 1 represents these movements within our coding scheme. As we moved back and forth between developing our coding scheme and watching the video, we also noticed moments that did not align necessarily with these transitions but were necessary for supporting next steps - where certain knowledge or skills were needed for students to move forward. The first two authors discussed the coding together and adjudicated all disagreements. As a form of member checking, we shared our account with Melissa, who provided additional interpretations of her actions and students' experiences.

Table 1
Identifying Moments of Alignment Moving Across Data Modeling Coding Scheme

Code	Description / *Examples*
For Specifying the Data Model	
Deciding What to Privilege as Evidence	Build understanding of available attributes; Understand what the scientists did who collected the data; Identify the attributes that are best for answering their question; Predict or anticipate what the data might look like. Examples: *Students connect factors that affect food availability with how to measure it; Melissa problematizes this measurement dilemma, bringing students into this practice*.
For Interpreting Evidence from the Data Model	
Representing Data	Land on the data representation(s) that can communicate the claim with the data set. Example: *Some students graphed the relationship between rainfall AND population*
Determining Conclusions	Make sense of what the data and data representations tell in relation to their question. Example: *Melissa pressed for evidence-based explanations: "How do we know they are moving around?"*
Background Knowledge and Skills	Integrated as needed for supporting alignments and next steps: Using a new tool. Example: *Curriculum provided support for using CODAP*; Additional background information Example: *Curriculum and Melissa provided context of the Serengeti*; Connections to prior learning and students' everyday experiences. Example: *Student compares drought to Dust Bowl.*

Analysis and findings

We present our findings as a "play-by-play" (Derry et al., 2010) of the teacher enacting and students engaging in the lesson 2 data excursion, focusing on data modeling. We answer our research questions by describing how the teacher, curriculum, and students worked together leading up to and *specifying the data model*, in part by deciding what to privilege as evidence, and subsequently *interpreting evidence from the data model*, in deciding what data to represent and determining conclusions about the data model.

Specifying the data model

On the first day of this lesson, Melissa began by re-engaging students about the larger phenomenon under study, as called for in the curriculum. Having noticed there was a huge population increase in wildebeest and buffalo from 1960-75 in the previous lesson, she prompts students to consider why scientists wanted to investigate that. She asks, problematizing the phenomenon itself, "Why was that weird? Why did they start studying it?" Melissa then asked students to recall, "What did we think we should look at first?" Here, there is work in aligning the phenomenon to an initial investigation model, by helping students determine the relevant parts of the phenomenon and deciding what next steps are needed to build an explanation of it. Students came up with ideas like, "food, predation, and climate," as starting points for investigating the phenomenon further.

Melissa and the students agreed that the class should start with whether an increase in food caused the increase in wildebeest and buffalo populations. The curriculum calls for students to generate ideas for what the data would need to show, if the increase in food was in fact the cause of the population increase. As prompted in the materials, Melissa asks, "What changes would tell us that food was a reasonable cause for the [population] growth?" This prompted students to consider the attributes that are best for answering their question and beginning to anticipate what the data might look like.

This was a challenging thought experiment for students, so Melissa problematized how to answer the question for students, making clear this was not an easy task for scientists either. She started by asking, "How could they measure this?' and, "What might be challenging about measuring it?" One student puts forth, "have a robot do it?" Melissa, while acknowledging the idea, reminded students that this took place from 1960-1975, meaning the technology couldn't do that. Melissa followed with, "If they couldn't measure it directly, how could they estimate food availability?" These moves supported students in understanding what the scientists did and the context for collecting the data. Students seemed to struggle in coming up with a proxy for estimating this attribute, so she asks, "What do we think influences it the most?"

Melissa noticed a moment of needing to draw on prior background knowledge and explicitly invites students to make connections to what they've learned about how plants grow and thrive. Students drew on their prior everyday and school-based knowledge - responding with "sun, soil, water, and it depends on the weather." Melissa named this as similar to the real work of scientists: "This skill of figuring out what data to look at to answer a question is not an easy one. This is what legit, actual scientists have to do. Of all this data, how do we make sense of it? What do we need to pull and use and what do we need to be able to put aside?"

Before engaging in any graphing, Melissa asked students to consider what questions could, and couldn't be answered by the data at hand, as called for in the materials. Here, she supported deciding what to privilege as evidence (in this case, the attributes available) about whether the main investigation question could be answered with the given dataset. Also, as the curriculum directed, students made a plan for what relationships to graph and anticipate what the graphs would be likely to say, if more food is the cause of the increase.

In this part of the lesson, Melissa and the curriculum both supported students in aligning an investigation question to constructing a data model, by scaffolding what attributes would be helpful as evidence, bringing students into the uncertainty that the scientists grappled with around measuring food availability in a place as large as the Serengeti, and asking them to anticipate what the data model will show if food was the driver of the population increase.

Interpreting evidence from the data model

On day two, students made graphs focused on discovering, as the teacher put it, "what they can about the ecosystem," or as directed in the materials, whether there's a relationship between rainfall and buffalo and wildebeest populations (a question for which the dataset can provide an answer).

Students first watched a video explaining how to create and manipulate graphs in CODAP, providing the skills needed to access the tool, and modeling how to look at the population of buffalo and wildebeest over the course of a year in three locations in the Serengeti. Then, students made CODAP graphs in small groups. Melissa instructed them to construct "other graphs to better understand what was happening in the Serengeti." The graphs students produced mostly imitate the video tutorial in visualizing some attribute over the course of the year in the three locations. Students chose wildebeest population, buffalo population and monthly rainfall as the attribute to visualize in this way, but only two of the eight student groups made graphs that looked at both wildebeest (or buffalo) population AND rainfall simultaneously, which would be necessary to investigate the relationship between rainfall and population. In the subsequent discussion, Melissa called on those two groups to share what these particular graphs showed.

As students turned towards making sense of the data and representations, Melissa's interventions suggest they need reminders of what the data actually convey, and in some respects, the students' struggles with producing graphs that could help them see the patterns the curriculum intend prove to be a stumbling block for collective sensemaking. Melissa asked students to try and account for the relationship of rainfall and population through a line of questioning. Melissa pushed them for mechanisms, too, though it's not clear that they could answer the question she posed to them from the data at hand, she asks, "How do we know they are moving around? What are their needs that are different?" Student responses here included, "Wildebeest are in the plains in the wet season and then go to the other regions in the dry season," and, "They go to the other regions because there's water there," connecting to previous observations that there were rivers in certain regions.

She also pressed students to go beyond the simple statements of patterns they are seeing, and to specify what the connection between rainfall and population would be if food were the cause of the population increase: "We still haven't made a connection between them, though. So, what is the connection?" She started the sentence, "When the rainfall increases, they…" Here, we see Melissa guiding students in making sense of what the data and data representations tell them in relation to their question.

Towards the end of this lesson, Melissa invited students to go back to the Driving Question Board (DQB), a record of their own questions from the first lesson developed to guide their investigations, as a resource to remind them of the bigger question they came to the lesson with: whether the rapid increase in population from 1960-75 was due to an increase in rainfall. She asked, "Do we have data over several years?" "No," students say. In fact, the lesson did present them with such data, but students hadn't figured out successfully as a class which graphs would help them answer their question. She followed with, "What questions do we still have? What have we still not figured out? Let's go back to our DQB. Do we know why they are increasing? Remember, this is where we started."

In this part of the lesson, students interpreted evidence from their data models in order to answer the question about whether they see a relationship between rainfall and population size, and once they answered that, they considered if they can attribute food as the cause for the large growth in population size from 1960-75.

Melissa and the curriculum supported this ‘narrowing in’ on a piece of the phenomenon, taking a deep dive into the data, making sense of the data in order to explain this one aspect of the phenomenon, and then expanding back out to the central phenomenon of the unit, explaining the increase in buffalo and wildebeest populations on the Serengeti. Further, we see how students can be made aware of and be involved in some of the decision-making around data, and we see how the curriculum and the teacher support alignment in moving from question to evidence to explanation.

Discussion

Through this case study, we have analyzed how sensemaking about data can be supported in a high school biology unit focused on ecological systems. In addition to considering the complexities of using previously-collected data, we consider how data analysis is particularly challenging in the context of ecology, in which multiple time scales are relevant and simple causation is elusive. We have highlighted, too, how both curriculum and teacher moves can support navigating this complexity.

While Manz and colleagues (2020) and Lehrer and English (2018) wrote about contexts in which students collect firsthand data, our study provides the opportunity to showcase the complexities of presenting students with real-world datasets collected by scientists and what it can look like to engage students in understanding the circumstances under which the data were collected. We see here that the curriculum and the teacher are doing some of the “heavy lifting” students might have done if they had instead collected their own data. For example, the problems of measuring relevant quantities are highlighted to them in the materials, in the form of a video presentation and teacher moves that problematize how to measure food availability. The teacher, for her part, poses questions highlighting decisions needed to be made and why they are not simple to make.

In addition to the explicit data modeling moves outlined in Lehrer and English, we observed moves teachers can make to notice trends in data that then facilitate students’ sensemaking. We saw how Melissa was responsive to her students’ needs and took time to provide students with language and routines for looking at graphs, in one instance, not mentioned in our findings, introducing language around ‘positive’ and ‘negative’ relationships. As we have continued to revise the data excursions based on field testing, such instances have helped us realize that we need to provide more support for looking at and noticing patterns in data. Further, our coding helped us realize how the investigations framework does not yet account for a “time for telling” (Schwartz & Bransford, 1998), to provide students the background knowledge and skills they need to participate, while not giving away what we are hoping students can figure out together.

This case also highlights the zooming in and out that the teacher supports, so that students can see the big picture of what they are doing. This is a form of navigation (Reiser et al, 2021) – that is, helping students anticipate continuously where they are headed, so that they make sensible decisions in the present. This is especially salient in phenomenon-based units taking place over several weeks.

Though there was limited direct evidence of a broad range of students’ participation in the classroom from the video, Melissa expertly made space for students’ diverse ideas and frequently revoiced students’ contributions, so we were still able to get a sense of the ways students participated. However, it was not clear that this bid to engage in sensemaking was necessarily taken up by all students and we have more to uncover about how students’ own framing of the activity may have shaped their participation (cf., Munson, 2021).

Further, we saw many of the data modeling moves take place, but it is partly due to the intentional design of the curriculum and the skillful moves of the teacher, placing the heavy lift on the curriculum and teacher here, rather than on students. This may come at a cost for students’ opportunities to plan and carry out investigations, even if it is how science sometimes takes place in using data collected by others. It would be interesting to see how students work with collecting data firsthand, in contrast to a case like ours, where students are provided the datasets and the conditions of the scientists’ investigation model to work with.

Conclusion

This case study highlights some of the work needed to support the “practice turn” as part of current science education reform efforts, and reconceptualizing planning and conducting investigations, with particular attention on including students in the decision-making taking place in aligning questions to evidence to explanation. Such alignment work also mutually supports the use of the other science and engineering practices; for instance, we saw how students were engaged in asking questions and arguing from evidence while deeply engaged with data.

It is clear that students need support for data modeling even in a well-orchestrated classroom. This teacher played an active and nimble role in being responsive to students' needs as they grappled with data modeling, moving from phenomenon to explanation. We need to deepen our understanding of how teachers and curriculum work with students in moving away from ‘doing school’ and towards being actively involved in making and understanding the decisions surrounding data-based investigations.

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Anti-Black Racism & Mathematics: Designs for Intentionally Fostering Courageous Conversations in a Knowledge Building Community

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Abstract: In recent years, there has been growing attention in the learning sciences to address fundamental assumptions surrounding the nature of knowing and learning together, with renewed urgency to intentionally design for more equitable classroom practices. This study explores the implementation of a principles-based approach to designing an anti-racist mathematics classroom focused on fostering students' critical data literacy skills. Over the course of one semester, a grade 8 teacher engaged her students in critical conversations about carding in Toronto through sustained engagement with authoritative sources, real-world datasets, student-generated theories in Knowledge Building circles and Knowledge Forum. Qualitative analyses reveal the power of using analytic tools to restructure power dynamics in the classroom, as well as the critical role of idea diversity in helping students arrive at rise above theories of systemic oppression. Educational and moral implications of this work are discussed within the context of growing inequities in today's societies.

Introduction

Traditionally, science and mathematics have been taught as apolitical bodies of knowledge – as disjointed sets of facts, rules, explanations, and theorems for students to learn and acquire. Not only are these methods not effective for promoting deep and lasting learning (Bransford, Brown & Cocking, 2000), they fail to acknowledge two core issues: the cultural-historical systems of power upon which knowledge was built and the emergent, dynamic sociotechnical systems that are actively reshaping and advancing these bodies of knowledge in our societies today. More recently, there has been renewed attention in the learning sciences to address fundamental assumptions surrounding the nature of knowing and learning together. For example, "What "should" people learn?", "Who determines whose knowledge counts?", and "Which pedagogical approaches promote "good learning"?". As Esmonde and Booker (2016, p. 1) assert, "The learning sciences, therefore, must necessarily center conceptions of equity, diverse experience, and the dynamics of power and privilege expressed in and through learning environments."

Race, class, age, and gender have been critical issues in STEM education for a number of years, while renewed urgency to combat anti-black racism persists in many classrooms. In direct response to this pressing challenge, learning scientists have been working with teachers to critically engage with epistemological assumptions, values, and dispositions. One powerful outcome of such partnerships is the reframing of diversity as a pedagogical asset in classrooms, with teachers prioritizing the community funds of knowledge during curriculum design to create learning environments that connect with and reflect the lived experiences of their students (Nasir et al., 2006). Examples of such practices include the use of embodied imagining and argumentation to bootstrap scientific sense-making practices with youth from non-dominant groups (Bang, et al., 2012); the use of cultural datasets to leverage local knowledge during the problem solving process (Lee, 2008); the repositioning of students as "doers" of mathematics by anchoring learning activities in everyday cultural practices (Gutiérrez & Rogoff, 2003); and the exploration of social histories interwoven with data such as "family geobiographies" (Kahn, 2019) and personal data narratives (Stornaiuolo, 2019).

The proliferation of open datasets offer a realm of possibilities for students to extend their practices from "doers" of mathematics to "doers" of data science (Wilkerson & Polman, 2020). Not only is it a moral imperative "to empower students as informed decision-makers and stewards of their own data" (Ma et al., 2021), it is essential for them to engage in critical data literacy practices – to actively represent, interpret, and manipulate data (Wise, 2020) and to cultivate awareness of the ideological, historical, and political layers involved in data production (Irgens et al., 2020). In particular regard to mathematics, inequity is measurable. Critical conversations around real-world datasets enable students to conceptualize complex issues at the intersect of race, class, age, and gender and to engage more directly in conversations about social justice, the growing inequities in today's societies, and the lived experiences of marginalized groups in their own neighbourhoods. Furthermore, the place-based, authentic nature of locally collected datasets can inspire students to take transformative action (Phillip et al., 2013; Taylor, 2017).

Theoretical framework

The current study aims to extend this emergent line of work on critical data literacy by adopting a humanistic stance toward data science (Lee et al., 2021). More specifically, we used the Knowledge Building principles (Scardamalia, 2002) as an evolving framework for intentionally designing epistemic norms in data learning activities to unpack anti-black racism and empower marginalized voices to speak up in the mathematics classroom, with the ultimate goal of raising our collective critical consciousness.

We chose Knowledge Building as the pedagogical framework for this study because we view it as a fundamentally anti-oppressive approach to designing learning environments. Knowledge Building goes beyond socializing students as "doers" of disciplinary practices to nurturing students' identities as inventors of new disciplinary practices and creators of new knowledge (Bereiter & Scardamalia, 2014). For example, the principles of *real ideas, authentic problems* and *idea diversity* prioritize students' lived experiences and ideas as funds of knowledge worthy of time, reflection, and careful investigation by the entire community. The teacher fosters a culture where racial diversity and individual differences are viewed as strengths and encourages students to bring their unique perspectives to enrich discussions and promote idea development (Zhang et al., 2011; Tarchi et al., 2013). In doing so, the teacher engages in a continuous process of restructuring of power dynamics in the classroom to realize the principles of *epistemic agency, democratizing knowledge,* and *constructive use of authoritative sources.* Whereas in traditional classrooms, the teacher is positioned as the sole authoritative source of knowledge, in a Knowledge Building community, each and every member is positioned as a legitimate contributor to the community knowledge with students finding creative, idiosyncratic ways to contribute meaningfully to advance collective understanding (Zhang et al, 2009; Ma, Matsuzawa, & Scardamalia, 2016).

By intentionally de-centering ideas in the curriculum prescribed by experts (Teo, 2014) and shedding light on the promisingness of student's ideas (Chen et al., 2015), the teacher creates a safe and expansive space for all voices to be heard, acknowledged, and valued. Working closely with their students, the teacher also co-designs flexible discourse structures that encourage emergent collaboration, participatory leadership, and reflective restructuration (Tao & Zhang, 2020). For example, during *Knowledge Building discourse*, students are invited to set community goals, ask thought-provoking questions, build on each other's ideas, take risks with their learning by critiquing experts' ideas, and help each other generate better ideas, more coherent explanations, and *rise above* solutions that benefit not just themselves, but the community as a whole. In a Knowledge Building community, students develop a shared sense of belonging, interdependence, and ownership over their community knowledge – they find comfort in relying on one another for critical feedback and joy in supporting each other's learning through *symmetric knowledge advancement*.

In this paper, we elaborate on the exploratory and iterative processes involved in implementing a principles-based approach to designing an anti-racist mathematics classroom focused on fostering students' critical data literacy skills. More specifically, we follow the journey of Thelma Akyea, a secondary teacher in Toronto, Ontario dedicated to fostering a Knowledge Building community rooted in the principles of *epistemic agency, collective responsibility*, and *Knowledge Building discourse*. Over the course of one semester, Thelma engaged her grade 8 students in critical conversations to deconstruct authoritative sources and build theories about carding in Toronto based on local datasets derived from different neighborhoods. The ultimate goal was to deepen students' understandings of what the data really represented and how they can effect change in their everyday lives. Our research questions are: How did engaging students in critical data literacy deepen their awareness of anti-Black racism in Toronto? And What new insights and/or perspectives did students gain from their critical conversations?

Study design and implementation

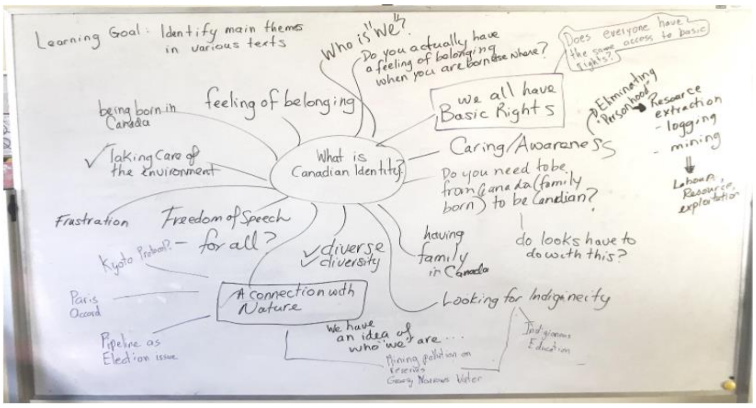
Using classroom-based design methodology (Barab, 2014) and the dual-layer Knowledge Building approach to teacher learning and co-design (Tan et al., 2016), Thelma and her colleague engaged in a mini Knowledge Building cycle of their own to explore the big ideas surrounding carding in Toronto. They experimented with strategies from the KB Gallery (Resendes & Dobbie, 2017), such as Knowledge Building circles; gathered online resources to map possible directions for deepening inquiry on Knowledge Forum (Figure 3b); and practiced holding critical conversations about anti-black racism to anticipate where students might go with their ideas. Additionally, Thelma worked with her colleague to ensure that her teaching practices themselves were equitable through regular check-ins to integrate students' interests, equity concerns, and lived experiences into her evolving classroom design. Her colleague also provided supports in the classroom for students with special learning needs. In the following section, we elaborate on each principles-based design iteration. Whereas the goal of the first design iteration was to co-create norms of interactions and use real-life provocations to initiate student discussions in Knowledge Building circles, the goal of the second design iteration was to foster inclusive ways of thinking and deepen students' empathy and reflexivity through sustained discussions on Knowledge Forum.

Design iteration 1: Critical conversations and KB circles

Epistemic agency, Idea diversity, Constructive use of authoritative sources, Knowledge Building discourse

As part of the design intervention, Thelma integrated Singleton & Linton's (2006) framework for courageous conversations as a layer on top of their classroom discourse, with the four commitments – stay engaged, speak your truth, experience discomfort, and expect and accept non-disclosure – serving as the explicit norms for their Knowledge Building circles. In reviewing key concepts, such as equity and inclusion, racism, anti-black racism, and microaggressions (Kendi, 2019), Thelma encouraged her students to adopt an anti-oppressive lense by being mindful of their own privilege and the space they occupied in their Knowledge Building circles (i.e., who speaks when and to whom). This meant that students agreed to be open to the possibility of feeling uncomfortable and agreed to be respectful and non-judgmental with their peers, even when they were being challenged. Thelma also provided assurance that her classroom was a safe space to take risks and make mistakes. Together, they would practice compassion and be gentle with each other throughout the process.

Figure 1
Diagram showing connections between students' ideas during their KB circle on Canadian identities



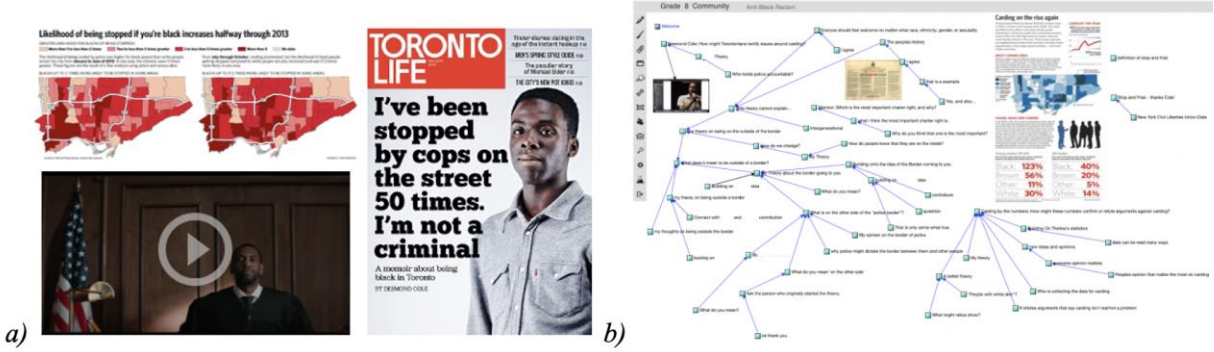
The first Knowledge Building circle was on the broad topic of Canadian identities to draw out students' lived experiences and funds of knowledge. Students provided numerous popular ideas of what it means to be Canadian, including basic rights, freedom of speech, a sense of belonging, and environmental stewardship (see Figure 1). Building on this first discussion, Thelma encouraged her students to unpack the notions of freedom and belonging by exploring how these concepts might be experienced by members of marginalized communities. For example, "Does everyone really have the same access to the basic rights?" and "Who is "we"? Do you actually have a feeling of belonging when you are born elsewhere?". Students read articles and opinion pieces online, including an essay about carding and anti-black racism in Toronto written by a prominent local journalist, Desmond Cole (2015), and together, they watched a debate about carding in Toronto (Figure 2a). Students then self-organized into small groups to dig deeper into articles of their choice by examining various infographics and making sense of the demographic data presented to address claims that anti-Black racism exists in Toronto.

Design iteration 2: Knowledge Forum and metadiscourse

Democratizing knowledge, Community knowledge, Improvable ideas, Rise above, Embedded assessment

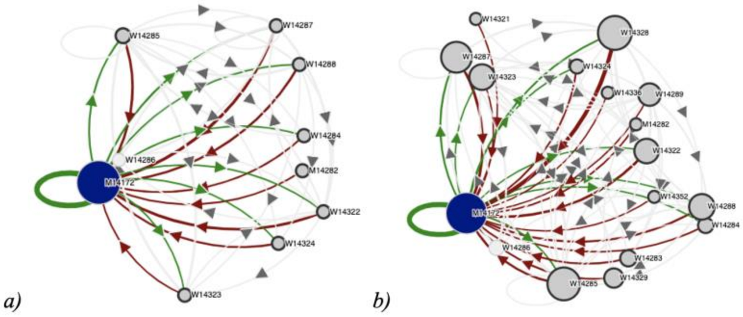
Thelma invited her students to continue their critical conversations on Knowledge Forum (Figure 2b) where they collectively unpacked what it meant to be carded by the police. Students shared and integrated information and multimedia between groups and actively worked toward improving their theories and explanations through use of epistemic scaffolds such as "My theory", "I need to understand", "This theory does not explain," and "A better theory". At one point in their discussion on anti-Black racism, students decided to return to their original theories about Canadian identities after re-examining the Canadian Charter of Rights and Freedoms with a more critical lense. They decided to create a new view in Knowledge Forum to share their revised theories of what it means to be Canadian and what it means to belong in Canada, including having a more nuanced discussion on the relations between identities, rights, and freedoms. This discussion prompted them to consider racism in a new light, with students expanding their conversation to think more deeply about what individuals, grassroots communities, and governments can do to protect the interests of people in marginalized communities and what changes must be made at each level to realize a more socially just society in Canada.

Figure 2
a) Authoritative resources on anti-black racism and b) students' discussion in Knowledge Forum.



At the beginning of this iteration, students were primarily building on the teacher (blue node in Figure 3a), but after a metadiscourse session facilitated by the social network visuals, students renewed their four commitments to critical conversations and worked more intentionally to build on each other's ideas as a way to democratize knowledge and foster a more inclusive community. Figure 3b shows the redistribution of ideas in the community, with more students (grey nodes) appearing the same size as the teacher (blue node) and denser, more mutual connections between students (green and red edges). Students also began renaming note titles to include "Building on [student's] idea" and using the scaffold "Putting our knowledge together" more frequently to intentionally seek coherence between the different ideas and perspectives represented in Knowledge Forum.

Figure 3
Social network of class a) before metadiscourse and b) after metadiscourse.



Data sources and analyses

Because this study focuses on fostering and sustaining critical conversations in the mathematics classroom, we collected various forms of discourse data to examine the community's evolution of thought over the course of the two interventions. Using teacher notes and teacher reflections from Knowledge Building circles and student notes in Knowledge Forum, we conducted content analysis to identify emergent themes and concepts in students' discussions. In an effort to maintain the holism of the classroom design, we adopted a complementary mixed methods approach (Creswell & Plano Clark, 2007) to triangulate results across the different data sources and seek convergence in addressing the research questions. More specifically, we integrated qualitative analyses of teacher notes and student notes with quantitative analyses of expert corpora, teacher notes, and student notes in Knowledge Forum to explore the conceptual space of student ideas. Students wrote almost 200 notes over the course of 4 months. On average, each student wrote 7.5 notes and read 5 notes for every note they wrote.

Student discourse in KB circles and Knowledge Forum

Figure 4 shows a comparison of word cloud's between Desmond Cole's article, Thelma's discourse, and the student discourse. In Desmond Cole's article, he challenged the idea of Toronto as "a post-racial city, a multicultural utopia where the colour of your skin has no bearing on your prospects" by sharing his personal experiences of being carded and interrogated by police for more than 50 times over the span of living in Toronto for almost a decade. He goes on to explain how "that unwanted scrutiny, that discriminatory surveillance, [makes him feel like] I'm a prisoner in my own city". In response to this article, Thelma's discourse was focused on issues of barriers and access of members in various marginalized communities, including black, indigenous, people of colour, and LGBTQ+ folks. Students' discourse, on the other hand, was focused on the issue of belonging: Who is considered on the inside/outside of borders? and Who gets to decide where a border starts and ends?.

Figure 4

Word Cloud of a) Desmond Cole's article, b) teacher discourse, and b) student discourse in Knowledge Forum.

To address these questions, students searched the official city website as an authoritative source to explore the datasets referenced in their articles and infographics to learn more about specific marginalized communities. Students drew from their understanding of Toronto's different neighbourhoods to parse out high- and low-income communities to compare and contrast patterns. One group visited the Toronto Police website to gather more data to learn more about other safety statistics in various Toronto neighbourhoods. Across all the groups, student consistently found a correlation between being a Black boy and the neighbourhood where they were carded. In their initial theory, they thought that Black boys would be more likely to be carded in all neighbourhoods, but a closer, more critical examination of the datasets suggested that was not the case. To their surprise, the income of the neighbourhood was a key mediating variable in the likelihood of a Black boy being carded. That is, they found that Black boys were more likely to be carded when they were in high-income areas and less likely to be carded when they were in low-income areas. This improved theory also surprised Thelma, and she encouraged her students to continue their conversation on Knowledge Forum to further upack the implicit gatekeeping purposes of carding and borders. Below is an excerpt of student discourse in Knowledge Forum, where students juxtaposed ideas of belonging from their conversation about Canadian identities with carding to understand who cards whom, when, where, and why:

> **Student A**: [My theory]: I would say that these stats confirm a big issue around carding. That is, black people get stopped and carded far more than white people. If you look at this data you can clearly see that out of all males carded 40% are black and only 14% are white.
> **Student B**: [A better theory]: What the numbers show is what is the portion of black people carded to the portion of the people with white skin. What is the ratio?
> **Student C**: [My theory]: We think that being on the outside of a border means that you weren't originally from the community/place that you are trying to cross to. I also think that to be on the outside of a border means you don't feel accepted or comfortable in that community.
> **Student D**: [This theory cannot explain]: How some people can be 5th generation Canadians, and they still have that feeling of exclusion based on race, religion, sexuality, gender, etc. That feeling of alienation does not mean they are not from that place, but rather that people are making them feel like they don't belong.
> **Student E**: What I think I means to be outside the border… I think that emotions comes with some of the part and I feel like a lot of people feel nervous and scared just because maybe they think they might get stopped or questioned.
> **Student F**: [My theory]: I would like to build on to Student D's theory that the police border can decide whether to let people in or not. I agree with Student D and I think that the police sometimes deliberately choose to let people through because of people's background or any other reason.
> **Student G**: [Putting our knowledge together]: it seems that being carded is like having a scary unmovable border approach you and you have no way of avoiding.
> **Teacher**: [I need to understand]: how we can change these feelings of being outside?

As can be seen from this excerpt, students really began to see the arbitrary nature of borders, how it takes away agency and alienates those it serves to exclude, and by extension, the hurtful and traumatic consequences these practices have and will continue to have on marginalized communities for generations. A compassionate reflection from a student, “I would say that everyone can have a different theory or opinion of carding, but I would say that the opinion that truly matters is the opinion of the people being carded.” was brought to a heated discussion in a Knowledge Building circle, where students touched upon the issues of microaggressions and racial gaslighting. One student asked, “I wonder what the percentage of people who were carded was dressed well… I feel like if someone could look like not a threat and they still could be carded” to which a student quickly responded, “I think… it’s not really the kind of irrelevant… they shouldn’t be pulling people over because of how they dressed. Flipping it, it would be weird no matter what it is – not the dress – I think police officers making that excuse is counterproductive”. Another student then added “Even if they look like a threat that doesn’t make it okay. Even if the police were justified in what they were doing”. It was at this point that students began to uncover the “self-perpetuating cycle of criminalization and imprisonment” of Black bodies in Toronto, and that “identities are not the same for everyone, although we should have the same rights and freedoms”. Through sustained discussions around Desmond Cole’s article and critical investigations of multiple datasets, they came to understand that carding affects the daily livelihoods of Black people living in their communities. As a Knowledge Building community committed to anti-Black racism, they began digging deeper into the Canadian Charter of Rights and Freedoms and started generating new discussions on Knowledge Forum on what they could do to be more intentional about combating anti-Black racism and reducing discrimination in their local neighbourhoods.

Discussion and implications for future work

This study aimed to extend the work on power and privilege in the learning sciences to explore how we – teachers, researchers, and students – can engage each other in iterative design for more equitable, anti-racist mathematics classrooms. Over the course of one semester, a grade 8 class engaged in critical conversations around real-world datasets to problematize the notion of Toronto as a “postracial city” and to unpack social, political, economic, and historical dimensions of “belonging” in Canada. By exploring and generating statistical trends in local demographic data, students grappled with complex issues at the intersect of race, class, age, and gender and reflected deeply on their roles in creating equitable, justice-oriented communities. To return to Esmonde and Booker’s (2016) three questions: Within the context of the secondary mathematics education, it is our view that students should learn critical data literacy (among other key mathematical competencies); students’ funds of knowledge should serve as the foundations of curriculum; and Knowledge Building offers one way to integrate the first two aims while helping students see themselves as legitimate creators of knowledge (Scardamalia & Bereiter, 2006), which bears with it a civic duty to create and advance ideas for public good.

It should be noted that even if the teacher is not at the center of classroom discussions, the teacher plays a central role in creating a safe space for having critical conversations with their students by setting explicit expectations on how they can hold discomfort, compassion, and mutual respect for one another; using a variety of strategies to reflect on and restructure power dynamics in the classroom (e.g., showing students the evolution of classroom dynamics and who is occupying a position of power during discussions), and co-creating inclusive and equitable practices with her students by extending her position of power to them and inviting them to listen deeply to one another’s ideas and build on each other’s ideas with intention, care, and kindness. For example, Thelma and her students responded differently to Desmond Cole’s article. Instead of directing her students along known paths of idea development, she placed trust in their collective potential and encouraged them to self-organize according to their emergent interests and shared community goals. Therefore, the principles of epistemic agency and idea diversity were key to driving students’ idea improvement, idea cohesion, and the generation of rise above perspectives on the broader implications of belonging, citizenship, and anti-Black racism in Canada. That is, students would not have been able to go deeply with their ideas had they not been given opportunities to pursue authentic issues they cared passionately about and reflect on the connections and direct consequences they had in their everyday lives – for themselves, their friends, their families, and neighbours in local communities.

A recent critique of Knowledge Building pedagogy suggests that taking an ideas-centered, principles-based approach (Hong & Sullivan, 2009) disregards the person-centeredness of learning (Hod et al., 2018). However, this case study proves that this cannot be further from the goal of engaging students in community knowledge advancement to raise critical consciousness. In this study, students engaged in critical data literacy with real-world datasets to develop a nuanced understanding of Canadian identities, freedoms, and rights; sense of belonging in communities; and policing practices that promote fear, alienation, and racism in the everyday lives of Black people, as well as the intergenerational effects of racism on communities of colour. Consistent with past work that aims to adopt a learner-experience-centered approach to data science education (Wilkerson & Polman, 2020), our study indicates that using a Knowledge Building approach can equally enhance students’ epistemic agency, social awareness, and expansive understanding. Put differently, our work readily aligns with what Lee and colleagues (2021) propose as a humanistic approach to data science, with students moving seamlessly across constellations of personal, cultural, and sociopolitical layers of data engagements during class discussions and learning activities. Furthermore, we contend that any type of humanistic account for learning must transcend systems of oppression so that all members of the human race – regardless of age, class, gender, ethnicity, religion, etc. – can thrive in mutually supportive and sustainable futures. Each and every student has a role to play in this vision and it is the moral responsibility of educators and learning scientists to design more equitable and inclusive learning environments to realize this vision in schools, at all levels of education. As we have stated previously, the classroom culture "co-created by [the teacher] and her students are not merely a reproduction of existing realities outside the classroom, but rather, a re-imagining of what life in a knowledge society can look like when all ideas are valued and all members are empowered to contribute equitably to the advancement of collective goals. For this to happen, Knowledge Building must be a way of life for the teacher as well as her students" (Horner & Ma, 2020).

To further this vision, a third design intervention with Thelma's class is underway to explore how the global pandemic has amplified inequities in Canadian societies, including access to health in marginalized communities. Thelma is working with more advanced open datasets and public dashboards, such as providing students with options to calculate and generate indices to measure inequities in Toronto and go deeper with issues at the intersect of race, class, age, and gender. Likewise, learning scientists must continually work with educators like Thelma and invite new teachers to unpack power and privilege in classrooms. As Farrell and colleagues (2021) note, research-practice partnerships must actively work toward reducing inequities in educational systems. What's more, research-practice partnerships offer us the space to intentionally create misalignments in education systems so that new re-alignments can be created (Tan et al., 2020) – ones that will restructure power dynamics to eradicate inequities, make knowledge accessible and pervasive for all, and enhance symmetric advances within and between communities toward building more inclusive and sustainable knowledge societies.

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Exploring Family Engagement with Photo-Taking to Support Observation During an Outdoor MAR Experience about Pollinators

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Abstract: Mobile technologies that include photo-taking elements help to support children's observation and exploration of the natural world; however, how families engage with digital photo-taking features has not been fully explored. We investigated how 22 families engage with digital photo-taking features of a MAR app that prompts place-based observation of the outdoors. Families' interactions with the app were qualitative coded and then two vignettes from different place-based micro-learning locations were developed to understand learning practices related to photo-taking. Findings show that families were deliberate in taking photos that recorded their observations of the outdoors; however, the environment and features within the app impacted families' observational talk and excitement levels during the photo taking activities themselves. These findings contribute to the understanding of the importance of photo-taking activities during MAR experiences.

Introduction

People use photographs to document the natural world, capturing their observations for later reflection. Scientific photo-taking, along with other tools, supports record-taking and encourages children to develop scientific observation skills (Eberbach & Crowley, 2009). Photo-taking features in mobile technologies, while providing an activity that appeals to children, have been shown to help people learn to observe and identify the nature around them (Land & Zimmerman, 2015; Kawas et al., 2019). Mobile augmented reality (MAR) technologies support families' exploration and observation of place-based experiences by virtually augmenting digital features onto local science phenomena (Zimmerman, Land, Faimon & Chiu, 2022; Yun et al., 2022). When designing an MAR experience, small design decisions can impact learners' interactions with and movement through the environment. However, there is a lack of research exploring how families interact with photo-taking activities to encourage scientific observation within MAR. This study explores: *how do families engage with digital photo-taking features of a MAR app that prompts place-based observation of the outdoors?*

Conceptual framework

Our research was designed with the concepts of learning-on-the-move (LOTM) (Marin, 2020; Silvis et al., 2018) and sensory observation and engagement (Eberbach & Crowley, 2009). LOTM emphasizes how people learn collaboratively as they move within spaces where their learning is grounded, such as learner's experiences and relationships with nature and family (Marin, 2020), and how multi-site, multi-modal technologies are used as learning tools (Silvis et al., 2018). Learning experiences are anchored within and influenced by the environment and place that learners move through. In designing for LOTM we encouraged families to explore the needs of pollinators and build knowledge by moving within and engaging with native pollinator's habitats through observation, prompts, and other activities grounded in place.

Mobile technologies encourage families and youth's engagement toward nature and science in outdoor spaces through observation, science talk and discussion, and tactile investigation of nature (Land & Zimmerman, 2015; McClain & Zimmerman, 2016; Kawas et al., 2019; Yun et al., 2022). Learning experiences that are situated in a specific outdoor place help to support families' observations and knowledge building of the world around them (Marin & Bang, 2018). Tactile and visual sensory engagement help support children's scientific observation, encouraging them to use their everyday observation skills as connected to disciplinary knowledge brought in by a family member or tool (Eberbach & Crowley, 2009). Additionally, scaffolding parents' and families' conversational techniques can aid in supporting joint attention and talk as families make observations of the natural world (Eberbach & Crowley, 2017). Children observe their world every day, but supporting scientific observation requires more structured activities or family support (Eberbach & Crowley, 2017), such as encouraging record-taking of children's observations (Eberbach & Crowley, 2009) through taking photos of the natural world in the structure of a scientific observation activity (Kawas et al., 2019). Previous work (Land & Zimmerman, 2015; Zimmerman et al., 2022) has demonstrated how photo-taking as part of an analysis, scientific classification, or field journal framework can encourage scientific talk. Building on this work, we explore how families engaged with the photo taking activities throughout the app as a tool designed to support scientific observation and structured recording of observations and science content.

Methods

This analysis is situated within a larger Design-Based Research (Sandoval & Bell, 2004) study, SPACES, to create MAR applications for outdoor science education for rural families. This analysis focuses on the second iteration of an app about pollinators designed for Shaver's Creek Environmental Center (SCEC), a 7,000 acres (28 km^2) outdoor learning center associated with Penn State University, for use on walking trails around the main building.

Nature center, app, and photo taking app features

The study was held at SCEC which serves approximately 100,000 visitors annually. Our team of learning scientists collaboratively designed our MAR app on pollinators with pollinator researchers and SCEC staff. The app took families on an outdoor tour around the main educational building focusing on pollinator gardens and other environmental features that a pollinator would need to survive in meadows and forested areas.

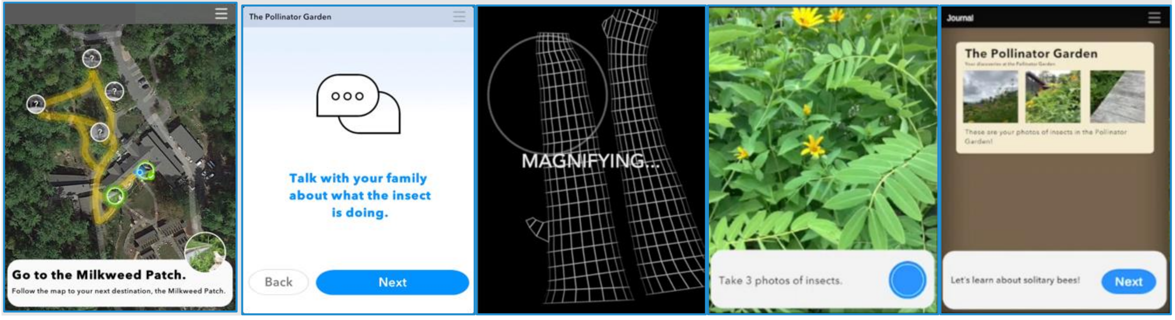
The Pollinator Explorers App is focused on a specific type of native pollinator—solitary bees—and what they need to thrive in a forest and meadow habitat. Families in our study used the app to explore six different GPS-triggered micro-learning locations around the outside perimeter of the nature center and collected evidence (through photos) of what these native bees need to live and thrive in this habitat. Our app was built with the ten design conjectures in Table 1, as guides for the development of the Pollinator Explorers App, with this analysis focusing on design conjectures five and six.

Table 1
The ten design conjectures guiding the development of the Pollinator Explorers App; our analysis here focuses on conjectures 5 and 6 (bolded)

Overarching Design Conjectures	**Features in the MAR app**
1. Visualize 'seeing the unseen' scientific phenomena in digital simulations and animations.	After scanning a flower, a magnified view of a pollen grain is shown.
2. Place-based photographs, line-art, and text-based descriptions of the science concepts that connect to families' communities in the present day.	At all microlearning locations, content is given and then families engage in an observational activity to find real-world examples of the phenomena shown.
3. Immersion through AR filters and digital storytelling allows learners to imagine that they are in a new place or time.	A log is scanned and then the visitors can imagine the inside of a typical nest for a solitary, native bee is shown.
4. Use of movement across a space to represent unfolding storyline, aspects of a concept, or changes across time, space, or season.	A wayfinding map allows visitors to emphasize four critical ecological phenomena that come together to support how bees survive.
5. Sensory engagement via tactile and visual observation of objects or specimens on-site to support scientific noticing.	**At the log microlearning location, families use content provided to count and collect data on downed trees.**
6. Channel attention to key scientific phenomena through the families' photo-taking activities.	**The families use the content provided to identify pollen in the center of flower.**
7. Integrate on-site observations with digitally presented science content by creating a scientific journal.	The learners' photographs and bee observation checklist (of yes or no answers) are populated in a journal that they can review after the visit.
8. Discussion prompts or place-based activities that support sense-making and knowledge integration via focusing conversation on scientific phenomena and big ideas.	Families are encouraged to answer questions about the evidence of bees or other pollinators, talk about what they notice, the difference between a pollinator and human tongue, and what bees need in a habitat.
9. Discussion prompts support personalizing the experience via focusing conversation on prior experiences of the families.	Families are encouraged to connect their prior experiences with flowers, bees, and beehives/nests with the new content presented.
10. Discussion prompts, content, and digital activities to support environmental stewardship, personal connections, or community awareness.	Families discuss they humans could help maintain healthy bee habitats (e.g., by planting flowers that bloom at different points in the season).

Families navigated between micro-learning locations using a GPS map that tracked their location (Figure 1a) All micro-learning locations included text, photographs, and line art to support observations related what a bee needs to survive (I.e., food for self and young, water, diverse landscape, nesting locations) (Figure 1b). Micro-learning locations included digital augmented reality elements of science phenomena (i.e., bee nests inside of logs, microscopic pollen grain) layered over real-world objects to further families' observations and immerse them in more deeply understanding bee needs and habitats (Figure 1b). At the end of each micro-learning location, families took photographs that recorded what they learned and observed based on specific photo taking prompts (Figure 1d), which were then saved in their journal (Figure 1e). The first five micro-learning locations focused on a specific aspect of what a bee needs to survive in habitats like meadows and forests, while the sixth micro-learning location included discussion questions and activities that helped families bring what they had learned together and make connections across stops and the environment. For this analysis, we focus on the first five micro-learning locations where families were asked to take photographs.

Figure 1
Pollination MAR App Features: (a) family discussion prompt, (b) AR log scan, (c) GPS map, (d) photo taking screen, and (e) journal summarizing content and photos taken


Go to the Milkweed Patch.
Follow the map to your next destination, the Milkweed Patch.
Talk with your family about what the insect is doing.
Take 3 photos of insects.
These are your photos of insects in the Pollinator Garden!
Let's learn about solitary bees!

(a) *(b)* *(c)* *(d)* *(e)*

Participants

Through our partnership with SCEC, the Center sent out Twitter, Instagram, and Facebook messages announcing the days and times that our team would be on-site conducting a research study. An article was included in the Center's member newsletter as well. Study recruitment bookmarks were placed at local libraries and a science center as well. Families had to have one child between the ages of 5-12 to participate and at least one of the adults who was present had to be the legal guardian or parent for all participating children. Families also had to be willing to be audio- and video-recorded; however, a legal guardian/parent had to opt-in to having their families' images shown in research-oriented publications such as this one. Families received one US $20 gift card for completing all study protocols.

Our team recruited 29 families on-site at the nature center; however, seven families were excluded from this analysis due to partial data. After written consent and children's assent was obtained, families borrowed an iPad^{TM} mini pre-loaded with the app, which also screen-recorded the family's tour experiences. At least one family member wore a GoPro mounted on a baseball hat to collect data from the learner's perspective. From the 22 families, there were 34 adults and 37 children. Of these families, their self-reported racial affiliation included White (77%), Hispanic or Latinx (6%), Asian (6%) and Other (1%). Children (male: 51%, female: 46%, nonbinary: 0%) were primarily 5-12 years old (78%; ages 0-4: 14%, ages 5-8: 49%, ages 9-12: 30%, ages 12+: 8%). Two families (7%) homeschooled their children. 68% of families had previously visited the nature center. All 22 families completed the MAR experience with just their consented family present and had full screen recording and GoPro — without interruptions of their recording due to battery, memory card, inadvertent shutting off screen recordings, or other common malfunctions.

Data sources and analysis

Data consisted of 14 hours of merged video data from 22 families. Post-visit interviews were conducted on-site and included questions about what families learned about pollinators as well as questions that asked families to reflect on their experience with the app to support further redesign. The families' screen recordings of the visit and GoPro videos were merged into side-by-side video files for researchers to consider both the outdoor environment and technological environment in the analysis. Post-visit interview files were created as well. The merged video files and post-visit interviews were transcribed professionally and checked by research team members for accuracy.

The merged data files were analyzed qualitatively by the first and second author. Researchers used a binary coding framework (I.e., yes/no questions) in Table 2 to analyze the recordings regarding if a) children were engaged during the photo taking activity, b) any family member made observations or connected to app content, and c) families or children expressed excitement during the photo taking activity for each GPS-triggered micro-learning location. Building on "blitzcoding" (Callanan, 2012), we used this binary coding scheme to quickly identify key learning locations throughout the data that could shed light on how families engaged with the digital photo taking features throughout the app experience. Prior to coding, the first and second author jointly viewed one video as a training session, and then independently coded five videos with 91% agreement. The coders worked through disagreement about discrepancies, and the code book was expanded and solidified. Next, the two researchers separately coded the rest of the videos with a shared understanding of the coding framework. We used the results from the coding to identify patterns across the families' interactions in the micro-learning locations. This coding analysis was then used to inform our selection of exemplar vignettes from two families at the different micro-learning locations. These vignettes served to expand upon the patterns in the coding analysis and to explore differences in family engagement and observations when taking photos with the MAR app. Post-experience interview videos were also reviewed to see how many families mentioned the photo-taking feature when asked for feedback about the app.

Table 2
Codebook for how families interacted with the photo taking app at each micro-learning location

Yes/No Questions	Description
Different photos?	The family takes three different photos (Ex: photos of three different flowers, photos of a log from three different angles)
Deliberate photos?	The family takes at least one picture that represents the photo taking prompt
Children engaged?	Engagement of at least one child in the photo taking activity. This could include taking photos, making observation, talk or non-verbal excitement or interest connected to the micro-learning location or photos during the activity
Scientific observation or talk?	At least one family member remarks about the app content or nature observed (Ex: "this one where there's a bug on it, that's the common milkweed.")
Children express excitement?	The children expressed excitement (Ex: running to find a flower, "Ooh, a bee!")
Other family excitement?	Other family members expressed excitement (Ex: pointing to a flower, "Ooh, a bee!")

Results

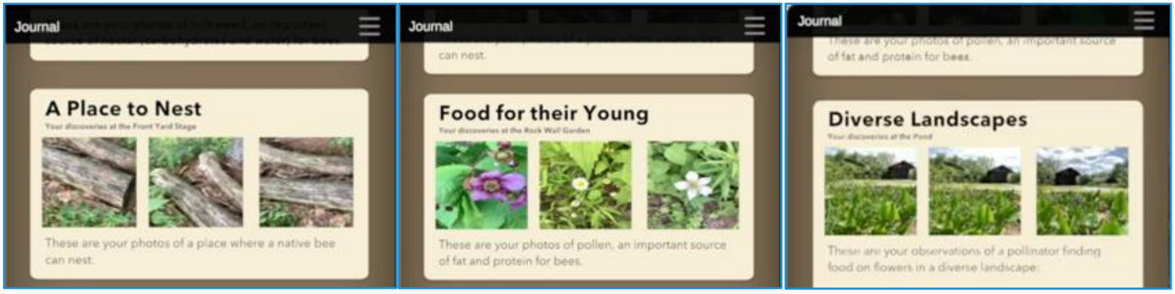
Overall, families enjoyed the ability to take photos, and the majority of families (55%) mentioned the photo taking activities as something that stood out to them when asked for feedback about the app. Throughout the MAR experience, families engaged with the photo-taking activities (Table 3) by taking the time to take different photos of aspects of nature they observed and make scientific observations or connections to the app content. While each micro-learning location included a similar photo-taking activity prompt around the selected ecological concept (Figure 1d, I.e., "take three photos of ___"), they all had different family discussion prompts and other activities that influenced families' interactions.

Table 3
Percentage of families that engaged with the photo-taking activity at each micro-learning location

Form of engagement	*Pollinators*	*Nectar*	*Nesting in Logs*	*Pollen*	*Diverse Habitat*
Different photos?	100%	100%	95%	100%	91%
Deliberate photos?	100%	100%	100%	100%	91%
Children engaged?	100%	95%	86%	100%	95%
Scientific observation/talk?	95%	86%	50%	95%	91%
Children's excitement?	73%	41%	27%	41%	73%
Other family excitement?	73%	41%	18%	55%	55%

The app asked families to take three photos but did not specify that those photos had to be of different things or at different angles (Figure 1d). Despite this all families did this at three of the micro-learning sites, and most did at the other two sites (95% at nesting in logs, 91% at diverse habitat). While families could have assumed that they were supposed to take three different photos, this practice could have also been driven by a desire to document different things that they had observed. At the other two micro-learning sites a small percentage of families did not take different photos, either because of an adult taking the same photo to get through that part of the app while the child was disengaged or because families were trying to capture one specific aspect of the location. All families also took "deliberate photos" or photos that represented the photo taking prompt at the first four micro-learning sites (Figure 2a, b, d), with two families not taking deliberate photos at the final micro-learning site. While one family was not engaged with the app at all, the other family was highly observant and engaged with the micro-learning location and photo taking prompt but was unable to find any pollinators to take photos of and just took pictures of the pond in general. Therefore, their photos did not fit our definition of "deliberate photos" despite the family spending a relatively long time trying to find a pollinator and making scientific observations about the location. Families with children that did not engage with the photo taking activity still could have one adult taking different or deliberate photos as a form of "rule following" but the children would be completely disengaged from the app. For example, one father took 3 different and deliberate photos at the nesting in logs micro-learning location but no one in the family spoke and their 8-year-old daughter was looking at something or watching her father take photos without engaging. Families could also have children that were engaged but did not take different photos. This only happened at the diverse habitat micro-learning location with two families while one of the children was attempting to take a close-up photo of the same pollinator that they had been observing (Figure 2c). Overall, 97% of families with children that were engaged with the photo taking activity also took different photos and/or deliberately took photos.

Figure 2
Families' photos in the journal showing examples of: different and deliberate photos at the (a) nesting in logs and (b) pollen micro-learning sites, and (c) deliberate but not different photos



Journal

A Place to Nest
Your discoveries at the Front Yard Stage
These are your photos of a place where a native bee can nest.

Journal

can nest.

Food for their Young
Your discoveries at the Rock Wall Garden
These are your photos of pollen, an important source of fat and protein for bees.

Journal

These are your photos of pollen, an important source of fat and protein for bees.

Diverse Landscapes
Your discoveries at the Pond
These are your observations of a pollinator finding food on flowers in a diverse landscape.

(a) *(b)* *(c)*

Individual micro-learning location analysis

The first micro-learning location about pollinators showed the highest levels of all coded aspects of engagement. This could have been because of the open-endedness of the photo taking prompt ("take three photos of insects"), the previous observation activity, or because it was the first part of a new learning experience. On the other hand, the solitary pollinators nesting in logs micro-learning location had the lowest levels of observation talk (50%), engagement (86%) and excitement (27% of children, 18% other family members). While families showed high levels of engagement during the rest of the activities at this micro-learning location, including an observation activity and an AR scan of the log, the photo taking activity did not elicit this response. This could have been because the families were still focused on the AR scan, or that the static nature of the photo taking prompt ("take three photos of logs") made this activity lackluster in relation to the other dynamic activities during this micro-learning location. The last photo taking location, covering diverse habitats at the pond, showed high levels of excitement (73% of children, 55% of other family members) and continued high levels of scientific observation and content comments (91%) but also showed a dip in taking different and deliberate photos (91%). These trends could have been influenced by this activity taking place late in the app experience (the fifth micro-learning location), children being excited to look at the other wildlife around the pond (frogs and turtles), or the two observation activities (family discussion and observation checklist) that preceded the photo taking activity at this micro-learning location. These trends demonstrate how families' experiences, talk, and engagement with the photo-taking as an observational recording tool differed based on app structure, environment, and family interactions at each micro-learning location. To investigate how families experienced the photo-taking activity, we analyzed vignettes from two families at different micro-learning locations in the tour.

Vignette 1: Photo-taking supporting observing flowers and pollinators on milkweed

At the nectar micro-learning experience (the second micro-learning location), families are introduced to two different forms of milkweed, common and swamp, that are planted locally as nectar for pollinators. The family of David (Father) and Amelia (6-year-old-girl) demonstrate how families used the photo-taking activity to continue their observations of pollinators that they did at the first find-a-pollinator location while adding in new content about milkweed and identification of flowers from the MAR app (Figure 3).

David: Milkweed ((points at the swamp milkweed))
Amelia: Okay. So, we'll first take a picture of the orange one with the bee on it. Got it. ((takes picture))
David: So that was the swamp milkweed, and then this one where there's a bug on it ((points to pink milkweed)), that's the common milkweed.
Amelia: All right. ((takes picture)) Now it said three photos. One more photo to do. Let's take a picture of two of them together. ((backs up to take a photo of the milkweed patch))

This family's interactions showed one way in which families engaged with the digital photo-taking features of a MAR app: supporting scientific observation by applying the content in the app with the specimens on-site. For instance, David brought together the content from the *MAR_app* with the local landscape during the photo-taking activity, referencing both types of milkweed plants (common and swamp) shown in the app when his family took pictures. While taking photographs, David and Amelia engaged in observations of the colors and types of milkweed flowers, as Amelia tried to take three different photos that captured what she observed. Their observations of pollinators on the flowers also influenced Amelia's choice of which orange milkweed to take a picture of, as she deliberately chooses the "one with the bee on it". In reviewing the photos, Amelia took in their journal, David remarked "those are great milkweed pictures", encouraging her photo taking and observation skills. In this way, the *MAR_app* supported families' sensory observation related to new science content such as the types of milkweed present on-site.

Figure 3
(a) iPad screen showing milkweed at the micro-learning location, (b) iPad screen of Amelia taking photos of the milkweed and pollinator, (c) David pointing out the milkweed, (d) journal showing their photos

There are two types of milkweed in front of you.

Can you find them?

Take 3 photos of the milkweed.

These are your photos of milkweed, an important source of nectar (carbohydrates and water) for bees.

Let's learn about meadow and forest habitats.

(a) *(b)* *(c)* *(d)*

Vignette 2: Photo-taking supporting identifying pollen on native flowers

During the photo taking activity at the pollen micro-learning location, families used visual observational practices to identify flowers containing pollen like those presented within the app. John (Father) helped his children, Maxwell (12-year-old boy) and Sean (6-year-old-boy) engage in these observations (Figure 4a, b). Both children showed excitement while photographing flowers containing pollen for their digital field journal.

John: Sean, are there any flowers over there, ready to find? Anything we can take pictures of? Sean, can you go over and see any flowers on that side?
Sean: I see purple! ((points to the flowers))
Maxwell: Oh, cool! ((excitement))
Sean: I want that one.
John: Okay, you got to take a picture of that. Good job, bud.

While helping the children select flowers that they could photograph, John shared prior knowledge in identifying the local flowers at the pollen micro-learning location. Through their visual observations, the children took photos of these flowers based on their interest and identification of pollen as seen across each flower.

John:	There's some more flowers right here. Did you see these ones?
Sean:	Oh yeah, I did.
John:	Those are daisies, maybe? ((points to the flowers))
Maxwell:	These are cool ones. I see a lot of pollen on these.
John:	That's right.

While reviewing their photos in the journal (Figure 4c) Maxwell showed excitement while saying "cool, right?" as he scrolled through the various photos that the family had taken up to that point in their MAR experience.

This family's interactions showed another way in which families engaged with digital photo-taking features of a MAR app: supporting scientific observation through prior knowledge and personal interests. Sean, for instance, focused on observing flowers that were a color he was interested in (i.e., I see purple!) and John was able to focus his family's second observation on daisies, something that Maxwell expressed interest in (i.e., These are cool ones.). By allowing the families to take multiple photographs, they connected the new content on pollen to each siblings' specific interests on-site.

Figure 4

(a) John pointing out flowers (b) iPad Screen of Maxwell taking photos, and (c) journal with their photos

Take 3 photos of pollen in flowers.

These are your photos of a place where a native bee can nest.

Food for their Young

These are your photos of pollen, an important source of fat and protein for bees.

Let's continue our journey, Pollinator Explorer!

(a) *(b)* *(c)*

Discussion

These findings demonstrate that throughout the MAR experience families were deliberate in taking photos that recorded their observations and the content of the app. Trends in across the micro-learning locations demonstrated how both the nature center environment and the features within the app impacted how families engaged with observations during the photo taking activities — especially the families' observational talk and excitement levels. As the two vignettes explored above demonstrate, families were able to use the MAR app's photo taking prompts to encourage observations of the environment and record-taking of those observations through the journal. In the first vignette, the photo-taking allowed Amelia and her father David to take photos that applied new scientific content of nectar and milkweed plants through their observations. In the second vignette, the photo-taking allowed siblings Maxwell and Sean and their father John to integrate their prior knowledge or personal interests with the new science content of pollen. These findings help to shed light on how families interact with photo taking, as a common design element in mobile technologies, within the broader MAR experience.

Returning to our orienting theory, the prior work has shown the importance of movement in outdoor education and science learning (Marin, 2020; Marin & Bang, 2008). Adding to this literature, this study's findings show that by designing for families to learn-on-the-move together, families could use digital photography to capture their observations of scientific phenomena. Table 3 showed that as family members moved through the gardens, all families took different and/or distinct photographs that captured their observations throughout the MAR experiences, moving through the space to take purposeful photographs that applied new scientific content.

Movement and sensory observations were important parts of the learning process as illustrated by John, Sean, and David pointing at flowers to orient family members observation. Families had to move around to capture different plants or pollinators, as shown by Amelia backing up to photograph both types of milkweed plants, and Maxwell moving around the pollen micro-learning location to photograph flowers in different locations. Other LOTM literature shows the importance of technologies such as GPS and mapping software (Silvis, et al., 2008; Taylor, 2017), as our work adds digital photography to the list of technologies that can help learners as they explore the outdoor places in their communities. While some prior work has shown the LOTM technologies can support interest (i.e., Kawas, et al, 2019), our work illustrates that having the opportunity to take multiple unique photographs may support families with siblings with different interests or ages (e.g., Maxwell and Sean), and that having directed photo-taking prompts may encourage families to look closer at their environment to connect content (e.g., Amelia), helping them stay engaged and focused on scientific observational tasks and ecological learning outcomes.

Our work has practical implications to informal science education. While AR and other related technologies have shown to support family learning (Kawas, et al, 2019; Yun, et al., 2022), our work demonstrates how an MAR technology including photo-taking, integrated into a specific location's walking trails, can support both science practices (i.e., observation) and science content (i.e., pollen and nectar as key food sources for native bees) learning outcomes.

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Weaving the Societal and the Technical into Teacher Experiences: Experienced Computing High School Teacher Learning in an Electronic Textiles Professional Development Session

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Abstract: Amongst efforts to realize computer science (CS) for all, recent critiques of racially biased technologies have emerged (e.g., facial recognition software), revealing a need to critically examine the interaction between computing solutions and societal factors. Yet within efforts to introduce K-12 students to such topics, studies examining *teachers'* learning of critical computing are rare. To understand how teachers learn to integrate societal issues within computing education, we analyzed video of a teacher professional development (PD) session with experienced computing teachers. Highlighting three particular episodes of conversation during PD, our analysis revealed how personal and classroom experiences—from making a sensor-based project to drawing on family and teaching experiences—tethered teachers' weaving of societal and technical aspects of CS and enabled reflections on their learning and pedagogy. We discuss the need for future PD efforts to build on teachers' experiences, draw in diverse teacher voices, and develop politicized trust among teachers.

Introduction

As CS moves into K-12 education, most PD, curriculum, and research efforts have focused on teaching and learning CS content: concepts to understand principles and processes of computers and software (Seehorn et al., 2011). Yet injustices amplified by computing applications (e.g., Benjamin, 2019) demand that equal attention be paid to computing's "impact on society" (Seehorn et al., 2011, p. 1). This call has initiated a critical turn in K-12 CS education (Kafai & Proctor, 2022; Ko et al., 2022) that advocates for moving beyond the oft-adopted value-free stance on computing. Through pedagogical frameworks, researchers recently have proposed similar critical shifts in K-12 curriculum (Kapor Center, 2021; Madkins et al., 2020). Integrating a critical stance with technical learning is important when racist logics are embedded in computing abstractions and algorithms in computing tools often employed to 'solve' societal issues around policing and justice (e.g., Benjamin, 2019).

While many studies concerning K-12 student learning have added discussion units or even whole courses to examine computing critically (e.g., Vakil, 2018), far fewer have focused on teacher preparation to teach social justice issues within computing classrooms. Most current efforts in computing teacher preparation concentrate on inducting teachers certified in other disciplines, focusing on building teachers' technical CS knowledge (Menekse, 2015). A few recent studies highlight the challenges teachers face as they integrate computing with societal issues such as race and gender (Everson et al., 2022) and how White teachers may evade and deflect conversations around race within teacher PD (Goode et al., 2020). These findings suggest the need to better understand how computing teachers can learn to engage with and integrate critical ideas while learning to teach computing.

In this paper, we turn our attention to teachers (rather than students) as learners of critical computing. We analyzed one PD session where experienced high school computing teachers learned to teach an electronic textiles (e-textiles) unit. This innovated session, developed by a teacher-facilitator, integrated technical aspects of designing sensor-based physical computing artifacts with societal concerns, such as racism, that are embedded within inadequately designed sensor-based devices. Inspired by interaction analysis (Erickson et al., 2017; Jordan & Henderson, 1995) and sociocultural theories of teacher learning (Vygotsky, 1987), we conducted a collaborative video analysis of the PD session (with six teachers as participants/learners) to answer the research question: how do teachers learn technical and societal aspects of computing while participating in an electronic textiles PD?

Background

The design of the PD and the ensuing data analysis were informed by sociocultural theories of teacher learning, PDs as sites for teacher learning, and the teacher learning of critical aspects within computing.

Theories of teacher learning

A sociocultural perspective of teacher learning highlights how situated, social and cultural aspects shape professional identity development (Fishman et al., 2014; Shulman, 1987). Shulman (1987) viewed teaching as a practice and teachers as a part of communities of practice with shared understandings of teaching. He further framed teacher learning as developing fluency with practices of teacher communities, in interactions with one another and in a distributed fashion with expertise distributed across teachers (Fishman et al., 2014). These theories posit that teachers do not learn discrete, disconnected facts or skills but learn concepts as they relate to their teaching contexts, classroom dynamics, and personal experiences (Bukor, 2014; Enyedy et al., 2006).

Classrooms and teacher PDs are two prominent sites of teacher learning studied within learning sciences (Fishman et al., 2014). Studies that have explored teacher learning in classroom settings have examined teachers' interactions with both resources (such as curricular materials) and students in shaping their practice (e.g., Sherin & Han, 2004). Similar efforts involving PDs have either focused on different facets of teacher knowledge (e.g., Shulman, 1987) or on the social nature of teacher learning and the development of communities of practice (Fishman et al., 2014). Though attention to processes of teacher learning during PDs is important, scarce research details processes of how teachers learn to critically engage with disciplines or ask questions about the relationship between disciplinary knowledge and its interactions with communities and societies. This gap is especially significant in the case of in-service, experienced teachers who rely on PDs for professional learning opportunities to grow their ability to teach critical computing (Fishman et al., 2015; Goode et al., 2020). While studies related to student learning have highlighted the importance of, for instance, politicized trust—a race-conscious way of understanding, respecting, and being in solidarity with one another—in shaping learning of critical aspects (Vakil & de Royston, 2019), similar examinations of learning processes within teacher PDs are lacking.

PDs as sites for computing teacher learning

Previous research within computing education has highlighted key PD aspects that shape teacher learning: duration of the PD, connections to classroom practice, focus on learning methods and pedagogical content knowledge, and relationships within school districts (Menekse, 2015). This aligns with Fishman and colleagues' (2014) review of teacher learning within learning sciences that emphasizes extended durations, opportunities for engagement with content knowledge, practice-related aspects such as student learning, and reflection. But most research on computing teacher learning relies on teacher surveys and interviews as methods, revealing very little about the processes of computing teacher learning (Menekse, 2015; Yadav et al., 2016). Further, prior studies within computing teacher PDs focus primarily on disciplinary knowledge as a collection of technical aspects (Menekse, 2015), barely interrogating how teachers learn to expand the disciplinary boundaries and integrate critical societal concerns with technical aspects. An exception is Goode and colleagues' (2020) examination of teacher learning of critical issues in computing through an analysis of teacher discussions and interactions within PDs. With increased computing tools around us and heightened implications for marginalized communities (e.g., Benjamin, 2019), teacher preparation efforts should support teachers in critically engaging with societal impacts of computing. Recent equity-centered computing pedagogical frameworks underscore the need to "situate technology ideas within their sociopolitical context and give students opportunities to critique and explore issues that are relevant to them" (Madkins et al., 2020, p. 13). Buttressing this call, Goode and colleagues' (2020) study surfaces the need to support experienced high school computing teachers in engaging with societal aspects such as race during PDs. While limited prior studies highlight the struggles of teachers as they integrate technical and societal aspects (e.g., Everson et al., 2022; Goode et al., 2020), there is a need to further understand how to support teachers in critically analyzing the connections of societal and technical dimensions of computing.

Critical computing teacher learning

Mathematics and science education have explored how to engage teachers critically (Bianchini et al., 2015), laying a path for examining learning of critical computing. Questioning the relationships between computing, people, communities, and societies can support students who belong to historically excluded groups find their voices, engage with the discipline in personally meaningful ways, and contribute agentically to the discipline (Goode et al., 2020; Vakil, 2018). With concerns of teachers evading or deflecting race-related issues or blaming individual students for failures that have roots in historical and systemic racial oppression (Segall & Garrett, 2013), teachers should engage with societal issues such as race and racism, gender, and ability in computing.

While prior studies have proposed equity-centered pedagogies (Madkins et al., 2020) and critical pedagogical frameworks in computing (Kapor Center, 2021), we know very little about how teachers learn or develop critical perspectives at the intersection of technical and societal aspects of computing. Most efforts have been additive in nature—i.e., introducing the societal aspects in addition to the technical aspects—rather than integrating social and technical dimensions (e.g., DeHart, 2022). In other efforts where race-based conversations were purposefully integrated into teacher PDs, race-related issues were discussed in terms of recruitment and retention of students from marginalized groups—i.e., working on strategies to remedy the structural lack of opportunities—while computing concepts and constructs were discussed separately from how computing algorithms may encode racism and have implications for users from marginalized communities (Goode et al., 2020). Integrative approaches that consider programs and algorithms hand in hand with societal aspects that shape them, rarely studied, are limited to researcher suggestions of potential classroom activities and examples (e.g., Ko et al., 2022) rather than explored in action in PDs. Thus, we know very little about what goes on within such PDs, despite recent calls to integrate the societal and technical concerns and shift away from an additive approach of disconnected modules on equity and social justice within computing (Goode et al., 2020; Ko et al., 2022).

Methods

Context and participants

This study was conducted with the *Exploring Computer Science (ECS)* teacher community, developed over 10+ years to support teachers to teach *ECS* curriculum (an introductory computing course) built on three pillars: computing concepts, equity, and pedagogy (Goode et al., 2012). PDs involve a weeklong session for two summers with four day-long quarterly sessions between the two. Previous research has found this model useful to develop teacher communities (Goode et al., 2014). With electronic textiles (e-textiles) offered as an optional unit within *ECS* (Kafai et al., 2019), the e-textiles online PD was designed along similar lines: *ECS* teachers with prior e-textile teaching experience facilitated summer and quarterly sessions for *ECS* teachers new to e-textiles. As a part of a research-practice partnership (RPP), the PD had a diverse group of participants: university researchers and a non-profit partner, e-textiles-experienced teachers who were teacher-facilitators, and e-textiles-beginner teachers who were teacher-learners. Annie, Davon, Elisa, Julie, Leah, Maggie, Maria, and Leisha (all pseudonyms) were the teacher-learners with a wide range of experience teaching *ECS* (see Table 1 for their racial and gender identities, teaching experience and contexts). We analyzed teacher interactions during one of the quarterly PD sessions where teachers, except Maria and Leisha (unable to attend this session (1)), worked on a sensor-based e-textiles Human Sensor project and discussed technical and societal topics around it.

Yasmin and Joanna were senior researchers. Deborah and Gail, also senior researchers, partnered with teacher-facilitators to design and implement the PD. Kate works for a non-profit organization responsible for supporting PD online. Ben and Jesse, with Angela (not present during this session) were *ECS* teacher-facilitators with 4-6 years of e-textiles experience teaching. Ben facilitated the session on Human Sensor project. Leo, Mia (not present during this session), and Gayithri were three graduate student researchers. All of us identify as cis-women or cis-men. Among cis-women, Gail, Joanna, Deborah, and Kate identify as White, Gayithri as South Asian, Mia as Black, Angela as Asian-American, and Yasmin as Indo-European. Among cis-male, Ben identifies as White, Jesse as Latino-European, and Leo as Latino. Shaped by our teaching, learning, and research experiences within CS across diverse contexts, we are committed to center justice in CS education.

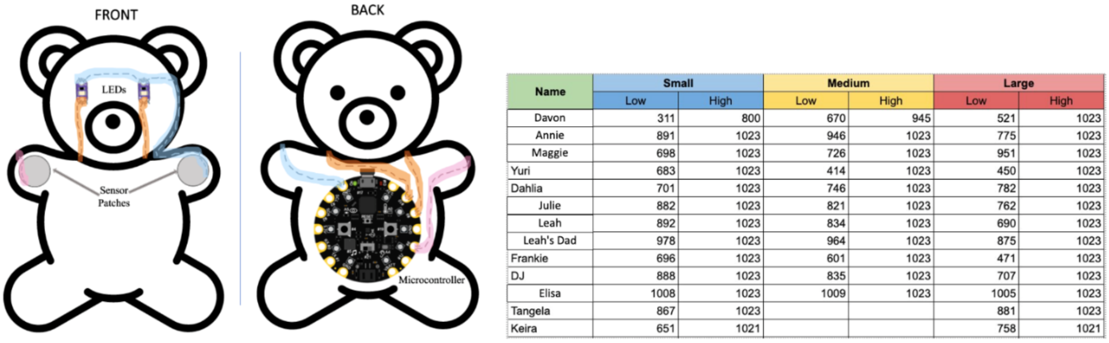
Table 1
Teacher-learner details.

Teacher name (Pseudonym)	Racial and gender identity	Teaching experience (years)	Teaching geography in the US	Student diversity[#]
Annie	White, female	26	Midwest suburban	40% RM; 30% FRL
Davon	Black, male	3	Southeast city	100% FRL
Elisa	White, female	10+	Northeast suburban	4% RM
Julie	White, female	19	Northeast suburban	33% RM; 20% FRL
Leah	White, female	28	Midwest suburban	7% RM; affluent
Maggie	White & Hispanic, female	8	Midwest city	Majority RM
Maria*	Black, female	6+	Midwest city	99% RM; 91% FRL
Leisha*	Black, female	20+	Southeast rural town	99% RM

The teacher-learners were working on the Human sensor project as a part of the constructionist-driven e-textiles unit (Kafai & Fields, 2019). As shown in Figure 1 (left), it required sewing a pair of aluminum patches to act as analog touch sensors when connected to the microcontroller pins and programmed using an Arduino programming environment. The teacher-facilitator team chose the lesson about computationally testing different sizes of aluminum patches as an opportunity for conversations about inclusivity of diverse users. By then, teachers had designed circuits and aesthetics to make 3-dimensional soft toys that would respond to different degrees of touch (no touch, soft, medium, and hard press). They tested sensors with family members and noted down the range of sensor values for different sizes of sensors (small, medium, big, Figure 1, right). The session after sensor testing was chosen for analysis since Ben orchestrated a conversation involving social and technical aspects of computing.

Figure 1

A human sensor project template (left) and analog sensor readings (right).



Name	Small		Medium		Large	
	Low	High	Low	High	Low	High
Davon	311	800	670	945	521	1023
Annie	891	1023	946	1023	775	1023
Maggie	698	1023	726	1023	951	1023
Yuri	683	1023	414	1023	450	1023
Dahlia	701	1023	746	1023	782	1023
Julie	882	1023	821	1023	762	1023
Leah	892	1023	834	1023	690	1023
Leah's Dad	978	1023	964	1023	875	1023
Frankie	696	1023	601	1023	471	1023
DJ	888	1023	835	1023	707	1023
Elisa	1008	1023	1009	1023	1005	1023
Tangela	867	1023			881	1023
Keira	651	1021			758	1021

Data collection and analysis

Screen recording of the online PD session (45 min.) is the primary data source. PD materials such as session agenda, teacher project designs, and teacher pre-PD interviews were analyzed to provide the video with context. As a first step, Gayithri analyzed teacher pre-PD interviews for teacher backgrounds and teaching contexts and examined project designs and the session agenda to contextualize conversations. The teacher group was the unit of analysis with a focus on group meaning making as discussions ensued during the session.

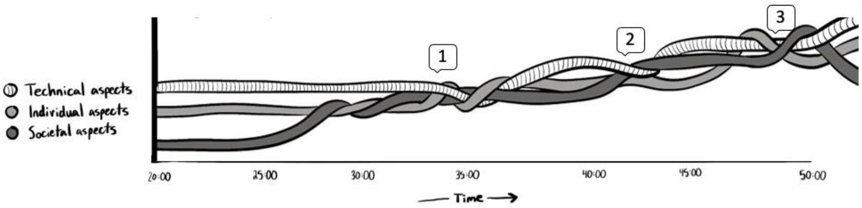
Inspired by interaction analysis (Jordan & Henderson, 1995), Gayithri structured collaborative video analysis (Erickson et al., 2017) supplemented by repeated individual viewing and interaction with the transcript. In this online PD session, interactions were multimodal, including verbal utterances, text-based chat, and screenshares, with embodied participation less visible. Gayithri initially viewed the video to prepare a multimodal transcript to capture talk, gestures, facial expressions, chat entries, and entries on shared documents. The transcript was elaborated with comments during three ~2-hour long iterative group viewing sessions attended by the author team. This allowed for cross-expertise discussions and exchanges of perspectives during video analysis (Erickson et al., 2017). The multimodal transcript served as a shared artifact that viewers interacted with while watching the video together, pausing the video for notetaking whenever required. Joint viewing sessions helped us identify three key episodes where the technical and societal dimensions interweaved in teacher discussions. Gayithri followed up with individual viewing sessions, rewatching the video in relation to the comments gathered, particularly to answer the research question. A visualization of the dynamics of the video was generated collaboratively by Mia and Gayithri (Figure 2) that represented the flow of the session, particularly how different aspects were initially individually discussed and then interweaved across the three episodes. The visualization was shared with the analysis group for further engagement with the emerging themes.

Findings

Teachers engaged with critical computing as they discussed inequities in technical designs and implications for diverse users within the context of their human sensor projects and real-world technologies, while anchoring discussions in their personal and classroom experiences (Figure 2 for visualization). Below we elaborate three episodes to demonstrate how teachers integrated the technical and the social aspects of computing, and how their experiences tethered their learning, supported by a trimmed version of the verbal transcript due to space limitation.

Figure 2

A visualization of the flow of the session.



Episode 1: Do you think everybody will be able to use your device the same?

During this episode, teachers grappled with technical decision-making around sensor value ranges within their individual projects and the implications of those decisions on different users. Upon designing the aesthetics, teachers had to determine the size of the analog sensor patches for their projects and program them to allow users to interact with them and generate four different light patterns. Towards that end, teachers were tasked with testing sensor patches of different sizes (small, medium, and large) with any family members around and noting the lowest and the highest values (Fig. 1, right). Ben asked teachers to determine four sensor value ranges that could be included within their programs to correspond to the four lighting patterns caused by different degrees of touch.

After the teachers determined the sensor ranges, Ben moved their attention towards the social aspects of the design. Connecting the numerical values to implications for users, he asked if "everybody will be able to use [the] device the same [way]?" (Table 2). While teachers had grappled with the dimensions of programming sensors at an individual level until now, they had to extend their individual observations and reasoning across their colleagues' datasets and discuss the human/social dimensions of these choices as they related to people who might interact with their projects. Design decisions, in this case, were couched inside the objective of not just making a functional project but one that includes diverse users. This brought in the broader societal issues of technology design in conversation with the technical details of programming, issues around who can and cannot use their projects. Teachers reasoned their choice of sensor value ranges in relation to their observations of their family members testing the sensors earlier and discussed implications of their decisions on such interactions. For instance, Davon noticed the effort it took him to realize a particular low value, reflected on how it might be difficult for Maggie's child who may not be able to exert the same pressure on the sensor. He said this led him to include the 0-500 range in his program to accommodate similar users. Maggie discussed her observations of her and her children's interactions with the sensor in terms of individual physiology and meaning making of possible interactions. Further, Davon acknowledged the limitation of sensor testing, i.e., he was the only person who tested his sensors (Figure 1, right) and how that further shaped his decisions around sensor value ranges for his project. Overall, in bringing the technical aspect of programming analog sensors in relation to users' interactions and experiences, social aspects were no longer a modularized concern but deeply integrated with the project code.

Table 2

Episode 1 transcript excerpt at 34:24.

Verbal transcript	Verbal transcript
Ben: **Do you think that everybody would be able to use your device the same?** *Elisa, Maggie, and Leah shake their head to tell no.* Davon: Probably not [unmuted by mistake]. Oh! Ben: So why don't you talk to me, why not? What differences do you see? How are the decisions that we make in these light patterns going to manifest in terms of how people use the thing that we're making? Davon: Well, I know for me like I'm using the regular one [medium-sized patch], so I don't know… I had to squeeze real hard just to get my lower numbers, **somebody might not be able to squeeze.** Ben: [reading from chat] Your light pattern four is from zero to 500 right. Did anyone get down to below 500? Maggie: I didn't but my daughter did. And, so in our case, at home, we all did it differently. I was pressing on top of the table. My oldest was holding and squeezing…	Maggie: And then, the youngest was just like, barely touching it. No, I don't think we'll all get the same, because we all did it differently… **it depends on the individual**, it depends on how they want to do it… all those little details I think matter. Ben: So, it sounds like there are differences in terms of individual physiology, number one. Number two, the cultural ideas of how we do the thing… There's an environmental aspect possible like maybe if you're in like a drier area, things might be different than if you're like in a wetter area… there could be some other things happening here and it's all completely individualized. Davon: Yeah, and that's what I was trying to say… my strength might be stronger than a child, Maggie's child, you know, was different. So that's why I didn't want to eliminate that 500 and below because you never know… because **we're just one person that kind of check the data**. Ben: I love what you're saying.

Episode 2: Everyday technologies that are not inclusive

In addition to connecting sensor ranges to user interactions within e-textiles projects, teachers continued to weave societal and technical aspects as they discussed various sensor-based technologies that excluded or caused ineffective outcomes for certain user groups. Conversations around inclusive design of individual projects in the previous episode shifted to everyday technologies that "did not think through inclusiveness" (Table 3). Teachers drew from a range of personal connections and discussed how technologies in their lives did not include marginalized populations. For instance, Leah mentioned cell phone touch screens that assume certain physiological characteristics such as shape and sensitivity, and Elisa shared the lack of consideration of human aspects in the design of motion-sensor lights in her classroom. Further, Julie shared about her five-year-old with Down's syndrome and his struggle with voice assistants like Alexa.

However, lively conversations only occurred when teachers related their lived experiences. Otherwise, there was awkward silence. For instance, teachers barely engaged when Deborah and Ben presented examples from outside personal experience, such as pulse oximeters that "don't work well for dark-skinned people" and airport scanners that have "a much higher significant hit on Black women's hair" respectively. Perhaps bringing in external sources disrupted the conversation or perhaps the lack of personal connections among teachers in the room triggered the silence. Except Davon, all other teachers in the room identified as non-Black and not dark-skinned (two Black female teachers were absent: Maria and Leisha, see Table 1) which could have led to silence around topics related to Black community's interaction with technology. This alludes to the need for diverse teacher experiences within PDs and supporting non-Black teachers to engage with race-related topics.

Table 3
Episode 2 transcript excerpt at 40:49.

Verbal transcript	Verbal transcript
Ben: Can anyone think of any **technologies that you work with every day that did not think through inclusiveness**, where there might be some users who might not be able to use the device based upon some physical or cultural or human things? Leah: I would say, touch screens on cell phones and individuals who have like large fingers, or their fingers are starting to lose sensation, and **it's really difficult to accurately press the right keys on those keyboards**. Ben: Yeah… For sure. What else? What are some other examples that you know that you might notice differences in how people interact the technology? Elisa: So, lights in my classroom. Well, one of my classrooms, goes off and like leaves me in the dark and it's not enough to do this [waving hand]. I have to get up and walk to the right place. Ben: So, **the sensor on your light was not designed with your configuration in mind.** Elisa: **With actual people probably** [laughs] Ben: [laughs] With actual people in mind. Julie: My son, my five-year-old has Down's syndrome, so we have a lot of adaptive technology and a lot of adaptive supplies like scissors, for example, is something that's adaptive because he doesn't have as much strength, so he has special scissors. But as far as tech go, like higher tech, you know, **Alexa is really hard for him to communicate with**…	Julie: I think Google somewhere in Canada, they're having people with Down's syndrome… collecting different people speeches to try to advance those technologies. Ben: Does anybody else here, or their family have challenges with using Alexa, or Google or any of those speaking technologies? [Ben raises hand in response to his question, and other teachers including Davon, Leah raise their hands too. Julie smiles and nods in agreement] Ben: Yeah, my grandma was from Russia, and good god trying to watch her try to integrate with Alexa… really frustrating for her, because it didn't understand her very, very thick accent… I've seen Texans struggle with Alexa… you think that the only foreign people can't use. No, no, like, people, people in Boston have difficulty with Alexa, because it doesn't know what about a car [in Boston accent] is. Ben: The sensors that measure oxygen by touching your fingers the pulse oximeter [reading from the chat]. What about that Deborah? Deborah: Well, **they don't work as well for darker skinned individuals**… So, clearly their user sample's not very great. Ben: Or for example, those things in the airport, they go around you like that zzzz, to make sure that there's nothing on you. **There's a much higher significant hit on Black women's hair**. So, if you are a Black woman going through that security system, you have a significantly higher chance of being removed from line. [**silence in the room**]

Episode 3: Experiences as a tether

Throughout, personal and classroom experiences tethered teachers' weaving of societal with technical aspects. Making the project put the teachers in students' shoes and enabled reflections on their learning and pedagogy (Episode 1). Building on Episode 2, teachers drew from their personal experiences with everyday technologies to identify bias. Drawing these together, Ben prompted teachers to "link" between the two (Table 4). Coming back to technical implications around determining sensor ranges in their projects, teachers concluded the need for "inclusive sample for testing" and again grounded conversation in their personal experiences.

When Ben encouraged teachers to connect classroom practice and think about supporting their students to do the same, teachers drew from their prior teaching and learning experiences to derive lessons for classroom practice. Of particular note, Annie shared how her students in a different class designed a pair of sunglasses without considering gender diversity among testers (Table 4). Narrating this instance, Annie reflected on her knowledge of her students and how she "ignorantly… thought [her students] would get inclusive feedback." She instead concluded that "it's very important to help kids understand who should be in the sample size." Not visible in the transcript, other teachers like Leah discussed other pedagogical approaches such as asking "who's missing in the sample data" to support students through critical computing. Overall teachers' experiences—technical, personal and classroom—acted as a tether to learn to integrate technical with societal concerns during the PD.

Table 4
Episode 3 transcript excerpt at 46:15.

Verbal transcript	Verbal transcript
Ben: So, how is this conversation, based upon the activity that we just did, **what's the link?** Ben: [reading from the chat] Making sure we're being inclusive in our, in our designing.... So how having a mindset for that we need to be purposeful in our designs. Leah says using an inclusive sample for testing. **Was our sample inclusive?** If we were trying to create a product for all people in the United States, is our sample, inclusive enough? Davon: No. Ben: Yeah, so maybe the people that you're sampling needs to broaden, maybe we need to bring more people in when we test. Absolutely... **What would you do in your classes, in this moment, to bring out this conversation, to bring out these ideas?** How would you handle it, would you handle it? Do you think that this is a moment that's important, and that needs to happen? Annie: **I just have to share this happened in my class this week.** I teach a manufacturing class. And, it's all boys and a male teacher and me. And one of my groups are manufacturing wooden sunglasses. So, they've made some different prototypes of these sunglasses and their challenge this past week, was to test them with their friends… get some feedback. So, then they came back and they said yep, you know, based on all of our feedback, this is what we're going to go with…	Annie: And then they're working with a local company in town to actually manufacture 100 of these prototyped sunglasses. So, they said they're ready to go, they've done their research. So, I said, well, you didn't ask me to try them yet. So, I said let me try them and give them feedback, and I put them on and they immediately fell off my face. And I said you guys. I don't think we're good yet to say, we have 100 of these, like, let's talk about the sample of who you checked with. Well, then talking with them and in my ignorance when I said go ask your friends go out to the cafeteria get feedback. **I thought they would get inclusive feedback**. They only tried them on other boys. So, and other boys their age, who have a different head size than me. So, I said—now we're going to classrooms throughout the building and asking people through it out different classes. And, so we actually talked about sample size… We have to come up with sample sizes that are inclusive. Ben: Talking about sample, when we're talking about design. Annie: Right. Very much so **it's very important to design and helping the kids understand *who* should be in that sample size**. Because I mistakenly thought they would have a broad representation, and then they didn't on their own. And I think some of these companies too, you know, you think you're good. And then all of a sudden, oh wait, we're not good.

Limitations

A limitation of this study is the context which involved a particular group of teachers—experienced *ECS* teachers with an established sense of community, developed while attending *ECS* PD sessions together in the past. Further, they were attuned to equity and justice issues in computing education as they read and discussed *Stuck in the Shallow End* (Margolis et al., 2017) in *ECS* PDs and developed politicized trust (Goode et al., 2020). The findings presented above are couched in this context and further research is needed to understand how these findings relate to PDs with teachers not necessarily having already established relationships and commitment to equity.

Discussions and conclusions

This analysis sheds light on dimensions of PD activities that can support teachers to engage critically with STEM disciplines like computing. Across the three episodes, teachers made connections with their lived and classroom experiences as they engaged with issues of technology design with implications for diverse users. The significant role played by teachers' personal experiences is comparable to earlier studies (Bianchini et al., 2015; Bukor, 2014). In cases where such connections were absent, as seen in episode two, teachers struggled to converse about critical issues brought up by leaders. This connects with prior research that revealed the struggles of White teachers in engaging with race-related conversations within computing PDs (Goode et al., 2020). Of note, even in our group of six teachers—four White—who had experience with discourses of equity through prior PDs (which they had all led), personal experience seemed particularly important for grounding both technical and societal sides of conversations. Future PDs need to consider how to build on teachers' lived experiences and create new experiences, draw in diverse teacher voices, and develop politicized trust among teachers.

Having diverse perspectives in PDs helps build thought-provoking interactions (as noted in episodes two and three), just as diverse technology design teams mitigate biases in technology design. As teachers build on their personal experiences from their lives and classrooms during PDs, having diversity along those lines will expand the accounts discussed in PD settings, just as Julie's personal experience with her child's use of voice assistants brought in a particular perspective to discussions around inclusive design of technologies and projects in episode two or Annie's classroom experience added a particular perspective in episode three.

Yet another key contribution of this analysis are the contextual factors that shaped the findings, in particular, creating a common project (like the human sensor e-textile project) and building on existing teacher relationships with politicized trust (from earlier shared PD experiences). Sensor-based devices, by their design, can encode inequities based on who's included in user-testing and who's left out (e.g., Benjamin, 2019). The e-textile human sensor project, which involved programming analog sensors, enabled teachers to discuss and consider programming aspects with broader societal issues around sensor testing and to connect with the larger issue of myopically designed sensor-based devices such as voice assistants, enabling conversations grounded in but extending beyond e-textiles. At the same time, this focused hour of PD built on six prior days of relational work, with shared crafting times, reflections, family interruptions (characteristic of long video calls) and other shared experiences, including an explicit invitation to test their sensors with others in their household members. Combined, these shared technical and social experiences made room for teachers to grapple with issues of inclusive design while trusting the space as safe to discuss their perspectives. Doing similar work with other teachers in other contexts will mean designing and creating such spaces for teachers to engage in similar ways. Sharing materials like a book, e.g., *Stuck in the Shallow End* (Margolis et al., 2017), that allow for political conversations in relation to the discipline (Goode et al., 2020) and creating technical projects, such as the human sensor project, lay the groundwork for disciplinary integration. Building relationships over many days, as the *ECS* model does across 14 days over two years, can provide the grounding for tethering technical, personal and societal aspects of computing. These combined technical and relational underpinnings will allow for integration beyond the more traditional additive or modular means of bringing up equity and justice-related issues in computing-like disciplines (DeHart, 2022). Many more future PD and teacher-learning studies are needed to explore integrating societal issues with computing content in the effort to bring critical computing to the fore in K-12 education.

Endnotes

(1) Teachers could not be present during the session analyzed; ($^{\#}$) RM == Racial Minority; FRL = Free and Reduced Lunch.

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“We Do Better Math When We’re Together”: Learning Mathematics From the Margins

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Abstract: This paper uses an intersectional feminist lens to examine the discursive practices of a researcher and mathematician engaged in conversation about the practice of mathematics. The mathematician, a Mexican American woman of color, shared experiences of marginalization and belonging in mathematics, and how these were shaped by her racial, gendered, and cultural subjectivities. By focusing on how participants in the conversation co-constructed ideas around what it means to do mathematics from a location in the margins of mathematics, analysis reveals the social, collaborative, and cross-cultural dimensions of the practice. It shows how the learning of mathematics was facilitated by participation across different communities, settings, and contexts. Findings urge for a closer attention to mathematics as inherently social and political in order to counter processes of erasure in mathematics education.

Purpose

What does it mean to become a mathematician? What does it mean to become a mathematician in the political and social margins of the field? Recent research on marginalization in STEM environments has elaborated on the ways in which those disaffected by mathematics and science persist in those fields and resist their oppressive impositions (e.g., Gholson & Martin, 2019; Sengupta-Irving, 2021; Sengupta-Irving and Vossoughi, 2019). Such accounts have made visible the often untold stories of marginalized persons in STEM by adopting critical feminist methods that take the margin seriously as a site of political, practical, and social transformation. We draw on hooks (2015) when thinking of the margin as a place of empowerment, from which to “see and create, to imagine new alternatives, new worlds” (p.150). To theorize from the margin is not merely about occupying a subjugated location; it is also about what one does from such a location and how moving across subjugated locations shifts what we see, how we see, and the stories we tell (Haraway, 1988). For Haraway, “the standpoints of the subjugated are not ‘innocent’ positions,” and they are indeed preferable as a location from which to conduct research “because they seem to promise more adequate, sustained, objective, transforming accounts of the world” (p. 584).

This paper is part of a study invested in surfacing the gendered and racialized facets of mathematics teaching and learning. By examining the role of race and gender in the production of mathematical knowledge, it seeks to make contributions towards understanding the political processes through which people come to be included in or excluded from mathematical work. The analysis presented here traces one scholar’s construction of herself as a woman of color in mathematics by analyzing a conversation she has with the first author about her journey through mathematics. The broader study takes a feminist phenomenological approach to center consciousness, intention, and orientation as people navigate their various (cultural, social, and practical) worlds (Ahmed, 2006). By surfacing the stories of mathematicians who experience race-, gender-, and class-based marginalization in mathematics, it aims to better understand why mathematics remains, two decades into the twenty-first century, an elusive pursuit to Black and Brown folk and gender minorities (Gutiérrez, 2013; Leyva 2017; Martin, Gholson, & Leonard, 2010; Waid, 2020). We use such stories to explore how race, gender, and society shape learning, knowledge production, and practice in mathematics.

Theoretical framework

Two theoretical perspectives frame the analysis presented here. First, the project is premised on the idea that being a part of the social life of mathematics occurs through shifting participation in communities of practice (Lave & Wenger, 1991). Legitimate peripheral participation (LPP) advances the idea that thought, learning, and action are mutually constitutive processes that unfold against a blended background of time, place, social and cultural relations, and politics. An LPP lens held over communities of practice (such as the practice of professional mathematicians) views learning as particular to the concerns, goals, and practices of the community, so that all learning is understood as shifts in participation in community practices. This contrasts with traditional cognitivist understandings of cognition as an internalization process, offering instead that learning (and by extension engaging in a community of practice) "concerns the whole person acting in the world" (Lave & Wenger, 1991, p. 49) rather than acquisition of knowledge and practices. The idea of the "peripheral" in LPP therefore refers to all participation in a practice, and as an analytic lens as "a source of power and powerlessness" (p. 36) helps surface the different ways in which actors may engage in the labor of the practice by participating in activities across multiple intersecting communities.

The second lens in our theoretical framework considers how experiences of marginalization shape how persons come to be in mathematics. Drawing on Star (1991), we conceive of marginalization in mathematics as the simultaneous experience of both *belonging and not belonging* to the community of mathematicians. Star described the often-fraught negotiations one must engage in when one is both a member of a community of practice (say, of mathematicians) and marginalized (say, by race and gender) within it. Thus, the experience of marginality engenders multiple selves, and the encounters of these selves across various intersecting communities affect how one might access, act upon, resist, and make meaning across these communities. In the analysis presented here, we explore how opportunities to participate in mathematical work are refracted through participants' cultural experiences and social commitments across communities. Engaging with the marginal in this way—as a site of contestation that exists both within and outside the field of mathematics—helps illuminate mathematical tradition and convention and how these are regularly challenged and transformed by those who experience marginalization (Becker, 2014).

Together, the idea of learning as shifting participation and Star's conception of marginalization as a transformative experience construct a theory of becoming, or of "the historical production, transformation, and change of persons" (Lave & Wenger, 1991, p. 51). Our use of the word "marginal" is distinct from Lave and Wenger's conception of the "peripheral" in "legitimate peripheral participation." Whereas marginal participation is produced and reinforced by shared experiences of isolation and exclusion from wider communities, legitimate peripheral participation describes *all* participation in a community. Lave and Wenger commented that peripheral participation "is about being located in the social world. Changing locations and perspectives are part of actors' learning trajectories, developing identities, and forms of membership" (p. 36). Peripherality is thus a moving social location "at the articulation of related communities" (p. 36) that facilitates exchange across these communities. In other words, whereas marginality within the community of mathematicians is engendered by political and cultural subjectivities, peripherality helps articulate movement within a community through differing participation.

Data and methods

Data analyzed in this paper consists of one 43-minute conversation over a virtual video medium between the lead author and the focal participant, Carmen, as they discuss their experiences as mathematicians, researchers, and educators across contexts on a Monday morning in the fall of 2022. Carmen is a Mexican American woman of color and professor of mathematics at a public university in a midwestern city in the United States. In addition to these identities, Carmen's experiences as a mother, wife, daughter, sibling, and second-generation immigrant emerge as salient in the analysis presented here. The first author, who is in conversation with Carmen, is a graduate student and faculty of mathematics education at her university; she became a mathematics teacher after experiencing discontent in higher mathematics. The first author also identifies as a queer South Asian brown woman in the US. Also present during the conversation is the sixth author, a Chinese-American woman and first-generation college student in the Mathematics Education program at the same university as the first author. The remaining authors are members of a research group with a shared commitment (as educators and researchers) to questions of marginalization in mathematics (as belonging, not belonging, and possibility) and collaborated on analysis. We do better analysis when we're together, too.

Throughout the discussion, Carmen and the first author are engaged in conversation and make different claims about the social life of mathematics, weaving a narrative that oscillates between portrayals of the practice as sometimes lonely, sometimes explicitly social, and at other times resolutely solitary. Our goal was to examine the conversation for insights into how Carmen viewed her arrival in mathematics, especially looking for ways in which mathematical work and learning are transformed by racialized and gendered subjectivities. Analysis showed that learning to become a mathematician entails engaging in the practices of several communities at once, and that together these practices shape access and belonging in the mathematics community. We argue that mathematics is a social and cultural practice that, for Carmen, is facilitated by racialized and gendered marginality and possibility. We contend that we are able to surface this telling through anti-patriarchal methods premised on the idea that historical contributions, curiosities, and relations of women of color have been transformative of science and society (Prescod-Weinstein, 2021). For Carmen's telling, this approach illuminates the dually productive and inhibitive familial and academic relationships that propel mathematics.

Analysis

We attempt to tell Carmen's story of becoming a mathematician by looking for the social, relational, and affective negotiations Carmen made when describing her experiences of mathematics. We center Carmen's location in the margins and consider her peripheral participation from this location across a set of related communities. Our analysis begins with Carmen's affective experiences of mathematics. We then analyze what she referred to as "life-changing" events that contributed to her "survival" through intense periods of social and disciplinary loneliness. Following this, we look at the various "contradictions" she noted between being a Mexican American and being a mathematician; along with her difficulty in balancing the demands made on her by her work with those made on her as a wife, mother, and daughter. We go on to argue that the very aspects of her home culture that Carmen experienced as being "at odds" with her pursuit of mathematics helped sustain that pursuit. We conclude our analysis by focusing on Carmen's construction of "the place where [she became] a mathematician."

The first author began the conversation by describing her experiences with mathematics, followed by Carmen describing her experiences at a community college and in graduate school.

> **Carmen**: So I – I started at community college when I was a – an undergraduate, and it really had me confront the fact that I was very mathematically um immature. I did not have the right background to start taking, like, calculus courses or anything like that. But starting, you know, I like my first math class in college was intermediate algebra, and so I would tell this story that I remember being in class, and the – you know, the teacher is saying, okay, we need to factor a polynomial and to do so, we need two numbers that you know multiply to six, and add to five. And I was like – like good luck, like numbers don't do that like?
> **Author 1**: <laughs>
> **Carmen**: <scoffing> What are you talking about, two numbers that multiply the six, and that add to five? And like I have this attitude of like, where and am I ever going to use this like? Why is this helpful, like? I was just so jaded. Um! And then she was just so kind, like, that teacher was just amazing, and she was just like, no, no, no, like you should practice like. Write down some numbers that you know that add to five, and then multiply them and see what you get. So I, as I was doing that, like I just remember this, like, vividly this moment where I was like, huh! Oh wow, like this actually works. And she just, you know she just encouraged me like I. It was just like such a fleeting moment, but like it has stuck with me so much because I think about it often like how a lot of the the culture, or like the really terrible things that I've experienced, have sort of always been fleeting, too, like they're like comments in passing; something that gets said in the hallway. Something that happens at a department meeting, and they, they bombard me like there's so many little—little tiny things that happen all the time that I try to remember these small little things that also happen that were life changing and like that was one of them, and had she not reacted in the way she did, at that point like I hadn't built enough resilience to have survived, had she reacted in any other way. And so I – so you know. And then from there on, like I just kept taking math classes. And so my – my math background got better and better and better. Um! But it really was, like, from starting where I needed to start. That was really helpful.

Carmen's speech patterns in this excerpt point to the affective nature of mathematical work: her references to being "mathematically immature," "so jaded," "bombarded" by unsettling incidents, and about not having "built enough resilience to have survived" indicate that Carmen's experiences of mathematics were also deeply felt. More specifically, engaging in mathematics can produce different kinds of feelings in participants: we see this in the urgency and excitement with which she describes moments of clarity in doing mathematics and in the halts and pauses in her speech when discussing moments of dejection. These feelings described simultaneously as "(small) little (tiny) things" and as "life changing," shaped how she was able to approach mathematics. In addition to feeling, the social-relational also emerges as salient in this excerpt: Carmen traced her "survival" in mathematics to her "kind" and "amazing" community college teacher who "encouraged [her]." Being a part of the mathematics community, then, can evoke different kinds of feelings, often in response to the interactions one has with other members of the community.

Carmen described another "life-changing" event, one in which she encountered a Latina Professor in Mathematics for the first time. This occurred at a mathematics conference, one of many she had started to attend as a way of combating the intense social and disciplinary loneliness she was experiencing in graduate school:

> **Carmen**: And so I went, and it's the first time I got to meet another Latina professor… You know she had just graduated, and she had a poster, and I don't even know — it was like, you know, solving some sort of equations with elliptic curves like it was not at all related to anything I knew, but I was just like I just remember staring at her face and just being like she's Latina, and she speaks Spanish, and her parents are from Mexico, and like it was so life-changing that I think, had I had that earlier on, I probably would have like just felt happier? Because I was lonely, and I was just making the best of it. But once I found her I was just like, okay, like there are people like me that do math who have good careers and, like, understand how sometimes the culture of being Mexican American sort of is in contradiction to being a mathematician.

Carmen spoke of how the loneliness she had so acutely felt in graduate school up until the experience of this conference dissipated upon finding "another Latina professor," even though this person was not doing anything "at all related" to her field of mathematical study. Becoming a mathematician, then, it as much about the particulars of the mathematical ideas one is grappling with, as it is about the social-cultural location from which one engages in mathematical work. Here, again, the affective current in her narrative is striking, from being "lonely" to feeling "happier" upon encountering someone else familiar with her subjective racialized and gendered experiences. When the first author asked Carmen to say more about the "contradiction" she had noted between being a Mexican American and being a mathematician, Carmen alluded to the demands made on her time by her various roles:

> **Carmen**: So there's like, this – this, like, tug, because I had demands on my time to like, be able to do graduate school justice, but also demands on — the expected sort of behaviors of what it means to be a wife that were imposed on from my mom's culture right? Like for her it was – you are — you are not a good wife unless you are ironing your husband's clothes, making sure that you were packing him a lunch every morning, you know, and make sure that he eats before anybody else. He sits down at the table before anybody else. Like, all of these very sort of traditional wife roles that I just was like. If I do all of that, I cannot do the things that I want to do, because there's just not enough time in the day. Um! And so that part always just felt so in contradiction, like I would see my you know my colleagues and my friends at school like they didn't have those demands, or like additional cultural burdens on them in some sense, right? Um! They could just go out on a Friday to go get a beer and talk math and like I never could, like. I had to figure out how to balance those two things that just felt that such odds? I think that's, that's sort of the—the thing that I—I'm thinking in my mind when I think about how in contradiction these two things were where you're like, where the mathematical culture is. You dedicated wholeheartedly, wholeheartedly your life, your time, your energy, your whole being, to solving mathematical problems. Well, that doesn't leave any time to be this, like, perfect wife and mother and daughter, who, like, values family and, and goes above and beyond in that realm like there's just not enough time to do, you know, all that.

Carmen described experiencing the tensions between her "mom's culture" and "mathematical culture." The demands made on her by her work were, she noted, at "such odds" with the demands made on her as a wife, mother, and daughter. Empirically, the tension that Carmen spoke of experiencing exemplifies what Lave and Wenger (1991) refer to as legitimate peripherality being "a position at the articulation of related communities" (p. 36). In describing the responsibilities she had at home as being "in contradiction" with mathematics, there were suggestions of her home culture "as a place in which one is kept from participating more fully" (p.36). Lave and Wenger discussed such legitimate peripherality as a place of *flux*, where it can serve to empower or disempower members from participating in the activities of the community. In her speech above, Carmen constructed burdens that disempowered her participation in the community of mathematicians that she saw as resulting from her subjectivity as a Mexican American woman, mother, daughter, and wife. Mathematics, as Carmen initially encountered the practice, was not organized around the cultural values and expectations of this subjective position. Notably, Carmen earlier had emphasized that educational opportunities had been kept from her parents; while some opportunities may have expanded for her to enter a graduate program, more full participation in mathematics demands cultural negotiation for mathematicians who experience racialized, gendered, and class-based oppression.

Carmen's difficulty in balancing "those two things that just felt at such odds" also emphasizes Star's (1991) argument of how marginality is experienced by members of a community: as the simultaneous experience of being part of the community and being apart from it. Access to some of the more traditional, informal ways in which mathematicians engage (such as getting a beer on a Friday night with other students and professors of mathematics) was restricted for Carmen, not because of an active exclusion by the community of mathematicians (which is certainly one dimension of marginalization), but instead through a more veiled exclusion based on incompatibility with her responsibilities in other spaces that precluded her from participating in the informal social practices of the mathematics community.

From a feminist perspective, Carmen's allusions to the particulars of her responsibilities at home evoke Prescod-Weinstein's (2021) call for an attention to what sustains the labor of the scientist:

> We don't talk about the women at home making those Nobel Prizes and experiments and theories possible. The mothers and wives who kept sheets and clothing clean and did all the kid-related things so that their husbands could focus. (p.184)

In not talking about these things, we are simultaneously erasing the possibility of these very groups—the groups that sustain the scientific workforce—pursuing scientific thought and careers themselves. Carmen—who, as we noted earlier, operates from the intersection of multiple communities and subjectivities—is called on to perform both the labor of the mathematician and the labor that *sustains* mathematical work. The absence of the latter would mean having to forgo the former, impeding her access to legitimate peripheral participation in the community of mathematicians. When directly asked about how she navigated this tension, Carmen speaks of the people in her personal life who helped her with her responsibilities at home:

> **Carmen**: Yeah, I think it also comes back to… so I'm the oldest of three. And my sister and my brother are six years younger than me, so my brother's six years younger than me, and then my sister another five. So she's eleven years younger than me. And so by the time that I had my daughter, my sister was a teenager.
> **Author 1**: <eyes widen> hmmm.
> **Carmen**: And so one thing that yeah, and my brother as well, right, but like would help me a lot. Once I found out that math conferences were a thing, I could go away for three days, you know. I could be like, okay <brother, sister>, can you watch <name of daughter> like stay at my house? Just watch her for those two days, three days, so I can go to this math conference, and they were like, okay, sure, like they're not doing much. And they're just working with the kid. And so they would stay at my house, and then you know my dad and my mom would drive by and give them food, or whatever, and but they're just sitting there watching the baby for those two three days, and then I could go, and I had like no responsibilities…
> **Author 1**: Mmhmm

In the excerpts above, Carmen's relationships and community at home were transformed into resources through which she was able to access mathematics spaces. The struggles she described earlier—of having to balance responsibilities at home with the responsibilities of being a mathematician—were overcome through the support of the very culture that was making other demands on her time. Support systems and networks of relationships at home enabled her to dedicate time to being a mathematician and mathematician alone ("I am here for the math"). This reliance on support systems in her home community speaks again to Lave and Wenger's (1991) assertion that legitimate peripherality is lived at the articulation of several related communities of practice, and this location can either prove to be empowering or disempowering. The very community that had earlier been described as being in contradiction with the work of being a mathematician emerged as crucial to supporting her work in mathematics. Here, the housework to sustain mathematical work was being performed by the communities and families of the woman of color at the center of this analysis. Her Mexican-American culture, thus, became a resource that enabled Carmen's fuller participation in the mathematics community. It made possible a life devoted to mathematics without having to attend to other demands:

> **Carmen**: I am here for the math. I am here for the people. I would talk to everyone. I would go to like, maximize all the talks I could go to, and then the afternoon. It was like time to write all of the things that I needed to do, you know, for my, my own research, my own talks. And so those like those short periods of time became what I imagine traditional mathematicians have every day. <laughs while saying this>
> **Author 1**: <follows with laugh as well>

> **Carmen**: Hide and concentrate. And you know I could just, you know, like the conference organized the food. I mean. It was like I had a wife right like it did. I didn't have to clean the hotel room like I didn't have to do laundry. I didn't have to let the dog out. I didn't have to think about feeding the baby, or putting her to bed or bathing her like I literally could just go away for those three days and just – just – be a mathematician.

Being in community with mathematicians entailed also being in community with her home culture. The two cultures were no longer framed as being "at odds" with one another, and the sustaining force of her familial relationships helped her participate in the social life of mathematics the way she imagines "traditional mathematicians" do. Without the responsibilities of cooking and cleaning, conference life "was like [she] had a wife," so in the "here" of the conference she could "just—*just*—be a mathematician." The "here" in her framing was also an elsewhere, a place different from home or even her university. It is worth noting that this empowering elsewhere of the conference space was realized by the labor of those at home who were helping her with other duties, and the labor of service workers cooking and cleaning for conference goers, many of whom also experience racialized and/or gendered oppression (Prescod-Weinstein, 2021).

It was in this elsewhere of the mathematics conference space that she was able to find herself in community with practitioners and the practice, wherein she was able to spend time with both the people, "talking to everyone," and then subsequently, with mathematics, for which she needed to "hide and concentrate." The account shows how participation in the community of mathematicians entails participation in explicitly social activities as well as engaging in the solitude of thinking through and making sense of all that emerged in those social activities. We argue that both the social interactions Carmen had with other scholars as well as the solitude she enjoyed with her own mathematical ideas—as coupled practices that build on each other—are community practices. The social life of the mathematician is, thus, a crucial resource for learning to be a mathematician.

> **Carmen**: So I started really like curating the set of conferences that mathematically might, for anybody else, mathematically might not be the best options there weren't, I mean. I went to those too. I went to, like, very specialized technical conferences, and the feeling of being there was just anxiety, and so I just, like, hid in my hotel, and I would use that as like writing time. But I wasn't going to the talks. I wasn't meeting anybody because people weren't there to meet this, you know, graduate student from a low tier ranking institution like they weren't there to get to meet me or know me or mentor me in any way, and I kind of quickly learned like, which are the conferences to go. If I want to see myself reflected in the speakers, or if I want somebody to actually come up to me during the lunch and say, where are you at? You know what? What has it been like being a graduate student? Um. And so it was kind of a trial and error. But then, quickly, like, did that work? Yes, that worked. Okay. I will go to that one again next time, and then just making it a habit to like I was traveling all the time … <shakes head> …just as much as I could. It became like the – yeah – it be – it became the place where I was a mathematician, you know, like when I was home, and I was balancing school and everything else, like, I – I was no good at either thing, but if I was away I could at least be a good mathematician during those three days that I was gone.

Here, the elsewhere of a conference is described as "the place where [she] was a mathematician." Mexican American culture was thus framed as both inhibitive and productive of Carmen's becoming as a mathematician: on one hand, her home culture and the responsibilities it brought with it were characterized as getting in the way of Carmen's progression in her career—so much so that she needed to find a way to get away from it and be "traveling all the time." On the other hand, it was the very systems and support afforded to her by familial and cultural relationships (with her brother, sister, and parents) that allowed her to eventually spend time on mathematical work. In other words, going away from her home life was crucially facilitated by the very home life she was trying to get away from. Furthermore, Carmen's choice to be away for stretches of time in order to pursue mathematics speaks to a departure from more traditional ways of doing mathematics. Such references to departures from tradition resonate with her reflections on her own practice and how that compares with others' views of her work:

> **Carmen**: It's been so interesting to just be able to kind of reflect on that and then see sort of from the outside what people see about me, and they're like: Oh, look at all her math papers, or all the work she does with undergraduates. And I'm like, yeah. But see you're counting like articles. And I'm just thinking about all the stories, of the relationship I have with those people,

> and like the part of my life that they've like helped flourish, you know, like – it's not like — the theorem is sort of like a little cherry on a really wonderful solid cake <gestures with hands> that people tend to like, not even see. And that's the part that that I think is—is the thing that has kept—kept me in math, because the traditional, like, climate and culture of departments, I haven't yet found one that's like that right? That, like, values people above the—the mathematics. And I think there's, there's people in every department that are very much like that. But the majority at times that are very vocal and loud, are very much about—about—the thing that's important is the science. Anything that deviates from the science takes away from the science, and therefore it's bad, and, and I think they've just never experienced the other side of it right? Because somebody like me, who started at Intermediate algebra in college, shouldn't be out-publishing these MIT professors, right? These Harvard Yale Educated professors. It was… There's nothing brilliant about me other than, like, building community, and understanding that you know, when you support people — like we do better math when we're together, and we feel that we value each other, and, and it's not just for science' sake.

From Carmen's perspective here, within a traditional mathematics department, "the thing that's important is the science" and what "deviates from the science takes away from the science," including "valu[ing] people" and relationships. Whereas a traditional read of the productivity or generativity of a mathematical life may look to article counts—both in Carmen's telling and emphasized in hiring, tenure, and promotion decisions—Carmen here highlights relationships, such as with undergraduate collaborators. Far from "taking away from" the math, foregrounding the cultivation of relations in community had been what makes "better math" possible. Throughout the conversation this value was connected to cultural practices in Carmen's Mexican American family and community; being a mathematician at racialized and gendered disciplinary margins offered non-normative ways of doing mathematics that often go unacknowledged as part of mathematical practice in academia.

Discussion

Marginalization in mathematics across levels is experienced simultaneously as inclusion and exclusion—where one might be a mathematician but, also, say, antithetically, one is a woman of color (Gholson & Martin, 2019; Prescod-Weinstein, 2021; Star, 1991). The story of how Carmen became a mathematician is a story of social, relational, and affective negotiations and contestations within communities and across cultures. Our analysis of Carmen's interview reveals how the labor of the mathematician, especially that of mathematicians from marginalized groups, is sustained and shaped by several different forms of labor that are carried out in the cultural and social life of the mathematician by various actors. The labor that Carmen engages in—especially that which is not explicitly seen as related to the doing of mathematics—is a kind of reproductive labor that has often gone unrecognized and unacknowledged in social scientific studies of mathematical learning and practice (Federici, 2004; Prescod-Weinstein, 2021). Turning our attention to it here offers us a window into the systems that make the work of the mathematician possible. Carmen's experiences as a Mexican American woman of color in mathematics were necessarily formed at the intersection of, at the very least, mathematical culture, the culture of her home life, and the gendered and raced subjectivities of her social life. Together, these seemingly disparate aspects of her cultural life are mutually constitutive of her membership across communities, including the community of mathematicians. Her life as a mathematician is thus realized by the cultural and political negotiations she (and others around her) undertake from a variety of moving social locations. For Carmen, then, to be a mathematician is inseparable from being a woman of color, an immigrant, a wife, a mother, a daughter, a sibling, and Mexican American. It shapes not only her access to mathematics, but also what mathematics comes to be in her hands.

Significance

Our analysis of the conversation between Carmen and the first author offers insights into the cultural politics of mathematical work, further pointing to the gendered and racialized character of the practice itself (Damarin, 2008; Subramaniam, 2009). Conventional descriptions of mathematical practices tend to be decontextualized and monolithic, in which doing mathematics involves participating in a set of narrowly selected activities (Martin, 2014). Such descriptions portray mathematics as untouched by political, social, material, and cultural forces, offering little in terms of an explanation of how processes of marginalization and underrepresentation in mathematics endure. Empirical methods grounded in feminist epistemologies pose a challenge to such traditional conceptions and allow us to expand our understandings of what mathematics is by looking at it "from below," or from the vantage of those subjected to and by it (Harding, 2008). This vantage animates not only how mathematics education, as a regime, constructs those who pursue it (PMENA, 2020), but also how those who pursue it resist its impositions and through such resistance transform it. Such an approach allows us to tell the stories of those marginalized and oppressed by mathematics (e.g., Gholson & Martin, 2019; Sengupta-Irving, 2021) and of those recruited into its greater political agendas (e.g., Gholson & Wilkes, 2017; Sengupta-Irving & Vossoughi, 2019). Further research of the kind carried out here can help expand the literature on learning mathematics as a social and cultural activity by: (1) providing a feminist social practice theory of mathematics; (2) broadening understandings of the social origin of mathematical work and how this influences teaching, learning and pedagogy; and (3) elaborating on the relationship between racialized and gender-based subjugation and mathematical epistemology.

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Co-Fostering Translanguaging Spaces through Design for Embodied (Re)connection

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Abstract: Building the scholarship on design and equity in the learning sciences, our work attends to the role of languages, power, and historicity in the design process. In this paper, we discuss our design approach to challenge normative power dynamics by centering the concept of translanguaging in a land-based program with refugee children, on an urban regenerative farm. Our design is nested in the larger vision shared by participating teachers for reclaiming power and shifting normative power dynamics through languages. Guided by the corporeal and spatial expansion of languages, we focused on children's embodied employment of collective community practices, land-based knowing and full repertoires of semiotic resources in the presented co-fostered interactional moments. Through our interaction analysis, we highlight the child-led expansion of semiotic repertoires, embodied representations of community, identity and (re)connection to the land. These child-led moments forge new pathways for equity and design.

Introduction: Power and historicity in design

Design is never politically neutral. From benches in the park to algorithms ubiquitously used in our daily lives, design discriminates (Benjamin, 2019). As we consider design that either perpetuates or challenges oppression and discrimination, we need to attend to the "account[s] for critical historicity, power and relationality" (Bang & Vossoughi, 2016, p. 173). Designing learning environments for equity explicitly focuses on the vision for breaking down existing oppressive systems and examines transformational learning opportunities for people and communities to make sense of their identities as designers of possible futures (Gutiérrez & Jurow, 2016). Focus on power and justice in design have been highlighted in the forms of participatory design (Bang & Vossoughi, 2016), social design-based experiments (Gutiérrez & Jurow, 2016), and design justice (Costanza-Chock, 2020). In the process of design toward equity and justice, researchers may outline a viable learning trajectory, but the pathway must remain open-ended for the community members and learners to imagine and design their own futures as "lived experience is non-transferable" (Costanza-Chock, 2020, p. 83). As "equity is both ideal and pragmatic" (Gutiérrez & Jurow, 2016, p. 6); designing for equity is an ongoing process where researchers critically evaluate any reproductions of oppressive norms and navigate tensions between systemic constraints and need for social transformation (Bang & Vossoughi, 2016). Building on this body of scholarship on design and equity, our work adds to the discussion on the role of power and historicity in design, by focusing on the role of languages in the design process. In our design of the land-based learning pedagogy, *Soil Camp,* we intentionally positioned facilitators, and children as *co-learners in front of the land*. Soil Camp is a summer outdoor learning opportunity serving refugee children in Calgary, Canada and a designed network toward eco-social justice (https://www.soilcamp.ca/). Alongside predominantly racialized, multilingual educators, together we collectively reconnect with the soil, community and silenced histories on land, while deepening our understandings through relational and embodied transdisciplinary STEM experiences. This was intentionally created as an act of "deepening learning and contributing to a more equitable social world" (Gutiérrez & Jurow, 2016, p. 30). Given that almost all the children who participated in Soil Camp are Indigenous in their countries of origin, reconnecting with the land is the act of *presencing* (Nxumalo, 2019) their intergenerational wisdoms in the predominantly white farmland landscape. This act of presencing is intertwined with resistance, agency, and transformation in the everyday acts of Othered bodies-in-places by making their presence visible through occupying, gathering, and renewing the place (Nxumalo, 2019).

In this paper, we draw from the concept of translanguaging in our design, the agentic and dynamic linguistic practices of multilingual people, which cannot be confined to named languages (García & Wei, 2014). Translanguaging challenges colonial monolinguistic norms and dominant deficit discourses on language minoritized people and communities by recentering the speaker and their unique lived bilingual language experience and semiotic repertoires embedded in (their displaced) lands (Thraya & Takeuchi, 2022). In our design of Soil Camp, we closely attended to spatial aspects of translanguaging inspired by Wei (2011): "translanguaging spaces are not physical locations or historical contexts only, but are networks of social relations...that are created by individuals through distinctive (of the network) and shared (amongst the network members) practices for specific social purposes" (p. 1225).

An iterative process to design was employed using the aforementioned framing and guided by the voices of our co-learners, their organic languaging practices, and holistic identities. In our Year Two of the design, by bringing forth the notion of translanguaging design for equity, we attended to the aforementioned need for “critical historicity, power and relationality” (p.173) as discussed by Bang and Vossoughi (2016). The central thesis for this design saw translanguaging spaces as nested in the larger vision for reclaiming power and shifting normative and oppressive power dynamics. This co-fostering process challenged the colonial matrix of power that exists within educational spaces that continues cycles of oppression due to the differential power ascribed to peoples, languages, histories, and ways of knowing. Through this, as we will show in our Findings, democratized relationships emerged across these contexts. This paper is guided by the following inter-related and nested research questions:

1. How did facilitators and children enact participatory design in a translanguaging space that centers equity and shifted the normative power dynamics?
2. In the designed space, how did co-learners co-construct the translanguaging space?
3. How can co-fostered translanguaging spaces develop avenues for collective and individual (re)connection?

Framing languages in design for learning: Designing translanguaging spaces for equity

The designing of learning environments that carefully attend to and listen to polylingual repertoires can open up new pathways for non-dominant children’s identity and learning (Gutiérrez, Bien, Selland, & Pierce, 2011; Lizárraga & Gutiérrez, 2018). As Lizárraga and Gutiérrez (2018) have shown, children can open up the new learning as organizing possible futures in the spaces that embrace fluid boundary crossing and *nepantla literacies* (p. 39), which cannot be conformed into normative linguistic practices (e.g., the ones that have often been imposed on non-dominant children in school settings). Semiotic repertoires cannot be completely seen, but through design we can improve the accessibility to such resources. Our design and analysis share this orientation to in-betweenness, fluidity, and children-led space creation leveraging their already existing linguistic repertoires.

Thus far, the conceptualization of translanguaging has been anthropocentric, focusing on human communications yet can be reframed as “a pedagogical tool for (re)connection with each other, intergenerational knowledge, and more-than-humans" (Thraya & Takeuchi, 2022, p.616). Moving beyond our previous conceptualization, we push for viewing translanguaging from an embodied and historicized lens. Marin (2020) reminds us that those who research STEM education should develop systems of analysis and ways of seeing and listening that allow us to "re-member (Grande & McCarty, 2018; Wa Thiong'o, 2009 as cited in Marin, 2020) relationships between land, humans, and more-than-human relatives" (p. 31). As children engage closely with more-than-human lives on lands (Marin & Bang, 2018), they could engage in translanguaging practices that go beyond human-to-human communications. Based upon our findings from Year One, we continued to explore the extended notion of translanguaging to account for the relationality beyond human-to-human connection, to include more-than-humans, land and silenced knowledges (Thraya & Takeuchi, 2022). This theoretical push is increasingly pertinent with the current global influx of displaced refugee families embodying agricultural experiences who are stripped from their generational connection to more-than-humans through the resettlement process.

Scholars who study translanguaging have proposed an expanded view of translanguaging to include nonlinguistic modes including embodied communicative practices (Blackledge & Creese, 2017; Suárez, 2020). The attention to embodied communicative practices within translanguaging enables “a holistic focus (addressing ideologies, histories, potential and constraints) on action that is both multilingual and multimodal” (Kusters et al., 2017, pp. 11). As Suárez (2020) demonstrated, embodied translanguaging practices enable linguistically minoritized learners’ expansive expression of scientific models. Such embodied translanguaging can be spatially expanded "assembled in situ, and in collaboration with others, in the manner of distributed practice…beyond the linguistic to include all possible semioticized resources” (Canagarajah, 2017, p. 37). Canagarajah (2017) emphasizes on the spatial repertoires being “embedded in the material ecology and facilitated by social networks” (p. 37). The semiotic ecosystem of Soil Camp showcases “an assemblage” of “different trajectories of people, semiotic resources and objects [can] meet at particular moments and places” (Pennycook, 2017, p. 280). These assemblages (as Pennycook conceptualized based on Deleuze and Guattari’s posthumanist conception of assemblage) are powerful interactional becomings, which are highlighted in the chosen episode.

Methodology

We draw from participatory social design research methodology (Gutiérrez & Jurow, 2016) that centers historicity, diversity, equity and ecological resilience as design principles and aims to co-design just practices and futures in partnership with a range of communities. We are also guided by Indigenous ways of knowing and decolonizing methodology that acknowledge colonial relationships reinforced by research and honour and carefully listen to the voices of Indigenous people (Smith, 2001; Marin, 2020). Aligned with design-based research that values iterative cycles of development, implementation, and study of design (The Design-Based Research Collective, 2003), our design has emerged from multi-year collaborations and redesign. One of the foci of redesign was around linguistic practices through our reflections on linguistic design for equity and justice. Our methodological commitment oriented us to analyze interactional phenomenon of translanguaging (García & Leiva, 2014) while historicizing the phenomenon of translanguaging in light of macro histories. As we analyzed the interactions, we closely attended to the power dynamics surrounding the participants, colonial histories (between humans and between humans and MTH), and linguistic norms reproduced or challenged in particular interactions.

Since 2021, in total, 85 children (5 years old to 15 years old) and over 20 families joined our program, Soil Camp. All attendees were refugees from Syria, Northern Iraq, Kurdistan, New Guinea, Pakistan, South Sudan, Ethiopia, and Eritrea who had resettled in Canada within the last five years. Eighteen teachers and teacher candidates (who are mainly racialized multilinguals) joined as facilitators of Soil Camp. A team of researchers collected the following datasets from two iterations of Soil Camp that took place over two years. The video data was collected using three modes (Go-Pro cameras worn by both the participants and by the researchers, Handycam video cameras held by the participants and researchers, as well as still cameras that were stationed on tripods in the primary spaces of interaction). A total of 91 hours and 35 minutes of video data was collected by the research team. For this paper, we draw from video data collected during the second iteration of Soil Camp (totaling 5 hours of video data) to gauge emerging interactional phenomenon under the design that was intentional about leveraging participants' translanguaging experiences.

Our analysis started from our collective reflections on learning moments that speak to the analytic foci of embodied translanguaging practices. These focused learning moments are partially guided by our positionalities as researchers/facilitators. Sophia Thraya (Author 1) is a second-generation Canadian of the Lebanese diaspora and self-identifies as bilingual, holding both English and Arabic in her linguistic repertoire and dear to her heart. Her partially shared histories and previous engagements with and within the community has provided her with ethical engagement affordances, but more importantly the responsibility to continue to seek guidance. All the co-authors were racialized, multilinguals with the lived experiences of immigration. Although our positionality goes beyond what can be summarized in these few sentences, our analyses were guided by our personal and collective histories that shape reflexivity and sensitivity to certain aspects of learning. Drawing upon theories of learning and knowing, we take an introspective multi-level sociocultural approach to critically analyze micro-moments of interaction within the greater macro institutional and historicized climates across spaces. Our analysis emerged from analytical gazes wherein first-, second-, and third-person testimonies are intertwined (Espinoza et al., 2020). Our analysis was possible because we had shared experiences of being together on the land with children during summer camps over the past two years. These shared experiences allowed us to surface the layered translanguaging practices and the interactional co-fostering of the translanguaging space through collective movements-with-the-land.

After analyzing the data from Year One, there were many significant insights into the organic languaging practices and the power of such a stance in learning environments. As we pursued analysis of Year Two data, we paid attention to the enactment of redesign and intentional enaction of translanguaging practices. We then analyzed segments of data where the participants were bringing in non-dominant (and often censored) languages in institutionalized schooling spaces. Collective viewing of data and collective analysis were followed to bring multiple voices into video data analysis. Subsequent to these collective viewing sessions, we transcribed key segments of data as compelling enactment of translanguaging initiated by the participating children. Guided by the corporal expansion of languages, we attend to children's embodied employment of collective community practices, land-based knowing and full repertoires of semiotic resources in the presented co-fostered interactional moments. We examined how children provided glimpses of their semiotic repertoires which forge new pathways for embodied representations of community, individual identity and MTH (re)connection by moving beyond the planned activities.

Findings

Iterative design reflection: Enacting participatory design in translanguaging spaces

Integral to Year Two iteration was the co-fostered translanguaging through intentionally concretized design elements. From the Year One observations of ideational artifacts (Nasir, 2004), Thraya concretized key elements within the space that served as "transformational tool[s] for deconstructing the colonial views of what it means to learn in educational spaces and with what languages" (Thraya & Takeuchi, 2022, p. 7). Concretized elements were both explicit and agentic in nature.

The first concretized element to this iteration was the official statement of listening together to the histories, languages, and stories through anti-colonial relationality within Soil Camp's vision and grounding epistemes; directly connected to the central thesis for design centering power and presencing in the linguistic design for equity and justice. Prior to the start of Soil Camp, the preservice and in-service teachers and researchers became familiarized with our grounding episteme through professional development sessions to explicitly discuss the theory and pedagogy of translanguaging as a tool for (re)connection based upon the Year One findings. This integral dimension of the project was revisited daily and reflected upon throughout the iteration as our predominantly racialized multilingual educators co-enacted this episteme with the children. This episteme was presented to the children through various collective consciousness raising conversations and whole-group exercises. An example of this is when all participants, including facilitators and researchers, shared the languages that they held in their hearts which we termed "translanguaging hearts." Going around in a circle, children witnessed the meeting of individual and community multilingual identities. This was a key moment in the assembly of the Soil Camp spatial repertoire. Seeing others with similar as well as different repertoires to their own coming together in the space was transformative in abolishing English monolingual superiority. As a result, languaging coming from the peripheries became centered in the "learning space." Our collective stance was reminded to all through our daily affirmation which was modelled by facilitators and repeated by all in our morning arrival meeting. Such an explicit affirmative stance directly countered the macro-level oppression and deficit linguistic ideologies present in disciplinary spaces as part of broader colonial agendas. The affirmation read: *I will learn with my whole language heart, I will connect with my beautiful knowledges and speak with the words that flow naturally, I will (re)connect and make new friendships using my whole self, with all the living things I meet, we will share, love and be together on this land.*

The second concretized element was embodied transdisciplinary experiences where translanguaging was nested, spontaneous and agentic. This was done consciously as facilitators saw how it could easily be extractive if done in ways that were too direct, where children were asked 'to language' by the ways of superficial translation work which could replicate dominant oppressive languaging practices and remove learner agency. As we demonstrated in the following section, with this adoption, we saw a shift from peripheral engagement to agentic, centered engagement of children. Alternatively, we designed transdisciplinary experiences where translanguaging was visible, heard, agentic, and embodied—where they engaged on their own terms. Embodied experiences such as a Blackfoot medicine and MTH meeting walk led by a Blackfoot knowledge-holder and educator offered a transformational space for embodied repertoire use.

The aforementioned concretized design elements were balanced with the spontaneous child-led moments of co-fostering in the translanguaging space. The greatest learning from Year One was done by listening to the children — not to their responses to our questions, but rather listening to how they responded to one another and to the space through agentic and embodied experiences. Attention paid to informal spaces, and micro-interactions were most insightful in understanding the children and their relationships to language as an avenue for (re)connection. We intentionally concretized the lead of our children as a central design element, as co-fostering such a space would not be possible without this work being done *with* the children.

Collaging

Through the aforementioned intentionally concretized design elements Soil Camp and the iterative design reflections, translanguaging had a commonplace during the planned and unplanned activities. Specifically, during a collaging activity that took place over two days, children were prompted to create collages of their collective and individual networks of community. This experience took place in an event tent on the land, while children came in to find the tables covered with a variety of print materials spread out for them to cut and paste from local cultural, event, and business magazines. All children in the identity collaging activity were Yazidi-identifying from Iraq working alongside Sophia and co-facilitator Layelle, an educator of Syrian descent. Notable translanguaging that went beyond named languages including the Kurdish dialect of Kurmanji, Arabic and English occurred in modes of verbal communication and child-led music selection which played in real-time in the co-fostered space. Through the intentional design and deep caring relationships developed among facilitators and the children over the course of two summers, these interactions broke down the hierarchy between "teachers" and "students" and actively countered the macro geopolitical, and linguistic matrix of power tied to identities in the space. While the designed experience encouraged learner agency and embodied expression through the medium of collage, the activity became a site where children, unrestricted by the design of the activity, took the opportunity to showcase parts of their shared identity on their own terms. Through an initial discussion of unpacking what community meant to them, the children articulated their complex, layered, and emerging relationships with languages, places, people and more-than-humans (MTH). The topic of discussion included what community is and how children located themselves within networks of community—geographically, locally and abroad, as ecosystems, culturally, linguistically, spatially, and through interest-based networks. We also discussed how Soil Camp was a meeting point that transcends boundaries and divides. As Dila (all the participants' names are pseudonyms), a girl-identified Yazidi participant expressed:

> I am still connected to Iraq, my language, I feel connected to Indigenous ways, it shows us many things, like Canada, like Calgary, and Arabic—it is kind of a language of ours but it's a little different. I connect to everything.

This quotation captures how Dila connected to core pieces of her identity, that are lived, and transcend borders and divides, including complex historical dynamics embedded in the fabric of her linguistic repertoire tied to the Arabic language. Arabic is the national language of the dominant majority in her country of origin and the officially adopted language of ISIL who were responsible for the unjust genocide and forced displacement of the Yazidi people (as brought up by children during the activity). Evident forms of redefining such relations through the new spatial repertoires formed in translanguaging spaces have surfaced across both years. We can see that for these racialized multilingual children language is seen as alive, embodied, and is employed as an act of sustaining relationality (Henne–Ochoa et al., 2020)—which is further unpacked explicitly in the subsequent section. The children collaboratively created the networks of community collage, with a significant inclusion of images and words related to environmental sustainability and more-than-humans that the children were in community with at Soil Camp. Some children used the scrapbook letter stickers to create words of the places in which they connected with—including countries of origin (Iraq, Syria) as well as Canada. Images of Treaty 7 territory were also focal to the collective piece including both natural features and man-made monuments—taken from the local magazines. Images of peoples donned in Indigenous cultural regalia, and other images of cultural celebrations were also featured on the poster. Following the completion of the collaborative poster, all were given a piece of scrapbook paper that they used as a base for their identity collage.

Embodied translanguaging and interactional presencing of dîlana kurdî

The following interaction highlights the equitable participatory design in action through the child-led moment of moving beyond the designed learning experience and into a space they co-fostered relationally in the moment. This assemblage exemplifies the dynamic exchange and the ways in which the children draw upon their lived-experiences, collective practice and other available spatial resources to co-create child-led artifacts that were embodied tools for storytelling, (re)connection, and collective remembering. This episode occurred during the individual collaging experience. As the children alongside the facilitators engaged in the artistic process, rich conversations emerged around MTH relationality among the group leading to one child to begin singing about her connection to MTHs that she described as "being a part of [me]." Sophia asked the group if they would like to play Kurdish songs on Sophia's iPhone and they were quickly met with a wave of excitement. The girls passed around the iPhone, taking turns playing Kurdish children's songs that they were fond of and listen(ed) to pre-migration in Iraq and after resettlement in Canada. An eruption of collective remembering, singing along and sharing connected to the songs emerged from this addition to the space. It was not until the introduction of music that the planned experience of collaging began to shift into a child-led employment of linguistic and non-linguistic resources for expression and collective remembering through music. This was the start of a powerful exchange with Sophia and the children about family traditions and customs of the ethnoreligious community around their celebration of Eid and weddings—touching upon food, clothing and celebratory practices including dance. Embedded and integral to this interaction was the ways in which this engagement was approached, the participants explained many pieces of this through a comparative lens—employing their knowledge of Sophia and the co-facilitators' religious and cultural identities (Muslim Arab women). They shared their knowledge of both common and differing experiences. Episode 1 began as the children were in the final stages of their pieces. Kurdish music filled the tent, and the co-facilitator suggested an Arabic song that her students enjoyed and asked if the children knew the song as well. The children immediately suggested the song be played and as the song began the majority of children began to sing along. Dila joins in dancing from her seat, rolling her shoulders forward to the beat.

Table 1

Excerpt 1: Child-Initiated invitation to dance together

Time Stamp	Speaker	Transcription
#12:22:47-8#	Dila	That is how Kurdish people dance
#12:22:52-0#	Tela	And kind of with their pinkies
#12:22:56-7#	Sophia	Can you show me?

Figure 1

Excerpt 1 in action

After this invitation by Sophia, there was an immediate response by the group. Lilan stopped her cutting and pasting and joined pinkies with Sophia and both Dila and Alal came from around the table to link pinkies. The girl-identified children began guiding Sophia through the motions of the dance. They took the opportunity to teach facilitators the isolated steps as their arms rowed forward synchronously, continuously linked by their pinkies. The children gently guided Sophia and took the time to explain the many variations in the dance known as Dîlana Kurdî, a Kurdish folk circle dance. Sophia paid close attention and asked clarifying questions related to the movements—following the children's lead. Dila invited and guided the group to move outside of the tent to continue the dance. A noteworthy use of language showcased the democratization of power occurring through this child-led interaction.

Table 2

Excerpt 2: Child-led movement on the land

Time Stamp	Speaker	Transcription
#12:24:01-5#	Dila	We can go outside and dance like this /holds pinky out/
#12:24:03-0#	Sophia	Should we ↑
#12:24:03-4#	Dila	Yeah, let's go

Prior to the re-interlacing of the pinkies and the circle dance commencing, a moment of joy was exhibited while moving-on-land, the children were dancing, jumping, clapping and hugging (see centered image in Figure 2). The Arabic song continued playing and the Dîlana Kurdî began again. The girls modeled with their bodily movements supplemented with counting and verbal feedback. The repurposed Arabic music became the soundtrack of this interaction. The girls verbally shared how much fun they were having, and the co-facilitator asked if they would like to learn Debka, a similar-styled Levant folk dance. The co-facilitator was met with enthusiastic responses and Sophia made explicit the commonality she found in both dances and explained the steps in a parallel manner to Dîlana Kurdî. The Arabic Debka music plays, and the girls recognized the song. The girls held hands and followed the lead of the facilitators. The Debka dance ends and Lilan shared her knowledge of how circle dances are common across cultures. The group found commonality as they discussed the importance of these dances in celebratory times including weddings and holidays such as Yazidi New Year. Dîlana Kurdî began again as Kurdish wedding music played, the co-facilitator heard a familiar word حياتي, hayati, a term of endearment meaning 'my life' in Arabic. The co-facilitator was met by the children sharing that this is a common word in Kurdish—an additional shared dimension of their semiotic repertoires.

Notable in these interactions are how all the participants started to become "co-learners" through embodied translanguaging—the ways that transcended borders between facilitators, who are Arabic speakers carrying Muslim diasporic practices and Yazidi children. We see a shift in conversation and moments of collective remembering emerge on a collective and individual level. Silenced personal experiences and the sharing of the collective story of the ethnoreligious group from the perspective of Lilan began. Layered sharing filled the hollow middle of the circle and was assembled in situ as all agentically shared. Lilan talked about the lived, pre-migratory and current oppressive histories of her peoples as she danced:

> For Êzidîans (Yazidis) back in the olden days, they had to do what adults had to do like at the age of 6. They weren't really treated that goodly and they really didn't have that much money. So, they had to make their own stuff and farm. But it was so much fun though, I miss those days. Now it's harder...there is still people trapped by the Daiş (ISIL) [It's not really like a war] that's why we had to move from that place.

Figure 2
Dîlana kurdî in action: Visualizing the assemblage

Together there was a shared use of translanguaging as a tool for (re)connection to one another, MTH, shared linguistic and non-linguistic embodied resources as well as silenced histories and stories. The meaning of translanguaging to (re)connect for co-facilitators in this moment manifested into being a witness and listener as the flow of sharing occurred. Translanguaging to connect for the participants in this moment meant connecting to memories of joy, loss, nostalgia and hope that were layered, heard and alive in the recounts as Tela shared, "I love the place that's, just like, flat and it is all green with daisy and flowers."

Discussion

In this paper, we have demonstrated how iterative design of translanguaging space towards equity and justice facilitated the emergence of an assemblage where silenced languaging, cultural practices and lived realities coming from the peripheries became centered in the learning space of our designed Soil Camp program. While the design initially focused on linguistic translanguaging experiences, dance was employed by the children as an embodied nonlinguistic resource; a meaningful piece of their semiotic repertoire deeply tied to historicized sociocultural dimensions and embodied connections to the land. It is in such a moment that "embodied communication [comes] plainly into view" (Blackledge & Creese, 2017, p. 255). Both the Kurdish circle folk dance and Levantine Debka have origins connecting to story, land, soil regeneration, promotion of plant growth and agricultural fertility (Al-Awwad, 1983). Circle folk dance, a common and integral part of all co-learner's repertoires were brought out and made visible through this child-led moment. It is in such moments that new avenues, unimagined by facilitators, come alive. The children employed dance as a mode of translanguaging to communicate silenced stories and lived experiences of their community through dance, which can be seen as an act of *presencing* (Nxumalo, 2019). The performances spontaneously emerged in new geographical locations, allowing for (re)connection with living things across cultural, species, spatial, linguistic and temporal divides.

Through these evolving intentional and explicitly designed disruptive practices, not only were children's multilingual identities validated, but also the intergenerational knowledge systems and stories that are intrinsically embedded within their repertoires—resulting in the co-creation of "new social realities" for learning (García & Leiva, 2014, p. 204). This can be seen as an assemblage of silenced histories, stories and collective remembering as a result of the promotion of child-led, dynamic opportunities for (re)connection. Children were then able to see how their repertoires are resources in all spaces and offer tools for (re)connecting relationally. It was evident that to foster an agentic and embodied translanguaging space we had to follow the *corriente* (García et al., 2017, p. 21) and lead of our co-learners. Facilitators welcomed and encouraged the in-the-moment adaptation of the learning experiences and space by participants. We see active and reflective listening centered in the episode, and as such, facilitators were able to follow children's agentic movements and insight as a way of reorganizing "systems of activity in which participants becom[e] designers of their own futures" (Gutiérrez & Jurow, 2016, p. 566) in line with social design experiments. As demonstrated in this paper, Soil Camp's spatial and embodied semiotic repertoire could emplace the silenced displacement of peoples, knowledges, and histories that are inextricably connected to land and MTH networks of connection. The explicit design intention to concretize linguistic elements of design toward corporeal expansion of translanguaging, while balancing such elements with spontaneous child-led moments is what led the researchers to dance with the children—a literal embodied pathway toward equity and justice.

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Examining Rights to Participate and Struggles to Belong in Science Classrooms through a Black Girl's Engagement in Argumentation

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Abstract: If we are to support students to become epistemic agents in the ways envisioned in reforms, we must acknowledge that classrooms can be spaces of injustice, where instructional efforts can propagate inequitable systems of oppression. In this case study, we describe the epistemic efforts of one Black girl, Jessie, and the rights and privileges afforded or denied to her as she worked with a group of her peers to develop and negotiate a scientific claim. Through examination of video data, transcripts, and student work products, we characterized students' efforts as about epistemic, rhetorical, and pseudo-argumentation, and how we explored how such efforts invited or constrained Jessie's epistemic agency. Jessie's pattern of persistence, which we understand to be her fight to have her rights as a scientific sensemaker acknowledged, surfaced issues of inequity in which Jessie's ongoing efforts to engage in epistemic argumentation were rejected by her peers.

Introduction

Educational reforms have positioned the development of science proficiency as the end goal of science instruction—that is, students should be able to use the tools of science to construct explanations of phenomena (NGSS Lead States, 2013). This work requires that students are positioned as epistemic agents (Miller et al., 2018; Stroupe, 2014) who share, discuss, and refine their thinking (Berland & Reiser, 2009; McNeill, 2011).

To support students to be epistemic agents, classrooms need to be structured as equitable spaces where students feel their ideas are valued by themselves, their peers, and their teachers--that is, they must be viewed by others and themselves as entitled to and worthy of contributing to the classroom community's advancement of scientific knowledge (González-Howard & McNeill, 2020). Equity, however, is often framed around ideas of access and inclusion for *all* (Martin, 2019). This framing does not always acknowledge that classroom spaces are embedded in cultural systems of knowledge and practice grounded in whiteness and heteropatriarchy (Calabrese-Barton et al., 2022; Ladson-Billings, 2006) that position historically marginalized students as outsiders with minimal power and authority (Nasir & Vakil, 2017). Inviting students into these spaces and expecting them to participate in the dominant discourses and practices that manifest in systems of privilege and oppression (Milner, 2015) may limit their agency in the classroom. More importantly, it may also impact the value they place on engaging in similar future endeavors given the required effort and associated costs (e.g., emotional, epistemic) this engagement requires (Eccles et al., 1983; Wigfield & Cambria, 2010).

If we are to support students to become epistemic agents in the equitable ways envisioned in reforms and discussed among the science education community, we must acknowledge that classrooms are spaces of injustice where a singular approach does not work. We must understand how instructional reform efforts can propagate inequitable systems of oppression. As Calabrese-Barton and colleagues (2022) point out, we must renegotiate "what the rights to being and learning in science are or could be" (p. 54), especially for historically marginalized students. To engage in this renegotiation, we must attend to who has the rights and privileges to participate, and to understand the struggles to belong in science that arise in learning environments constructed to engage students in the epistemic work of science.

Accordingly, this research aims to understand rights and privileges viewed through the experience of one Black middle school girl, Jessie, and her efforts to participate in scientific argumentation in a science classroom. We build from the work of González-Howard and McNeill (2020) that points to engagement in argumentation as consequential for learners' sense of agency. Agency is shaped not only by one's own comfort and perceived capability to engage in the epistemic work and practices of scientific argumentation, such as construction and critique of ideas, but also by the rights and privileges that are afforded by one's community to participate in this work, that is how one's community takes up these efforts (Calabrese-Barton & Tan, 2020; González-Howard & McNeill, 2020).

When students engage in *epistemic ways of argumentation*, they participate in knowledge critique and refinement by using evidence and reasoning to support a claim, challenging the evidence and reasoning of others with competing claims, or examining evidence and reasoning against existing theories (Berland & Reiser, 2009; Duschl, 2008). When students engage in these ways, they come to see their ideas as valid for scientific sensemaking and consequential to the learning community (González-Howard & McNeill, 2020). However, non-scientific ways of argumentation present in science classrooms (Berland & Hammer, 2012) move away from these potentialities and may work to undermine learners' epistemic agency. These ways of argumentation include rhetorical and pseudo argumentation. When students engage in *rhetorical ways of argumentation*, they engage in persuasive aspects of argumentation in which they take a competitive stance stressing differences of opinions rather than working to understand those differences, or emphasizing the correctness of their claim with minimal regard for evidence, reasoning, or competing claims presented by others (Mercer, 2000; van Eemeren et al., 1996; Walton, 1998). When students engage in *pseudo-argumentation*, they engage in the ways of doing school, that is when they work to satisfy the teacher or focus on completing the task, without attention to sensemaking or to coming to a consensus understanding (Berland & Hammer, 2012).

The research presented here aims to better understand the epistemic efforts of Jessie and the rights and privileges afforded to her as she works with her peers to develop and negotiate a scientific claim. We use the theoretical lens of ways of argumentation and ask the following research questions: (1) What ways of argumentation do Jessie and her group members engage in during a small group argumentation activity? and (2) How do these ways of argumentation invite or discourage Jessie's epistemic agency?

Methods

Context and participants

In this research, we took a case study approach— an approach that allows for an in-depth examination of complex issues bounded by context (Creswell, 2007; Miles et al., 2014). In this case, we study the interactions of Jessie (all names are pseudonyms), and her group members during a small group argumentation episode bounded by a lesson. The group consisted of Jessie (a Black girl), Lee (an Asian boy), Chad (a white boy), and Kendall (a Black girl) as well as another student that interacted with the group named Joseph (a white boy). The lesson was led by Mr. Jerry, the white male teacher of this middle school biology class. Mr. Jerry was a teacher enrolled in a professional development (PD) opportunity, a larger project from which this research is drawn. The PD was centered on supporting teachers to develop instructional practices and knowledge to engage their students in epistemic discourse to learn science in ways that align with science education reforms (NGSS, 2013; NRC, 2012). As part of this PD, Mr. Jerry implemented a four-day lesson called *Cell Structure* (Sampson et al., 2014). This lesson was structured to engage students in scientific argumentation where students were involved in collecting data and using those data as evidence to support a claim that they negotiate with their peers.

For this research, we examined video data and corresponding transcripts from a small group episode and associated student work products. The episode was the main source of data and was analyzed to identify ways of argumentation, as described above. In this analysis, we attended to discourse and multimodal affective markers to understand how Jessie's peers' responses invited or discouraged her epistemic agency.

Analytical approach and stages of analysis

This work began when we, the three authors of this research, were examining small group interactions during argumentation activities to better understand how teachers support students to engage in productive epistemic discourse. As we were focusing in on different small group interactions, the interactions surrounding one student, Jessie, stood out, and we began to recognize that her epistemic efforts were taken up by her group members in different ways during their interactions. We were particularly interested in Jessie because she had a powerful presence in the classroom (e.g., often bringing her ideas forward during whole group discussions and being animated in these interactions) and because she was persistent in her attempts to have her ideas heard and taken up when working in the small group component of activities, work that far exceeded those exerted by others in the activities, and because of the affective frustrations that she exhibited in these interactions.

We began our analysis by examining the efforts that Jessie engaged in as she worked to bring her ideas forward in one argumentation activity, *Cell Structures*. In this analysis, we independently watched videos and examined transcripts of the activity and then met to discuss the dynamics we were observing, how Jessie's efforts were or were not taken up by her group members, the work that was required of Jessie in these efforts, and the salient affective moments that stood out. We recognize that these interactions may be influenced by existing relationships and power dynamics between individuals and within this classroom space. However, we focus on this one lesson, not to minimize the power of these histories but, instead, to closely examine manifestations of these dynamic within this learning context. After multiple views and discussions, we focused on one 24-minute episode that occurred on day three, when the group began developing their argument. This development included deciding on their claim and the evidence that they would use to support this claim. We chose this episode because it included students' idea negotiations, multiple claims, and evidence consideration in an effort to identify the claim that best accounted for the data.

To further understand the interaction dynamics of this episode, we watched and rewatched video recordings of the group as they made observations and discussed these observations at a microscope and as they worked to develop their claim, evidence, and reasoning (CER) poster at their lab table. The authors watched the video independently and came together to discuss what they were noticing. They noted particular moments that stood out to them from the episode, including moments of discourse and affect that they felt were particularly salient. The authors continued to engage in watching and then discussing the video and examining the transcript to gain a better understanding of the group dynamics and Jessie's efforts within this work.

After this initial analysis, the first author examined the episode and identified thirteen segments. Segments were a period of interactions when the group, or members of the group, held a common focus before shifting to another focus. Many of the segments occurred when the group moved between the microscope and lab table spaces or when one group member physically left the space. However, because of the recursive nature of the group's deliberations, multiple segments occurred within these spaces.

The first author coded each segment using the ways of argumentation framework described earlier. Further, she identified whether there were particular moments of affective expressions (e.g., gestures and voice intonation) of frustration associated with these utterances and interactions. She focused on these expressions because the authors had noticed in their examination of the data that Jessie's ways of argumentation were often marked by her visible frustration with her peer's ways of argumentation or engagement. While all group members exhibited affective markers, here we focus on Jessie because they were the most pronounced of all group members and because of our concentration on her. Screenshots of these affective moments were captured and added to a summary of each segment, which included an overview of the segment, a description of each student's interaction, and a description of affective dynamics at play.

Once all segments had been coded, the first author created a visualization of the segments showing the different ways of argumentation present within segments, the participants involved, and Jessie's affective markers associated around her frustration when they emerged. We used this visualization and segment summaries to examine the data and answer the research questions, paying particular attention to affective markers, shifts between segments, and ways of argumentation.

Researchers' positionalities

The three authors, two white women (the first and third author) and one immigrant Arab from Middle Eastern background (the second author), were intimately involved in the larger project from which this research is drawn. We began this project to understand group dynamics at play in students' sensemaking spaces, but as we examined the data from Jerry's classroom, particularly those videos from Jessie's small group, we were struck by Jessie's extensive efforts to be recognized as a contributing member of her group's ideas. As we engaged further in these data, we began to understand the racial and gender dynamics at play in these spaces. While we could understand some of the gender dynamics occurring in the space, given that all three of us have experienced forms of gender inequities as female science learners and scientists, we understand that we do not bring a history informed by racial marginalization, particularly around the lived experiences of blacks in the United States. To account for this positionality, the authors have worked to understand intersecting issues of race, social justice, and gender by examining literature and research around these issues and attending to these ideas in their examinations and discussion of this case. While the researchers acknowledge that these endeavors do not provide an insider view of Jessie's experience, they did provide groundings by which the researchers could work to attend to the intersectionality as outsiders of the community.

Relevant background to situate the episode

In the four day *Cell Structure* lesson, students were tasked with determining how an unknown microscopic organism should be classified (Sampson et al., 2014). On day 1 and 2 of the lesson, students examined plant and animal cells at microscope stations at the back of the classroom. They were tasked with drawing and describing what they saw on a worksheet with one column for the drawing and one column for the written characteristics of the cell. On day 2, a slide mount of an unknown organism was introduced and students were tasked with making observations of the slide before beginning to develop an argument answering the guiding question, "How should the unknown microscopic organism be classified?" On day 3, students continued developing their argument and created a claim, evidence, and reasoning (CER) poster. This required the majority of the class session. During this time, students worked with their groups at their lab tables, while revisiting the microscope slides to check their ongoing sensemaking. Towards the end of the day, groups shared their posters with their peers in a round-robin format in which one member of the group stayed with and shared the results of the posters with students from other groups. On day 4, students individually wrote up their argument.

Findings

Jessie and her group engaged in multiple ways of argumentation during the episode examined here. The group, particularly Jessie, largely engaged in the epistemic ways of argumentation in which ideas or evidence brought forward by group members were attended to or pushed against, and evidence to support a claim were brought forward. These epistemic ways of argumentation occurred frequently across the episode. However, the ways of rhetorical and pseudo argumentation by particular group members, which occurred to a much lesser extent, worked to constrain Jessie's rights and privileges to have her ideas taken up. We saw evidence of Jessie's frustration as she was not being given full access to the learning space. This evidence manifested in her affective expressions which included gestures (e.g., eye rolls, downward eye gaze, and hand movements) and changes in voice intonation (e.g., raised or softened voice) as she brought forward evidence to support her claim ("The cell is a plant cell because *it has a cell wall*") or brought attention to the fact that group members were not attending to her ideas ("You guys are not listening."). These markers of frustration shifted from ones reflective of Jessie's exasperation to ones that indicated a sense of somberness at the end of the episode as Jessie's persistent attempts were not taken up in the group's argument and she was tasked to present an alternative claim, a claim that did not represent the ideas that she worked so hard to bring forward.

Ways of argumentation that Jessie and her group members engaged in

An overview of the ways of argumentation that the group engaged in are represented in Figure 1. In the figure, column headers indicate the different segments (1 to 13) of the episode. The width of each segment represents the proportion of time the segment took out of the 24-minute episode. Gaps in these segments represent moments when the group was not observed to be focused on argumentation. Rows are separated by each of the three ways of argumentation and their characteristic(s). Colored boxes in these rows indicate when something that a student said or did was coded in this way. Orange boxes indicate moments when one of the group engaged in the epistemic ways of argumentation. Green boxes denote when one of the group engaged in rhetorical argumentation including telling an answer or emphasizing the correctness of a claim with minimal or no regard for supporting that claim with evidence, reasoning, or considering the claims of others. Blue boxes denote pseudo argumentation indicating when students were focused on completing the poster. Figure 1 shows the broad distribution of students' engagement in the epistemic ways of argumentation, of which bringing forth evidence occurred most often. Rhetorical and pseudo argumentation occurred less frequently and are clumped within particular segments.

Figure 1

General Overview of Ways of Argumentation Identified Across Lesson Segments

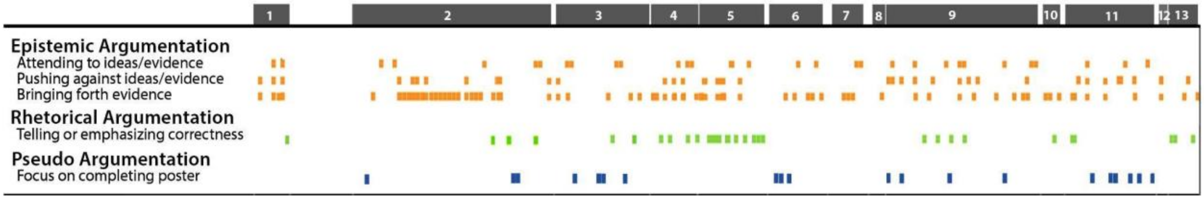
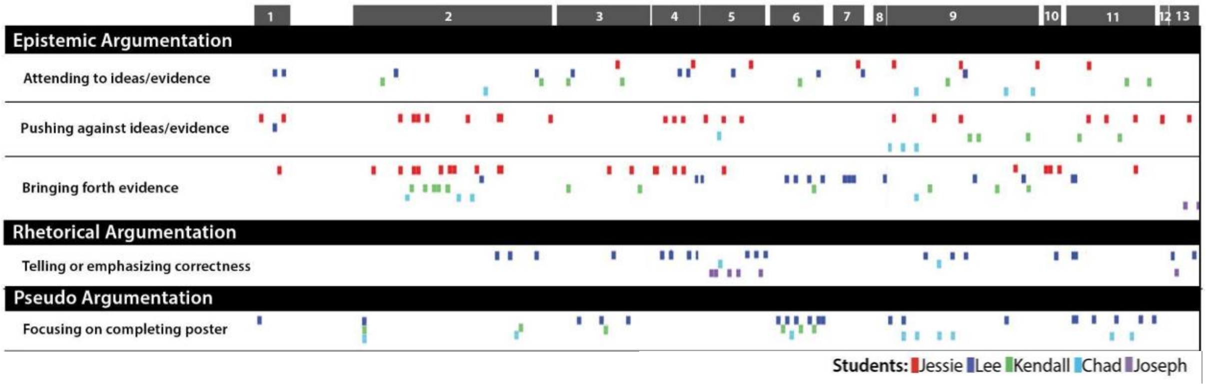


Figure 2 shows patterns in particular students' ways of argumentation. This figure is organized in a similar way to Figure 1 in which column headers represent segments and column rows represent ways of argumentation. However, here students' individual ways of argumentation are visible by the colored box within each row. Jessie is represented in red, Lee in blue, Kendall in green, Chad in light blue, and Joseph in purple.

In this figure, we see that Jessie engaged in the epistemic ways of argumentation across the episode. She engaged in multiple epistemic ways including attending to her group's ideas and the evidence they present, pushing against their ideas and evidence, and bringing forth evidence in support of her claim. Bringing forth evidence and pushing against her peers' ideas occurred more frequently than attending to the ideas or evidence of her peers. In this work, she argued that the cell represents a plant because it had a cell wall, an argument that she made consistently across the episode drawing upon evidence in her notebook, the group's worksheet, and the microscope slide to support her claim. She attended to her notebook, a place where she has written down the underlying concepts of the lesson, to "research" her claim or for evidence to support her claim. She used the worksheet, an artifact that represents the observations that the group made when examining the cell slides under the microscope, as evidence to support her claim. And, she referred back to the microscope to push against Lee's ideas or as evidence to support her claim. Jessie did not engage in rhetorical or pseudo argumentation.

Figure 2
Ways of Argumentation by Enacted by Students Across Lesson Segments



Kendall interacted in epistemic ways as well by attending to ideas or evidence, pushing against the ideas or evidence of others, and bringing forth evidence herself. These interactions were largely with Jessie and Chad. While Kendall engaged in epistemic ways of argumentation, she also engaged in pseudo argumentation when she focused on constructing the poster for completion, a way of argumentation that Chad similarly engaged in. Chad, who was tasked by Lee with constructing the CER poster, engaged in all forms of argumentation. However, he remained largely focused on drawing the component parts of the poster and making sure the group presented a complete claim on the poster, as evidenced by the light blue marks in the pseudo argumentation category in Figure 2.

Lee similarly engaged in all ways of argumentation. He engaged across the episode in epistemic ways and also participated in rhetorical and pseudo argumentation. Lee's rhetorical argumentation occurred when he told the group the claim (i.e., the unknown slide represented an animal cell) providing minimal evidence to support the idea and when he pressed Jessie to convince him that her claim was correct. These rhetorical ways of argumentation are located around moments when Lee brought forth evidence in ways aligned with epistemic argumentation to support his claim as well as times when he also engaged in pseudo argumentation as he directed the poster construction. This mixture of argumentation resulted in rhetorical and pseudo argumentation being foregrounded in the interaction he has with his peers, a dynamic explored in more detail below.

Lastly, Joseph, a student from a nearby group, who is denoted in purple in Figure 2, engaged with the group in mostly rhetorical ways of argumentation when he told Jessie how the evidence should be interpreted in the middle of the lesson and again at the end of the lesson in support of Lee's argument.

Ways of argumentation that invited or discouraged jessie's epistemic agency

As noted in the introduction of this section and as shown by the density and distribution of Jessie's argumentation efforts, Jessie consistently engaged in epistemic ways. This portrait of engagement intertwined with her peers' ways of argumentation might suggest that Jessie had equal access to the sensemaking space. That is, from a cursory examination, one might assume that a student's engagement in the epistemic ways of argumentation or the interactions of one's peers around this argumentation, as visualized in Figure 2, means that students are collaboratively considering each other's ideas and negotiating these ideas towards a shared understanding. However, upon closer examination of these interactions and the affective markers surrounding them, mainly Jessie's exhibits of visible and verbal frustration, we came to understand that Jessie's persistent efforts were an ongoing attempt to gain access to the group's sensemaking efforts and to have her ideas heard and considered. All the while, the ways of rhetorical and pseudo argumentation Jessie's peers engaged in were powerful in acting against her epistemic agency, reducing her rights and privileges in the learning space.

In Figure 3, we overlay the affective markers of Jessie's expressions of frustration that we identified to assist in visualizing and animating these dynamics. These markers are presented as red squares in the first row of the figure and represent moments when Jessie was visibly and/or verbally frustrated in a segment. These moments were marked by Jessie cupping her face in her hands, putting her head up towards the ceiling, spreading her fingers and putting her hands out in front of her, shrugging her shoulders, hunching over, rolling her eyes, putting her hands on her hips, or making statements such as, "You guys aren't listening to me" or "If I'm wrong I'm going to feel like a failure." in raised or softened intonations. Figure 4 provides examples of some of these gestures.

Figure 3
Ways of Argumentation by Student

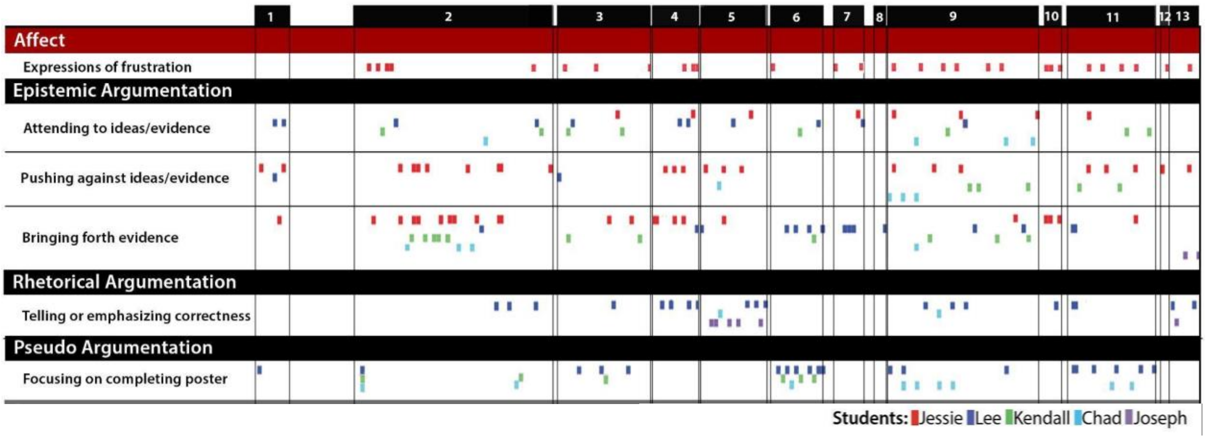


Figure 4
Examples of Jessie's Affective Gestures

These moments of frustration occurred at the bookends of many segments. Black column lines have been added to Figure 3 to help visualize the location of these markers in relationship to these segment boundaries. One example of such a frustration occurred in segment 2 when Lee was directing Chad and Kendall in constructing the structural elements on the poster (i.e., a section for the claim, evidence, and reasoning). In this interaction, Jessie was arguing that the unknown cell represented on the slide was a plant because it looked like the plant cell that the group had observed and drawn on their data sheet. Jessie pointed to the group's worksheet where they had recorded their observations of the plant cell and told the group "it looked like that because it [the unknown cell], it looked like it had lines." The group continued working on the poster without attending to Jessie's comment. Jessie then told the group to "Listen." to her and she continued to describe the slide saying "before, before somebody moved it [the slide mount under the microscope], it had, it didn't look like that [point to an animal cell on the worksheet]." She then questioned the group pointing to the unknown cell on the worksheet and saying in a raised tone, "This is the unknown right there, so why would it be this [an animal cell] when it looked like this [a plant cell]?" The group continued to focus on the poster and Jessie said "You guys are not listening. You are drawing on the piece of paper. Can you listen now?". In this interaction, Jessie is leaning on the table with her hands placed in front of her, she had an exasperated look on her face with her eyes wide open, and she asked for the group's attention in a raised tone. These efforts worked to shift Kendall and Chad's attention away from the poster to engage with Jessie's ideas, represented by the green and light blue marks in the ways of argumentation rows in the middle portion of segment 2 in Figure 3. Lee enters the conversion after these interactions saying "But, that's clumped up [the depiction of the unknown cell] and everything. It's clumped up." He then poses the question "So are we saying animal or are we saying plant?". This question is not answered by the group and instead results in Chad and Kendall moving back to focus on the poster (i.e., pseudo argumentation). Jessie remains focused on presenting evidence to support her claim and pushing against the evidence brought forward by the group saying,

> You guys are saying that this [the representation of the animal cell on the worksheet] is the same thing as this [the drawing of the unknown cell], but when you have these lines and you see these dots inside those lines [characteristics the unknown with matches a plant cell] that's not the same thing. That cannot be the same thing when it looks that different. It's not an animal cell!

In response, Lee tells Jessie that she might be right but that she needs to "give us evidence", "support the evidence", and "support your claim". Here, Lee's comments represent rhetorical ways of argumentation because he is requiring Jessie to convince him of her claim using the vocabulary of argumentation without using the conventions of the disciple (e.g., bringing forth evidence to support an alternative claim). In response to Lee's comment and his disregard for the epistemic work that she was doing, Jessie puts her hand behind her head in exasperation before saying "If I'm wrong…" in a frustrated tone before she moved to her notebook to do "research" before putting her it down slowly and turning back to the group to look at what they are doing.

The example just provided is an exemplar of the kinds of effort (cognitively and emotionally) required of Jessie to have her ideas heard by the group. She raised her voice and asked for the group's attention ("Can you listen now?") and while she obtained Chad and Kendall's attention, she lost this focus when Lee entered the conversation. In this space, Lee directed Chad and Kendall in the development of the poster and he pressed Jessie to justify her claim that the cell was a plant, justifications that she made (e.g., pointing to the group's representation of an animal cell that did not match the characteristics of the group's representation of the unknown cell) but were disregarded. In these presses, he provided minimal evidence to support his claim that the cell was an animal and, instead, took the stance that he needed to be convinced that his idea was not correct (i.e., rhetorical argumentation). The red marks in the row for ways of epistemic argumentation in segments 9, 10, and 11 in Figure 3 show that Jessie continuously engaged in the epistemic ways of argumentation across these segments. Also shown are the corresponding expressions of frustration that Jessie exhibited as she made these efforts for her ideas to be taken up.

Notable in this depiction are the marked increases of Jessie's expressions of frustration across segments 9 to 12. These related not only to Lee's requirement for Jessie to convince him that her argument was valid, but also to the group's uptake of Lee's claim, even when Chad acknowledged that it did not represent the group's ideas ("We think it's a plant but they [Lee] think it's an animal"). In this interchange, Chad asked Mr. Jerry what to do about this disconnect between Lee and the alternative claim. Mr. Jerry responded by telling the group to "roll" with what they had on their poster ("you wrote animal, so go with that") and then to give their "side of the story". Jessie exhibited exasperation that her ideas, again, are not being considered, asking if she had to argue for the alternative claim ("Do I have to argue this?) and stating "If I'm wrong, I'm going to feel like a failure." in segment 12. While Jessie continued to push against these ideas in segment 13, she ultimately shared the claim that the cell was an animal during the first round robin interchange. She stated, "The evidence is that there is no cell wall, the cell doesn't have a defined shape", both pieces of evidence that she argued against throughout the episode. As she described the claim on the poster, she said:

> Okay, so basically we looked. They looked for. Lee, Lee looked for everything that were in plants to see if it was in the cell that we are observing and he determined that they don't have any characteristics.

In this statement, Jessie is positioning herself as an outsider to the group, shifting from the use of the collective "we" to then distance herself from the action with the pronoun "they", referring to her group members, and ultimately calling out Lee in particular as the one in charge of this sensemaking effort. In this interaction, Jessie is somber and soft spoken as she leans up against the wall as she shares the claim, one that was counter to what she had continually argued for. These affective markers contrast those for which she exhibited during the episode when she was more energetically focused (e.g., animated hand gestures and raised intonation) as she worked to have her voice heard and ideas taken up by her group.

While we share these examples as evidence that Jessie engaged in considerable effort, in the epistemic ways of argumentation, to gain access to the scientific sensemaking of the group, privileges and rights were blocked Lee, Kendall, and Chad through their use of the tools of rhetorical and pseudo argumentation. We would also like to make note of Joseph, the fourth student that entered this group from time to time. We attend to Joseph's interaction with the group because they worked to bolster Lee's position and to further push against Jessie's epistemic agency as his efforts served to validate Lee's claim, often in the ways of rhetorical argumentation, in which he told Jessie that Lee's claim was correct (i.e., the cell represented an animal). We think that these interactions, while infrequent, were powerful in enforcing Lee's rhetorical efforts and Jessie's access to the learning space.

Conclusion

The case study presented here is an attempt to understand the rights and privileges to participate, and to understand the struggles to belong in science that arise in science learning environments through the lens of a young woman of color, Jessie, and her experiences. Our analysis as shown in Figures 2 and 3 provides an account of Jessie's efforts, detailing the extensive and continued work she engaged in to have her epistemic agency acknowledged by her peers. In many ways, Jessie's continued efforts to be seen as an active contributor to the construction and critique of knowledge claims are to be celebrated given the ways in which her peers (often boys) worked either actively or by omission to push her efforts as a Black girl toward the periphery. At the same time, further examination of these efforts highlights that Jessie's persistence is a reflection of her fight to have her rights as a scientific sensemaker acknowledged, and surface issues of inequity in which Jessie's efforts to exert her epistemic agency were eventually rejected by her peers. In this case, we see Jessie's continuous efforts to have her rightful presence acknowledged when the tools of argumentation were used to marginalize and subvert her privilege.

This analysis illustrates the interplay of the personal and communal in the performance of students' epistemic agency and the power that the community has in shaping this dynamic (Calabrese-Barton & Tan, 2020; González-Howard & McNeill, 2020). Recognizing and understanding this interplay and the power dynamics inherent in classroom spaces are essential if we are to push against systems of oppression inherent in classroom spaces towards more equitable and just science learning environments.

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Examining the Effects of Teacher Instructional Approaches on Shifting Students' Experiences Towards Epistemic Practices During Scientific Modeling

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Abstract: The spread of misinformation regarding socioscientific issues necessitates that science teachers shift focus towards promoting students' use of reliable scientific reasoning strategies and practices (in addition to content knowledge) during instruction. Our goals in this study are twofold: 1) to develop a trustworthy survey instrument that can effectively measure students' experiences engaging in the epistemic practices (EPs) of scientists in the classroom, and 2) to better understand the mechanistic link between instructional approaches and student outcomes. We present a mixed-methods analysis of the variation in classroom experiences that emerged between two teachers with contrasting sets of student outcomes. This study represents one pathway to creating a novel, contextualized survey instrument that can effectively measure the extent to which learners might engage with aspects of EPs in their science classroom. It also further supports student-centered argumentation practices as an effective approach for shifting instruction towards promoting EPs.

Introduction

Given the rampant spread of misinformation regarding important scientific issues (e,g, vaccine safety, climate change), there is a pressing need to promote scientific literacy and, thus, an understanding of scientific practices in classrooms (Gorman & Gorman, 2021; NRC, 2012). This focus foregrounds the development of students' abilities to critically evaluate evidence and distinguish well-justified and accurate information from false and misleading claims (Chinn et al., 2020). It can be contrasted with traditional modes of teaching and evaluation, which have favored emphasizing science content instead of such scientific practices (Windschitl et al., 2012). The shift to bring scientific practices and reasoning skills to the forefront can be framed through research on developing learners' *epistemic cognition*—or the ways of thinking and practices used to establish, critique, and use knowledge within disciplines (Greene et al., 2016). An individual's epistemic cognition informs how they evaluate the reliability of scientific claims and how they come to understand how scientific knowledge is generated. Given this connection, we refer to a set of scientific practices and reasoning skills discussed in this study as examples of the *epistemic practices (EPs)* of scientists.

However, steep challenges exist in promoting EPs during science instruction. First, the link between instructional design and teaching practices that can help develop students' knowledge and use of EPs is not well understood (Muis et al., 2016). Further, little is currently known about how to effectively measure student outcomes in relation to EPs and how they might change over time (Hofer, 2016). As such, teacher educators have been grappling with how to optimize the design of professional development (PD) opportunities needed to help teachers further develop their own knowledge regarding the EPs of scientists, as well as the skills needed to facilitate students' understanding and use of EPs (e.g., Park et al., 2022). This includes, for example, knowing the reliable strategies scientists use for systematically evaluating evidence, justifying why scientific knowledge is reliable, and then engaging students in discussions around these topics to further their understanding.

In this study, we apply the Apt-AIR model of epistemic cognition, which outlines explicit goals for a successful epistemic education (Barzilai & Chinn, 2018), as a framework to inform the design of a curricular intervention in high school biology that we hypothesize, in turn will lead to improved classroom experiences for students. We focus specifically on EPs related to the domain of scientific modeling with complex systems (described in more detail below). Classrooms that incorporate learning environments like this can likely foster students' skill in understanding and enacting reliable EPs to accurately evaluate claims and evidence in their everyday lives (Chinn et al., 2020). We were guided by the following research questions:

1. How can we measure the extent to which students engage in the EPs of scientists during class?

2. What, if any, relationships can be drawn from student classroom experiences regarding their engagement in scientific EPs and what we know about how teachers implemented?

Measuring student experiences related to promoting apt EPs of modeling

Measuring student learning outcomes in science class as they relate to teachers' PD is both difficult and rare (Hofer, 2016). Within the field of epistemic cognition, there is a dearth of studies that use survey instruments with enough statistical rigor (e.g., they incorporate an analysis of model fit and/or the reliability of latent constructs) that reliably capture students' learning of this construct (Sandoval et al., 2016). These instruments are also difficult to validate given the contextualized natures of one's epistemic cognition and thus in the moment observations, as well as metacognitive reflections, are needed to help clarify relationships that might emerge in survey data (Bricker & Bell, 2016).

To address the need to focus on student learning outcomes using robust methodologies, we used elements of the Apt-AIR framework to inform the design of a survey instrument aimed at measuring students' experiences and opportunities in engaging in the EPs of scientific modeling. This framework integrates two models of epistemic thinking: the AIR model (Chinn et al., 2014) and the multifaceted framework of epistemic thinking (Barzilai & Zohar, 2014). The AIR model establishes aims, ideals, and reliable processes as the three main components of epistemic cognition. *Epistemic aims* are the specific goals related to an inquiry process. *Epistemic ideals* comprise the criteria that people use to evaluate whether their aims have been successful. *Reliable processes* denote the strategies that people use to achieve their aims and enact ideals. For the purposes of this study, we used the framing of ideals and reliable processes to help elucidate the specific set of EPs germane to the curricular intervention we were investigating. This is because preliminary coding analysis uncovered infrequent articulation of students' aims. For example, one of the ideals and its associated process relevant to this learning environment included *Rigorous fit with evidence that is systematic and conclusive* (Ideal) and *Considering multiple hypotheses* (Reliable Process used to enact that Ideal). These findings were then used as a basis for item design in the survey.

Furthermore, the multifaceted framework can be used to help design for the varying aspects that promote a comprehensive epistemic education. It states that education should include five key aspects of epistemic performance. These include (*with a survey item example to demonstrate how we attempted to capture each facet*):

i. Cognitive engagement in epistemic performance (e.g., engaging in an educational task in accordance with learning goals); *I often have opportunities to hypothesize and predict scientific results.*

ii. Adapting epistemic performance (e.g., adjusting learning strategies across environments to fit new contexts); *In my science class, my teacher points out how a focus on fitting models to evidence has parallels in science that I can see in the news*.

iii. Regulating and understanding epistemic performance (e.g., considering and reflecting on the purpose and processes of educational tasks); *In my science class, my teacher encourages me to discuss how to use reasoning practices in science out of school.*

iv. Caring about and enjoying epistemic performance (e.g., expressing curiosity, interest and enjoyment while engaged in educational tasks); *I learn science for my own interest.*

v. Participating in epistemic performance together with others (e.g., engaging in collaborative and collective discourse to achieve learning goals). *In my science class, I discuss or share my ideas with people using computer technologies.*

It is important to note that these aspects are not mutually exclusive (i.e., the same item can often fall within multiple aspects). However, using Apt-AIR is theorized to promote learners' abilities to achieve success through competence in epistemic activities (e.g., in the ability to reliably use data to formulate accurate inferences), as well as understanding how to regulate their use of EPs through metacompetence (e.g., in evaluating whether certain inferences can be made given the data available). Thus, we invoked the Apt-AIR model here to measure the wide-ranging aspects of students' experiences related to engaging in what we describe as the *apt EPs of modeling*, which comprise the ideals and processes situated within the context of this intervention. The goal is to demonstrate how this instrument might be used to detect any shifts in students' classroom experience in engaging in apt EPs. Ultimately, constructing a survey like this could be used to assess global classroom experiences, which is important when considering how to scale-up interventions and optimize student impacts. In addition, it would help researchers uncover the links between instructional approach and the degree to which students engage in EPs. To this end, we incorporated findings from qualitative data to elucidate how teachers' instructional approaches might be linked to any shifts that occurred. We now briefly turn to select research on how teachers' instructional approach might promote students' development of epistemic cognition.

Instructional approaches that can promote apt EPs in the science classroom

The call for science instruction to shift emphasis from content to the real practices and reasoning strategies of scientists has been well-established (Duschl, 2008; NRC, 2012), yet the exact approaches teachers can implement to enact this shift are difficult to identify and vary across contexts (Windschitl et al., 2012). One type of generalized approach identified as a critical area for teachers to focus instruction on involves immersing students in argumentative practices, especially in science classrooms as it is through these practices that knowledge advances in the field (Hand et al., 2016). Focusing on argumentative practices requires an emphasis on language through active dialogue, collaboration, and various forms of communication (Hand et al., 2021).

For example, science classroom dialogue should focus students' attention on interpreting data to make evidence-based claims, evaluating opposing claims, and communicating these ideas through verbal, written and graphical forms. To generate knowledge in this way, the classroom environment needs to be student-centered and deemphasize the need to "get" to the right answer (Hand et al., 2016; Muis et al., 2016). In this study, we used qualitative data to understand how teachers' instructional approach when engaging their students in scientific argumentation may have contributed to the quantitative differences in student outcomes that emerged from the survey data. Therefore, this study represents an attempt to draw clear links between the instructional approaches that can lead students to further developing their knowledge and use of EPs during class.

Methods

This study builds upon a larger project that engages high school science students in data collection and analysis through complex systems modeling curricula (Yoon et al., 2017). These curricula consist of five stand-alone units (covering topics spanning biochemistry to ecology and evolution). In this exploratory investigation, the research team collaborated with 8 teachers considered expert in implementing these modeling units to help further theirs (and their students') understanding of apt EPs as they relate to scientific modeling. We also engaged teachers in co-design work in partnering with them to revise the curricula to better promote apt EPs. We present a brief description of the PD below.

The summer workshop portion of the PD occurred over 10 days (with up to 4 hours of synchronous and asynchronous work each day) from August 3-17, 2021 and consisted of introducing teachers to the terms *epistemic cognition* and the AIR model. Next, we explored the differences between cognition and metacognition, the notion of aptness when engaging in EPs, and how to avoid cognitive biases when evaluating evidence. Finally, we discussed instructional strategies for promoting apt EPs and how to extend the EPs of scientific modeling to reasoning about socioscientific issues. In addition, we held four synchronous, 1h meetups with teachers during the school year to analyze the progression of teachers' implementation towards promoting apt EPs. In implementing this sustained PD with teachers, our goal was to improve teachers' understanding and skill in supporting student development of EPs and to increase the infusion of apt EPs into their instruction. In addition, we followed the eight teachers who participated in the PD into their classrooms to understand how their teaching practice might have changed and how that might impact their students. Half of the teachers taught at private, college preparatory schools and the other half taught at large suburban public schools in the north or southeastern U.S. The eight teachers were selected for this study as they represented teacher experts with respect to the modeling units being studied (i.e., they had implemented the curricula multiple times already and helped to facilitate other teachers' uptake of it). These teachers had, on average, 10 years of teaching experience, with a range of 5–18 years at the time the summer workshop occurred.

Participation in student surveys was voluntary, so this study includes survey data from 215 self-selecting students across teachers. Sample sizes of students per teacher ranged from 10 – 52 students and averaged 28 pre- and post-responses per teacher. Despite these sampling limitations teachers indicated that the participating students represented a broad range with respect to performance level. Of students who chose to report their demographics, 56% identified as female, 41% as male, and 3% as non-binary or gender conforming; 1% identified as American Indian Pacific Islander, 17% as Asian, 6% as Black or African American, 2% as Hispanic, 60% as White, non-Hispanic, and 14% as multiple races.

To address the first research question, we created a Likert-scale survey administered to students pre- and post-intervention to measure aspects of their science classroom experience. The survey consisted of 50 statements and was designed to measure latent constructs related to apt EPs of modeling (e.g., engaging in inquiry, problem solving, and scientific reasoning). Students responded to these statements using a five-point agreement rating scale (1=strongly disagree to 5=strongly agree). We employed an exploratory factor analysis (EFA) to reduce the survey dimensions to a lesser number of constructs based on patterns in the respondent data. Construct validity emerged by running the EFA on pre-survey data and retaining items only if they produced factor loadings greater than 0.40 and retaining factors only if 3 or more items clustered under it. We used visual inspection of the parallel analysis scree plot to determine that a solution of 4-6 factors was likely. We then ran three EFAs using a 4-, 5-

and 6-factor solution and compared the outputs. We determined that a 6-factor solution was the most reliable and simplest with Cronbach alpha scores for each factor ranging 0.81-0.92, no items identified as too ambiguous (i.e., clustering significantly under more than one factor), and fewer items clustering under each factor (ranging from 4 to 9) when compared to the other solutions. Eleven questions were identified as too indeterminate (i.e., correlated with none of the factors >0.40) and these were dropped from the item pool. The research team came to consensus on the construct names based on the pattern of items that clustered together (see Table 1). We averaged the responses for all students within a given factor and compared them pre- and post-intervention using paired t-tests. We then calculated Cohen's *d* (interpreted as small-0.2, medium-0.5, and large-0.8) if significant differences from pre- to post-survey emerged.

Table 1
Six Factors and Corresponding Latent Constructs from Student Survey Responses

Factor (Alpha)	**Construct**	**Example Items Comprising the Factor**
Factor 1 (0.81)	Engaging in empirical investigations in the science classroom	• I have opportunities to collect data to test and modify hypotheses. • I often hypothesize and predict scientific results. • I often have opportunities to find out answers on my own.
Factor 2 (0.82)	Engaging in problem-solving and communicating using multiple sources with others	• I discuss or share my ideas with people using computer technologies. • I often practice these skills…solving real world problems. • …communicating in multiple ways (e.g., through graphs, email, Internet, web-based tools, writing).
Factor 3 (0.83)	Connecting scientific reasoning in class to everyday life	• In my science class, my teacher encourages me…to discuss how to use reasoning practices in science outside of school. • …to point out how a focus on fitting models to evidence has parallels in science that I can see in the news.
Factor 4 (0.92)	Positive attitudes towards learning science	• I am motivated to learn more science in the future. • I learn science for my own interest.
Factor 5 (0.85)	Using modeling and modeling practices to learn about and do science	• I use computer models to conduct experiments and produce evidence to help me reason and understand scientific ideas. • I use computer simulations, images or animations to collect and analyze data and to draw conclusions.
Factor 6 (0.83)	Using and discussing criteria for good models	• In my science class, my teacher encourages me…to discuss the common characteristics of good complex systems models. • …to discuss why good models should fit all the evidence.

Next, we addressed the second research question by testing whether the overall shifts in students' classroom experience varied by teacher. We ran paired t-tests *by teacher* to investigate any changes pre to post for the factors that showed significant growth in the overall sample paired t-tests described above. Of the 8 teachers, we chose to highlight two for the purposes of this study, where one teacher's (Rachel) students showed negative average growth, whereas the other teacher's (Catherine) students showed significantly positive average growth. In focusing on two teachers with contrasting student outcomes, we aimed to elucidate the teacher implementation strategies that may have led to the differences in student reported outcomes. To do this, we turned to our qualitative data (i.e., video-recorded classroom observations, teacher debriefs and student focus group interviews) collected in each classroom to uncover what differences in instructional approaches may have existed. This in-depth qualitative approach would help us discern if the survey instrument was sensitive enough to detect variation across classroom experiences.

Results

Below we first present any changes in classroom experience regarding students' engagement in the 6 apt EPs measured. Second, we compare the student outcomes of two teachers, Rachel and Catherine, and then use their observational and interview data to better understand the links between teachers' implementation and the differences in students' classroom experience that emerged in the quantitative analysis.

Students show significant growth in three classroom experience factors

Overall, students across the 8 teachers' classrooms made significant gains in three of the six factors measured (see Table 2). Namely, students expressed having more opportunities to *Engage in Empirical Investigations in Science Class*, *Connect Scientific Reasoning in Class to Everyday Life*, and *Use Models and Modeling Practices to Learn* *about and Do Science* after the intervention. Effect sizes ranged from small to medium and suggest that the modeling units were at least partially successful in increasing students' engagement in apt EPs.

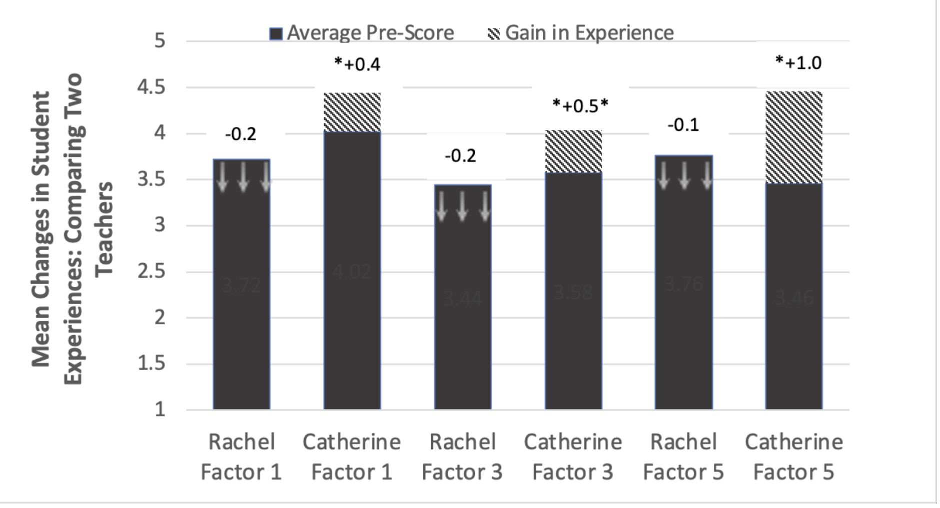
Table 2
Students' Overall Changes in Apt EP Experiences Before and After the Intervention

Factor	Pre Avg (SD)	Post Avg (SD)	Average Gain	Paired t-test results	Cohen's *d*
1-Engaging in empirical investigations in the science classroom	3.86 (0.96)	4.11 (0.90)	+0.24	t = -5.1, df = 214, p<0.0001*	**0.39**
2-Engaging in problem-solving and communicating using multiple sources with others	4.09 (0.88)	4.16 (0.83)	+0.07	t = -1.9, df = 214, p= 0.06	—
3-Connecting scientific reasoning in class to everyday life	3.64 (0.97)	3.85 (0.94)	+0.21	t = -4.0, df = 214, p<0.0001*	**0.28**
4-Positive attitudes towards learning science	3.90 (1.0)	3.91 (0.99)	+0.01	t = -0.13, df = 214, p= 0.89	—
5-Using modeling and modeling practices to learn about and do science	3.68 (0.99)	4.11 (0.86)	+0.43	t = -7.6, df = 214, p<0.0001*	**0.62**
6-Using and discussing criteria for good models	4.16 (0.84)	4.13 (0.81)	-0.03	t = 0.67, df = 214, p=0.50	—

Student classroom experiences vary by teacher

We next evaluated the three significantly different factors from above *by teacher* to uncover what, if any, variation in student outcomes existed across teachers' classrooms. For this smaller study, we present only the results from Rachel's and Catherine's implementation, as analysis at the teacher level showed these teachers' students demonstrated opposing trends in the survey data (see Figure 1 with * denoting the change from pre to post was significantly different). Paired t-test results showed that Rachel's students (n= 24) exhibited no significant measurable change across the three factors (Factor 1 t=1.3, p=0.2; Factor 2 t=1.7, p=0.1; Factor 5 t=0.8, p=0.5); however, Catherine's students (n=21) reported significant growth in all three (Factor 1 t=-2.3, p=0.03; Factor 2 t=-3.6, p=0.002; Factor 5 t=-7.0, p<0.0001). We now turn to qualitative data sources to better understand how teachers' instructional approach may have contributed to the differences in student outcomes that emerged.

Figure 1
Comparison of Student Experience Outcomes for Teachers with Opposing Trends



Selected differences in the instructional approaches of Rachel and Catherine

Here we present select details regarding the differences in how the two teachers implemented the project units to better understand how their instructional approach may have resulted in differing student experiences. However, we want to note that this study is in its early stage, and more complete coding of the full dataset is forthcoming.

The first noteworthy difference between Rachel and Catherine was in the number of units implemented. Rachel implemented only two of five units, and these were clustered towards the beginning of the school year (November and December). She had indicated her intention of implementing a third at the end of the school year

(June) but ultimately ran out of time. In contrast, Catherine implemented all five units and these were spread out over the course of the year (October, November, February, March, and May). This shows that the instructional time spent on curricula designed to emphasize the apt EPs of modeling (i.e., the "dosage" of the intervention) was much greater in Catherine's classroom.

Next, we compared how the two teachers facilitated the same group discussion, which was a Claim-Evidence-Reasoning (CER) prompt embedded within the Sugar Transport model. This model allows students to visualize the processes by which nutrients are transported from the intestines and into the bloodstream. In Rachel's class, students had worked in their groups for about 20 minutes to make observations about how the molecules were moving through the simulation. When facilitating the large group discussion about what mechanism was responsible for the spreading out of molecules, she called on each group in turn, asking "What did [your group] pick?" One student from each group would respond simply with the letter of the claim they chose without providing any evidence or reasoning behind their choice. Group 1 had chosen Claim B, while the other 7 groups called on after them had chosen Claim A. Rachel then exclaimed, "A! It is claim A. The random motion of the molecules is responsible for it spreading out. What evidence do we have of that?" A student from Group 1 discussed their reasoning behind choosing Claim B (i.e., the molecules repel because they "would spin a bit and then fling off"). Rachel seemed to avoid trying to unpack why Claim B did not fit the evidence in that moment when responding, "I guess you can say [that], but what evidence do we have of their random motion?" and shifted students' attention to justifying Claim A instead. She then called on 3 different students, solicited their ideas, listened to their responses, and then summarized back to them the take home message,

> We should have seen that the molecules moved in all different directions, which is random motion…so no particular pattern, it was random, they were moving in different directions. They may have bumped into each other and changed direction, and eventually they spread out evenly. Any questions? [Then Rachel moves on with the next activity in the packet].

In this episode, Rachel encouraged students to articulate the evidence they collected in the model from their various observations and confirmed that Claim A was correct. She geared the discussion towards primarily justifying the correct claim. In total she spent 2 minutes and 25 seconds on the class discussion of the CER.

Catherine, on the other hand, had tried out a new approach to facilitating this CER discussion with her students. In a debrief with her after the class, she mentioned how the PD workshop had impacted her decision to "do things a little a differently" this time.

> I was thinking about what we had talked [at the workshop] when I was planning for this. And just really leaning in to more like…I really feel like I'm guilty of…being like okay we need to get to the right answer. And then once we're there we need to immediately pick back up, or we're not going to finish. Because we're always just stressed for time...So that was me trying to kind of, let's actually take some time on this group discussion. And I modified the student handout so it only had this one group discussion so we could take the time. And I wanted them to think about alternate hypotheses and not just read it and be like, which is most right, and then not even consider the validity of the other two.

In her planning, Catherine anticipated that if she asked the students "what's right? [They're] gonna all say similar things", so she wanted to "explore" the validity of the other two claims a little bit. To do this, she assigned two groups each to Claim A, B and C and posed the question that if the claim they were assigned was correct, what evidence would students see in the simulation to prove that it is correct? She then had students talk in groups for about 5 minutes and told them to come to the board when they were ready to write and share the ideas they discussed. Going through the evidence on the board for each claim, she posed questions to students about whether they saw the evidence described. Students engaged in lively discussions, with one articulating in regard to Claim C (blood flow causes the molecules to spread out) that they "did not have enough evidence yet" from the simulation to determine if it plays a role, but they suspect that it did. Catherine replied, "That's totally fine to say" and validated this student's thinking even though Claim C was technically incorrect. This student was so engaged in the discussion that he stayed after class to work with the model to gather the evidence he needed to be sure.

After various students had the chance to articulate their ideas, she then ultimately asked them to rate each claim as to whether they thought it was the correct one via thumbs up (agree), thumbs side (partially agree), or thumbs down (disagree). She summarized her take home message,

> You always want to be looking for the *why* in biology. It's kind of lazy if we just say, "They just do!" We need to figure out why… It's like pool balls on an empty table in one area, if we shake it, they're going to bounce and spread out into the empty space. And I liked how we talked about cycle, tying back to our complex systems idea, this is not beginning or end, right? There is no end point. It's a cycle, and there would be more bouncing and more spreading out. That's what diffusion is. That's how things move out randomly without energy, it's a very interesting scientific concept we don't think about a lot…So take a moment with your partner, pick what claim you are most convinced by…And then talk about how you want to articulate your reasoning. *Why* does that evidence prove your claim is correct? [Then Catherine has students continue working on the packet]

In this episode, Catherine encourages students to predict what they would see, think about the reasoning behind it, and then decide which claim was correct, without indicating there was only one correct answer. She geared the discussion towards careful evaluation of each claim, making sure she engaged different students in articulating their thinking out loud. In total she spent 28 minutes and 28 seconds on the class discussion of the CER.

In comparing these instructional episodes across the two teachers, we can see elements of Factor 1 (*Engaging in Empirical Investigations)* emphasized in Catherine's practice, where she actively encouraged students to make predictions and find out the information on their own. Catherine's students also exhibited their largest gain in Factor 5 (*Using Modeling and Modeling Practices to Learn About and Do Science)*, and we can see clear demonstrations of this in her emphasis on using models to understand scientific ideas and to engage in scientific reasoning and inferencing. While Factor 3 (*Connecting Scientific Reasoning to Everyday Life)* was not necessarily on display in either episode, Catherine did later describe a fad diet project she implements with students in conjunction with this Sugar Transport model. She gives students a choice of researching 1 of 4 fad diets, all which make claims about how they increase athletic performance and energy. It is possible the connection to fad diets is something students found useful in their everyday lives, and similar to the episode presented here, Catherine tasks students with systematically evaluating whether these claims can be substantiated.

In contrast, Rachel mentioned in the debrief after her class that she's "usually pretty 'notes heavy' with biology just because [she] still feels like [she's] a new bio teacher." Her training was in chemistry-education and her course shift to biology occurred three years prior to this episode (compared to Catherine who was trained in biology and had six years of teaching experience). Rachel's students further elaborated on her practice in their focus group interview that in her biology class they would "write everything down, and that would be the entire class. It was just memorizing facts and definitions." From the comparison of these two episodes and approaches, we see that Catherine displayed a shift towards emphasizing apt EPs whereas Rachel's practice seemed largely focused on emphasizing content; furthermore, these differences were detected in the survey instrument.

Discussion

In this study, we used the Apt-AIR framework to inform the design of PD with high school biology teachers and administered a Likert-scale survey to the students in their classrooms to measure the extent to which teachers enacted shifts towards promoting apt EPs in their instruction. The survey was sensitive enough to detect significant shifts from pre to post in three constructs related to students' classroom experiences (*Engaging in Empirical Investigations, Connecting Scientific Reasoning to Everyday Life,* and *Using Modeling and Modeling Practices to Learn About and Do Science*). This study represents one pathway to creating a novel, contextualized survey instrument that can effectively measure the extent to which learners might engage with at least some aspects of apt EPs in their science classroom. In addition, we lend support to the findings from the survey data with observational and interview data that focused on the instructional approach of two teachers with contrasting student experience trends. This underscores the value in engaging with multiple assessment methods when measuring outcomes related to epistemic cognition (Bricker & Bell, 2016). Ultimately this research can help address the need to examine broad-level student impacts that extend beyond individualized case studies (Hand et al., 2016). Our future work building from this study will include a more systematic analysis of teacher variation and the qualitative data associated with it. For example, more analysis is needed to determine if the survey instrument is sensitive enough to detect differences among the other teachers in the cohort.

This study addresses another gap in the literature in that we aimed to draw relationships from student classroom experiences regarding their engagement in apt EPs and what we know about how teachers implemented. This can help uncover the connections between the instructional approaches that led students to further develop their knowledge and use of EPs (Muis et al., 2016). We can attribute at least some of this shift towards foregrounding EPs in Catherine's instruction to participation in the PD, as she cited it as part of her planning of the CER discussion that engaged her students in many apt EPs (e.g., engaging in multiple hypotheses, systematically evaluating evidence). She also facilitated a rich discussion with her students that prompted them to articulate their reasoning and evaluate opposing claims through various forms of communication (verbal and written), which has previously been identified as an effective approach in promoting EPs (Hand et al., 2021). However, Catherine admitted feeling “guilty” of focusing too much on performance goals (i.e., getting to the ”right” answer) due to time pressure in the past. We saw this focus emerge in Rachel’s approach, where she emphasized discussing the evidence for the correct claim only in her relatively brief CER discussion example. It is thus important for PD developers to focus more attention on developing teachers’ instructional approaches while also considering the intense time constraints that teachers face in their everyday practice (Hand et al., 2021). Overall, this work is important in developing informed citizens that can transfer their use and understanding of EPs to their everyday decision-making regarding current socioscientific issues (Chinn et al., 2020).

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Epistemic Systems: A Knowledge-Level Characterization of Epistemic Games

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Abstract: Engaging students in epistemic practices, including explanation, modeling, and sense-making more generally, has become an important focus of science education. This paper draws from two theoretical frameworks: *epistemic forms and games* and *knowledge in pieces*, to create a framework for building fine-grained models of the knowledge involved in scientist and student engagement in epistemic games. The *epistemic systems framework* (ESF) features two main components: one perceptual and one cognitive. The perceptual component includes the perceptual strategies the individual uses to extract raw information from the world. The cognitive component includes the network of knowledge the individual uses to make sense of that raw information and turn it into an epistemic artifact (e.g., an explanation or model). The paper presents two case studies to demonstrate how the ESF can be used to model student engagement in both informal and formal epistemic games.

Introduction

Engaging students in epistemic practices has become a central focus of science education (Duschl, 2008). Epistemic practices are knowledge-building practices of science. They include theory-building practices, such as modeling and explanation. They include empirical practices, such as representing, analyzing, and interpreting data. They include practices that bridge theory and data, such as argumentation. In general, these practices engage students in sense-making and support their construction of knowledge through the same practices that scientists use in their construction of formal knowledge (Schwarz et al., 2017). Engagement in epistemic practices can help students develop understanding of scientific phenomena, as well as skills for engaging in scientific practices. Importantly, constructing knowledge through epistemic practices challenges students' beliefs about who has the authority to generate and evaluate scientific knowledge (Ford & Foreman, 2006; Manz, 2015).

A number of research programs have sought to characterize students' engagement in epistemic practices in the context of classroom activities (Lehrer & Schauble, 2000). Some of this work has characterized the nature of student participation in computational modeling (Wilensky & Reisman, 2006). Another strand of work has examined elements of students' mechanistic reasoning in the context of modeling and explanation activities (Krist et al., 2019; Russ et al., 2008). Yet other work has examined the knowledge students have about the nature of scientific products and practices, including their epistemic considerations when constructing and critiquing explanatory models (Berland et al.; 2016), their meta-modeling knowledge (Schwarz & White, 2005), and their criteria for scientific models (Pluta et al., 2011).

These characterizations provide a good foundation for understanding student engagement in epistemic practices. diSessa has articulated a need for building knowledge-level characterizations of student engagement in knowledge-construction activities (diSessa, 2014). Such characterizations would include fine-grained models of cognitive processes underlying students' participation in and learning through epistemic practices. Such models can help us understand the knowledge and cognitive dynamics involved in the construction of new knowledge. This, in turn, can inform the design of instruction that effectively helps students learn scientific material through participation in epistemic practices. This paper introduces a framework for modeling the knowledge leveraged by individuals engaged in epistemic practices, including informal sense-making and more formalized scientific knowledge-building processes.

Theoretical foundations

The theoretical framework introduced in this paper integrates ideas from two existing theoretical frameworks. The first, *epistemic forms and games* (Collins & Ferguson, 1993), is concerned with characterizing scientific knowledge-building practices. The second, *knowledge in pieces* (KiP; diSessa, 1993), is concerned with modeling, at a fine grain size, the structure and dynamics of both naive and expert knowledge. Synthesizing the two frameworks enables the construction of fine-grained models of the structure and dynamics of knowledge involved in both informal and formal knowledge-building processes.

Epistemic forms and games

Collins and Ferguson (1993) introduced *epistemic games*, to characterize the knowledge-construction activities of scientists and other scholars. Example epistemic games include building temporal models of processes, hierarchical lists of related entities, and computational models. Each epistemic game is played to produce a particular epistemic artifact, which is a specific instantiation of a general epistemic form. For example, in the case of the "temporal decomposition" game, the target form is a timeline of events in a larger process and a resulting artifact might be a stage model of cognitive development. In the case of the "hierarchical list" game, the target form is a list organized by a hierarchy of categories and a resulting artifact might be a taxonomy of mammals in the animal kingdom. In the case of the "computational modeling" game, the target form might be an agent-based computational model and the resulting artifact might be a model of predator/prey dynamics.

The epistemic form can be thought of as a template with slots that, when filled, answer the question driving an inquiry. The form constrains the game played to fill the slots. Collins and Ferguson unpack the example of an inquiry inspired by the question "What is the nature of X?" The answer to this question may take the form of a list of characteristics of X. A *list* is a template with slots for distinct characteristics of X. The corresponding *list* game is played to fill out this template. The game is characterized by moves such as adding, removing, merging, and splitting list items. For example, a scientist might ask the question: "What is the nature of the Zebrafish?" They might list characteristics such as "lives in freshwater," "belongs to the minnow family," "originates in both tropical and subtropical climates."

Collins and Ferguson present a list of epistemic forms and games. They divide games into structural, functional, and process games, and illustrate each kind of game with examples. For each example, they describe the form and the basic moves by which the game is played. The theoretical framework introduced in the present paper is designed to characterize the knowledge an individual draws on in their enactment of an epistemic game.

Knowledge in pieces

Knowledge in pieces (KiP; diSessa, 1993) is a cognitive theory of knowledge and learning. In contrast with cognitive perspectives that view the knowledge of an individual as a unitary structure consistently used across contexts (Wiser & Carey, 2014), KiP views the knowledge of an individual as a complex system of elements that are drawn into networks in response to the sense-making demands of a given context.

From a KiP perspective, the naive knowledge system consists of elements that are activated inconsistently across contexts, while the expert system has more consistent connections between elements and contexts. In the naive system, elements may be activated in contexts where they are productive as well as in contexts where they are not productive. In the expert system, elements are activated reliably in contexts where they are productive. The transition from novice to expert (i.e., learning) is viewed as a gradual tuning to expertise through which the individual's knowledge system is reorganized and refined. Elements of prior knowledge that were unproductive in one context may be repurposed and used productively in a new context. For this reason, KiP views a learner's prior knowledge as rich with potentially productive *resources* for the construction of more formal knowledge. This sets KiP apart from "misconceptions" perspectives, which view learners' commonsense conceptions as obstacles to learning (McClosky, 1983). While "misconceptions" perspectives view students through a deficit lens, KiP views students through an asset-based anti-deficit lens (Adiredja, 2019).

A primary goal of KiP is to build theoretical machinery for modeling the structure, dynamics, and development of an individual's knowledge system. Towards this aim, a number of scholars working within the KiP paradigm have developed ontologies of knowledge elements and knowledge structures, which bring knowledge elements together synergistically to accomplish particular goals.

Knowledge elements

KiP researchers have proposed elements belonging to a number of different knowledge ontologies. *Conceptual knowledge elements* have been proposed to account for individuals' intuitive sense of mechanism and their sense of satisfaction with explanations or predictions of phenomena. This kind of knowledge includes phenomenological primitives (p-prims; diSessa, 1993). A well-documented p-prim called "Ohm's p-prim" captures the intuition that "greater effort leads to greater result." An individual might draw on this intuition when asked to provide an explanation for why they are able to push a couch across the room with greater speed, saying: "Because I pushed harder." *Epistemological resources* have been proposed to explain how individuals understand the nature of knowledge. This kind of knowledge includes ideas about the origins of knowledge and the nature of its validity, as well as epistemic forms and their associated entry conditions and constraints (Hammer & Elby, 2002). Epistemological resources for understanding the nature of knowledge include ideas such as "knowledge must be transferred from one person to another" and "anyone can make up a new idea." In addition to conceptual and epistemological resources, a category of knowledge has been proposed, which facilitates the enactment of *epistemic game moves* (Swanson, 2023). This includes knowledge facilitating an individual's division of a larger process into smaller pieces during a temporal decomposition game, or their identification of similarities and differences in a move to merge items during a list game.

Knowledge structures

An important knowledge structure developed within the KiP paradigm is the coordination class. Coordination classes were invented to model knowledge systems used by individuals when obtaining measurable information from the world, such as force or velocity (diSessa & Sherin, 1996). Coordination classes are knowledge systems that feature two components, one perceptual and one cognitive. The perceptual component consists of the sensory machinery used by an individual to attend to objects and events and extract raw data from the world. This component has been called *readout strategies*, because it consists of the perceptual strategies the individual uses to "read out" data from the world. The cognitive component consists of the knowledge used by an individual to direct their attention to particular objects and events, and the knowledge they use to infer the desired information from the extracted data. Because it includes knowledge supporting an individual's ability to infer information from the world, the cognitive component has been called the *inferential net*. The combination of readout strategies and inferential net used by an individual to obtain a particular kind of measurable information from a particular context is called a *concept projection* (diSessa & Wagner, 2005). An individual may have multiple concept projections for obtaining the same information from different contexts. The greater number of contexts for which an individual has productive concept projections, the greater their expertise regarding that information.

A concrete example may be helpful for illustrating the different components of a coordination class. Imagine an individual trying to determine which of two vehicles travels with greater speed around a track. The individual's inferential net includes knowledge that directs their attention to the relative positions of the vehicles, because their knowledge contains ideas about the connection between position and speed, as well as the knowledge that the vehicles began to move at the same moment from the same initial position. Their readout strategies extract data that Vehicle A is further away from the initial position than Vehicle B. Their inferential net then draws on knowledge relating speed to change in position with respect to change in time, helping the individual infer that Vehicle A must be traveling faster. The particular readout strategies and inferential net used by the individual in this situation would be the concept projection they used to determine which vehicle moved with greater speed.

The knowledge structure introduced in the present paper is similar to the coordination class in that it features both perceptual and cognitive components. While coordination classes are knowledge structures used to obtain measurable information from the world, the knowledge structure proposed below is activated when an individual engages in an epistemic game, whether it be informal sense-making or a more formalized process such as scientific theory building. I present this knowledge structure, which I call an *epistemic system*, next.

Epistemic systems

The *epistemic systems framework* (ESF) incorporates elements from both epistemic forms and games and KiP. Drawing on epistemic forms and games, it aims to characterize individuals' informal sense-making and formal knowledge construction as engagement in epistemic games. It draws on elements of KiP to characterize both the informal and formal knowledge involved in the enactment of epistemic games at a fine grain size. It uses coordination class theory as a reference model and likewise has two components: one perceptual and one cognitive. The perceptual component is the same as in the coordination class model: it consists of the perceptual strategies (e.g., sense of hearing and sight) which mediate an individual's perception of particular objects and events in the world, allowing them to extract raw data about those objects and events. The cognitive component is similar to that of the coordination class model and is referred to as the *epistemic net*. The epistemic net is the knowledge network drawn on by an individual during an epistemic game.

The epistemic net can be further decomposed into different kinds of knowledge resources, each serving different functions in the enactment of the epistemic game. This includes *epistemological*, *conceptual*, and *epistemic game move resources*. The individual's epistemological knowledge orients their attention to relevant raw data. This is because their epistemological knowledge includes knowledge of both informal epistemic forms (e.g., intuitive expectations for what comprises a satisfactory explanation) and formal epistemic forms (e.g., a stage model), which motivates their inquiry and guides it towards a particular end goal. The individual's conceptual knowledge is used as raw material for generating explanations, and as a benchmark for comparison and assessment of the reasonableness of given explanations or phenomena. The individual's epistemic game move resources are used to fill out the epistemic form by connecting conceptual knowledge elements and evaluating and refining the epistemic artifact. As in the case of the coordination class, an individual may draw on different combinations of perceptual and cognitive components when enacting the same basic epistemic game in different contexts. Each unique combination is considered a different *epistemic projection*.

How system elements might work together in the case of informal epistemic games

In the case of informal epistemic games, the system elements work together to support the individual's sense-making activity. For example, imagine that one morning, an individual walks barefoot across a lawn towards a building. As they approach the building, they notice their feet becoming wet. They wonder why their feet have become wet, while just a moment before their feet were dry. Let us examine the activity of their epistemic system from this moment forward. Epistemological resources within their epistemic net make them feel there must be a plausible explanation for this phenomenon. This drives them to seek a causal explanation (an intuitive epistemic form), which directs their senses to aspects of their environment where they anticipate they might find clues. Through their sense of touch, they extract information that the grass closest to the building is quite wet and coldest in temperature. Through their sense of sight, they determine that this grass is in the shade produced by the building. The grass just beside the shaded region is in the sun, it is still damp but not as cold or wet. Just a few steps further out the grass is dry and warm. The individual enlists epistemic game move resources to compare the wet and dry regions. They determine that the shaded regions are wettest and coldest, regions nearest to the shade but in the sun are damp and slightly warm, and regions far from the shade and in broad daylight are dry and warm. The individual draws on conceptual knowledge, including ideas about sunlight causing water to evaporate and about the rising sun shrinking the shaded region around the building. By synergistically drawing on their perceptual and cognitive components, the individual takes in the phenomenon and makes sense of it. They produce the explanation that as the sun has been rising, the shaded region of grass beside the building has been shrinking, leaving the grass driest in spots furthest from the building, wettest closest to the building where it is still covered in shade, and somewhere on a gradient between wet and dry between these two zones.

How system elements might work together in the case of formal epistemic games

A formal epistemic game can also be modeled using the ESF. In this case, the individual's epistemological resources would also include a formal epistemic form, which would orient the individual to their knowledge construction task. For example, the individual may be interested in creating a computational agent-based model to explain the dry-to-wet gradient of the grass on their morning walk to work. The agent-based model would act as a template with slots to be filled, guiding their epistemic game. Specifically, these slots would prompt the individual to name the agents in the model (e.g., photons and water droplets), to specify their initial conditions (e.g., photons leave the sun with some range of energy values, water droplets are randomly distributed across grass blades and have some range of initial energy values), and to specify their behaviors (e.g., photons leave the sun and travel in a straight line, water droplets absorb photons, gain energy, and fly away from the grass in random directions with varying probabilities). Needing these particular pieces of information might cause the individual to look for and extract particular data, drawing perhaps on their memory of the different entities in their morning stroll, and the warmth of the sun and the cold wet grass under their feet. They might use epistemic game moves to compare the relative temperatures and moisture levels of the grass in the sun with the grass in the shade, and their conceptual knowledge might allow them to make decisions about assigning initial energy levels to the photons and water droplets in the model, based on their temperatures. By orchestrating the perceptual and cognitive components of their epistemic system, the individual engages in a formal epistemic game of building a computational agent-based model, which simulates and validates their informal sense-making.

Methodology

Data featured in the following section were taken from a larger study, which investigated students' engagement in an 8th grade science elective course that focused on the generation, evaluation, and refinement of pattern theories (Swanson, 2019). The kinds of patterns featured in the course were patterns in behaviors or processes that led systems to change over time, including threshold and equilibration. These kinds of patterns can be found in phenomena across domains, from physical to psychosocial. For example, a pattern of threshold can be recognized in a tipping point of a tower of blocks, as well as the limit of a person's patience.

The course, called the Patterns class, was implemented and refined across four iterations. Data from the final implementation are reported in this paper. This implementation occurred in a middle school located in an economically depressed neighborhood of the U.S. West Coast. It was the primary curriculum of an 8th grade science elective course, which had traditionally been used as an enrichment period for students who had scored above average on tests of basic math and the English language. The course met for 40 minutes, 3 times a week over the entire school year, for a total of 52 hours. Twenty-one students participated in the course (11 girls, 10 boys). The majority of the students spoke English as a second language and had immigrated to the U.S. from Central America and Mexico. The author was the primary teacher of the course.

The Patterns class engaged students in an epistemic theory-building game, in which students generated, evaluated, and refined pattern theories. Their theories were simply descriptions and/or explanations of the patterns they found in multiple phenomena. For example, for the pattern of threshold, one student's pattern theory read:

"Adding more until you get a reaction." The course guided students' exploration and articulation of four patterns: threshold, equilibration, exponential growth, and oscillation. Data from the equilibration unit are presented in this paper. For each pattern, students explored two example phenomena and then wrote their first theory draft. They then evaluated their theory against a third example and wrote a second draft. They then generated examples of phenomena from their own lives that followed the pattern, evaluated their second drafts against these, and wrote third draft theories. Through cycles of generation, evaluation, and refinement, the students iteratively revised their pattern theories and their thinking.

Data were collected in the form of video footage, student work, and teacher/researcher reflections. Two video cameras captured each session. One was positioned at the front of the room and captured the students working at their tables or participating in class discussions. The other camera was positioned at the back of the room and captured presentations made at the front of the room by the students or teacher, and what was written on the white board. Student work was collected at the end of each class session and scanned or photographed and then returned to the students at the start of the next class period. The teacher wrote reflections at the end of each period, noting anything that stood out from that day in terms of student thinking, activity design, and classroom management.

Data were analyzed using knowledge analysis (KA), a suite of techniques developed for analyzing data through a knowledge in pieces lens (diSessa et al., 2016). Reflecting its KiP orientation, KA views data through a cognitive lens, with a goal of modeling the structure, dynamics, or development of individuals' knowledge systems. Analyses typically focus on characterizing these phenomena at a fine-grain size. Knowledge structures are therefore described in terms of the smaller elements of which they are composed, and the systems' dynamics and development are described in terms of smaller moves in an individual's reasoning or the piecemeal shifts in thinking occurring at fine time-scales. Knowledge analysis often moves in a bottom-up direction, with a goal of inventing new models to characterize data. Below, Patterns class data are analyzed through a fine-grained lens to model the structure of the epistemic system students draw on when engaging in informal and formal epistemic games. For the informal epistemic game, video footage of a whole-class discussion is analyzed. For the formal epistemic game, student work is analyzed. Pseudonyms are used in the place of student names.

Findings

I present examples of both informal and formal epistemic games enacted by students in the Patterns class. For each example, I present data and then use the ESF to characterize the epistemic projection of one student.

Informal epistemic game

The example of student engagement in an informal epistemic game is drawn from a whole-class discussion, which occurred near the beginning of the equilibration unit. The discussion followed an activity in which the students investigated a glass of cold milk warming to room temperature. The graph of the milk's temperature over time showed that the milk warmed fast at first, and then slowed down as the milk reached room temperature. The class discussion focused the students on generating a causal explanation for the "fast-then-slow" warming phenomenon. Just prior to the discussion, the teacher had asked the students to write down their initial explanations.

The teacher seeded the discussion by reading aloud each of the students' explanations, leaving them anonymous. She then asked them to consider one idea in particular: "Because it was getting to room temperature at the end, so it was slowing down. It's like a race, when you're getting to the destination you start to slow down." The students debated the idea, pushing the student who had written it to unpack his thinking and explain why approaching room temperature would cause the milk to slow down. This student was Alvaro, though, due to the anonymity of the activity, no one knew this but he and the teacher.

> Leo: Why would you slow down when you're about to finish a race? It doesn't make sense.
> Teacher: Does anyone want to try and make a guess why?
> Alvaro: Say there's a wall. Are you going to run straight into it Leo?
> Leo: Well, I'm not gonna go slower though, because then I'll lose.
> Alvaro: Like no-no-no-no-no! Like, say you're winning 'cause you're going as fast as you can, then when you're gonna reach the wall, don't you start to like kinda? <stomps feet on ground>

Michelle then challenged Alvaro's race-to-a-wall analogy on the basis of its fit with the milk scenario.

> Michelle: Is there a wall?
> Alvaro: Yes, there's a wall.
> Michelle: There is no wall.

> Alvaro: There is a wall.
> Michelle: Where?
> Teacher: Alvaro, what would the wall be in the case of the milk warming up?
> Alvaro: The room temperature.

Because the debate had interrupted his explanation, the teacher asked Alvaro to summarize it.

> Alvaro: You're like running, like fast as you can, 'cause like just straight, and then you're like gonna run into the wall, you're not going to keep going the same speed <turns to Leo> dude, you're just going to […] You have to slow down to stop.

Alvaro's epistemic projection

Epistemological resources. Alvaro's epistemological resources frame the task at hand, orienting his attention and motivating his activity. In this segment of transcript, Alvaro hears Leo and Michelle challenge his explanation for the fast-then-slow warming. He is motivated to defend his ideas and craft a satisfactory causal explanation for his classmates. This intuitive epistemic form drives Alvaro to understand the problems his classmates have with his original explanation and to modify it accordingly.

Perceptual strategies. Alvaro's goal of crafting a causal explanation orients his attention to both his original explanation and the phenomenon he is trying to explain. He may be attending to the explanation that is written on the board, or he may be attending to his memory of it, which may include details that he has not publicly articulated. As for the phenomenon he is trying to explain, he may be focused on the graph or data table representing the temperature over time, both of which are drawn on the board. It is also possible his attention is focused on a memory of his participation in an activity where he demonstrated the temperature change of the milk by walking along a thermometer drawn horizontally on the board (Swanson & Trninic, 2021). From the objects of his attention, Alvaro's perceptual strategies enable his extraction of the information his explanation must account for: the milk is warming quickly at the start and then slows down as it approaches room temperature.

Epistemic game move resources. Alvaro employs a number of epistemic game moves in his attempt to make his explanation sensible to his classmates. His initial hypothesis had explained the slowing of the milk's warming in terms of a race analogy. Leo challenged his analogy on the basis of its logic, questioning why a runner would slow down at the end of a race. Alvaro recognized the problem with his logic and modified the analogy so that it was logical, by making the race end at a wall. Alvaro's moves suggest that he had knowledge facilitating their enactment, specifically knowledge enabling his evaluation of the logic behind his original explanation and recognition of its shortcoming, and knowledge enabling his evaluation of his proposed modification to the analogy. When Michelle challenged the analogy by pointing out a missing mapping (asking Alvaro what the wall was in the case of the milk), Alvaro clarified the mapping, stating that the wall in the case of the milk was room temperature. Again, Alvaro's moves suggest underlying knowledge, specifically knowledge facilitating his evaluation of the mappings between the race analogy and milk scenario and his identification and evaluation of the mapping implicit in his explanation.

Conceptual resources. Alvaro draws on several conceptual resources in attempting to make his explanation sensible to his classmates. These likely include knowledge of what it is like to run a race both in the open (where you wouldn't need to slow down to stop) and what it is like to run a race to a wall (where you would hurt yourself if you didn't slow down to stop), and an intuition which may be a p-prim: "you have to slow down to stop." This logic is at the heart of his explanation for why the milk is warming more slowly as it approaches room temperature and it is the key behavior illustrated by the race analogy. He draws on these conceptual resources in constructing his original explanation, and in modifying and more clearly articulating his explanation in response to his classmates' criticisms.

This example shows how the perceptual and cognitive elements of Alvaro's epistemic projection worked together to help him clarify the sensibility of his explanation for why the milk warms fast-then-slow.

Formal epistemic game

The example of a formal epistemic game is drawn from students' second draft equilibration theories, written towards the middle of the unit. Construction of pattern theories is considered a formal epistemic game, as it is guided by a formal epistemic form. The drafts were written following exploration of the examples: cold milk warming, hot tea cooling, and particle diffusion. For his second draft theory, Emre wrote:

> Fast then slow, fastest, faster, fast, slow, slower, slows, stop, slows down b/c reaching equilibrium goes fast in the beginning because it has more room to cover.

Emre’s epistemic projection

Epistemological resources. Emre’s epistemological resources frame his task, orienting his attention and motivating his activity. In this case, his epistemological resources include a formal epistemic form given to him by his teacher: the form of a pattern theory. This form is a template for a description of a behavior common to the behavior he had explored thus far (including the cold milk warming, hot tea cooling, and particle diffusion).

Perceptual strategies. The pattern form orients Emre’s engagement in an epistemic game of pattern-theory building and brings his attention to the three phenomena he has observed. It directs his attention to the behavior demonstrated by each phenomenon, as opposed to their surface features.

Epistemic game move resources. Emre employs epistemic game move resources in his attempt to find a behavior that is common to the three examples. The moves likely involve knowledge facilitating his comparison of the three example phenomena, and his identification of similarities in their behavior.

Conceptual resources. Emre draws on several conceptual resources in articulating his pattern theory. The idea that the milk “slows down b/c reaching equilibrium” suggests a conceptual resource like Alvaro’s, that one has to slow down to stop. “Goes fast in the beginning because it has more room to cover” may be another intuition, that one will move faster the further one is from one’s destination.

This example shows how the perceptual and cognitive elements of Emre’s epistemic projection worked together to help him write his second draft pattern theory. A notable difference between Emre’s epistemic projection and Alvaro’s is the nature of the epistemic forms employed by the students (Emre is using a formal epistemic form and Alvaro is using an informal epistemic form).

Discussion

The paper presented a theoretical framework for characterizing student engagement in epistemic games. The framework synthesized ideas from two existing theoretical frameworks: *epistemic forms and games* and *knowledge in pieces*. Like epistemic forms and games, the framework is meant to characterize an individual’s knowledge-construction process. Like KiP, the framework is meant to characterize the structure and dynamics of the individual’s informal and formal knowledge at a fine grain size. The resulting *epistemic systems framework* features two basic components: one perceptual and one cognitive. The perceptual component consists of the *perceptual strategies* the individual uses to extract raw data from the world. The cognitive component consists of the individual’s *epistemic net*, which is a network of knowledge resources including *epistemological*, *conceptual*, and *epistemic game move resources*. These resources orient and motivate the individual’s attention to their task, and facilitate their enactment of the epistemic game. The ESF is introduced and used to produce fine-grained models of instances of both informal and formal epistemic games.

The paper makes a theoretical contribution to literature concerned with characterizing the nature of scientist and student engagement in epistemic practices. As well, it extends the theoretical machinery of knowledge in pieces, producing a framework that researchers can use for modeling individuals’ engagement in epistemic games ranging from formal modeling to informal explanation and sense-making. The ESF is still in its infancy. Future directions include further investigation of both scientist and student engagement in epistemic games, with the aim of refining the framework. Of specific interest is investigation of the dynamic interplay between the different kinds of knowledge elements belonging to the epistemic net, to understand more clearly how the different kinds of knowledge elements interact in individuals’ knowledge-construction processes. Finally, it is well known that many epistemic games are not played by individuals in a vacuum, but rather, are distributed among individuals and materials (Dunbar, 1997). Therefore, understanding how epistemic systems can be used to model distributed epistemic games would be beneficial.

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Youth as Pattern Makers for Racial Justice: How Speculative Design Pedagogy in Science Can Promote Restorative Futures

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Abstract: In this article, we examine the development of youth sociopolitical consciousness and agency in an eighth-grade science classroom as students explore the multi-scalar, racial realities and possibilities of the science and engineering of pervasive digital technologies. Through case studies of two girls of color (ES and GS), we analyze the youths' cultural learning pathways. Our analyses show how youth use their felt, cultural, and community knowledges, and their developing physics knowledge, to confront and analyze manifestations of racial bias in technologies. The findings highlight the significance of teachers' pedagogical support and providing opportunities for meaningful transdisciplinary science investigations and speculative designing for more just and thriving futures. The Critical Speculative Design Pedagogy framework suggests how teachers can cultivate equitable, expansive, and consequential science learning. Please review the full journal article to see design principles relating pedagogical commitments to the instructional flow of the unit (Arada, Sanchez & Bell, 2023).

Introduction

In historical and ongoing ways, American education has been an institution committed to securing white settler futurities. We explore the pedagogical possibilities of *critical speculative design* to construct futures of STEM education which propel youth's development of sociopolitical consciousness and agency through an arc of science instruction, towards "community futurity work" that manifests collective power, love, care, and ancestral thriving (Harjo, 2019). Through our research, we explore the following questions:

1. How can school-based science learning environments support the critical speculative design pursuits of middle school Black, Brown, and Indigenous youth?
2. What socio-technical patterning processes do Black, Brown, and Indigenous youth develop and engage in as they imagine critical futures of light and computer vision technologies in society (e.g., for facial recognition, medical diagnosis, and more)?

Theoretical framework for critical speculative design involving science

We leverage, apply, and extend established theoretical frameworks for cultural learning pathways that attend to sociomaterial, relational, affective, and power laden dimensions of learning processes (Bell et al., 2012; Nasir et al., 2020). As a social practice theory of learning (Lave & Wenger, 1991), we elaborate cultural learning pathways to center specific sociopolitical edges of the learning environment that are salient to this work: (a) desettling the image of science and science education (Bang et al., 2012), (b) centering multiple ways of knowing and expression (Warren et al., 2020), and (c) supporting learning focused on the cultural thriving and joy of Black, Brown, and Indigenous youth and communities through sustaining and resurgent pedagogies (Paris & Alim, 2017). Focusing on learning pathways allows us to build knowledge about "chains of personally consequential activity and sense-making – that are temporally extended, spatially variable, and culturally diverse with respect to value systems and social practices" (Bell et al., 2012, p. 270). They reveal how engagement and cultural learning connect with identities of learners, with a focus on relational, affective, and motivational elements (Nasir et al., 2020). From a designed learning environment perspective, we conceptualize learning pathways to involve instructional phases of: *threading practices* as learners engage in sociopolitical interpretation; *weaving practices* as they coordinate multiple ways of knowing and being in relation to their interpretation; and *patternmaking practices* as they conceive of more just patterns, practices, and politics through speculative design (Benjamin, 2020).

Threading: Cultivating sociopolitical consciousness and interpretive practices

We develop *threading practices* as a felt, agentic, and collaborative process of historicized, embodied sense-making of generative themes, "iconic representations that have a powerful emotional impact in the daily lives of learners" (Freire, 1970). Learner inquiry into generative themes must involve political clarity of the connected ethical and political commitments, "being grounded not only in personal experience and consciousness but also in a continually evolving assemblage of ethical and political commitments towards engaging in rigorous and human research" (McKinney de Royston, Sengupta-Irving, & Cosby, in press). Discerning and mobilizing *political clarity* in STEM learning environments is a vital strategy for lifting up the relevant *threads* within generative themes—for analysis, commentary, and response practices. The subject matter and practices of science itself is inherently political and entangled with racialization processes and racist endeavors historically and scientifically (Marks, 2017). The felt, emotional dimensions of learning should also be situated as both an influence on learning and an intentional focus of what is to be learned (Vea, 2020). *Threading* asserts felt knowledges (Harjo, 2019; Million, 2009), disrupting the gatekeeping and gaslighting logics of white supremacy (McKittrick, 2021). Learning to apply critical consciousness and emotion to generative themes through *threading practices* involves the coordination and mobilization of context-dependent knowledge resources that produce emotionally and socially just ethical meanings. *Threading practices* set the stage for *weaving* multiple ways of knowing as part of further analyzing and contextualizing the topic from a racialized, sociopolitical perspective.

Weaving: Principled coordination of multiple ways of knowing

Weaving practices guide youth in the stitching of their learning and sensemaking resources with sociopolitical consciousness and purpose across their life pathways (Nasir et al., 2020), to see the systemicity of bias. Through the threading of their critical consciousness with unit learning content, students navigate ethical and moral sensemaking through *weaving* connections of (un)just, critical science phenomena across academic disciplines and real life, "a collaboration between sparking synapses and political struggle" (McKittrick, 2021, p. 70), thus recontextualizing learning in more consequential terms. Taking a horizontal learning approach (Warren et al., 2020) allows students to thread their critical consciousness and *weave* their axio-onto-epistemic heterogeneities, contextualizing science with living, to "engage in the imaginative, ethical, and political dimensions of knowing and being" (Bang, 2020). *Weaving* supports *patternmaking,* which present "conceptual openings" and opportunities for youth imagining and agentic constructing of collective alternatives.

Patternmaking: Imagining new patterns of liberation through speculative design

Through the *patternmaking practices* in speculative design, youth can challenge and refuse the racialized assumptions, preconceptions, and givens coded onto them (Benjamin, 2020; Nxumalo, 2021)—to then *make patterns* for generational flourishing. Speculative design pushes students to transcend settled disciplinary silos (Warren, et al., 2020) and braid the threads of felt, cultural, scientific, media, relational, and artistic knowledges. These principles act as a guide for teachers to design for and decipher manifestations of youth learning beyond normative science. When thoughtfully integrated with unit content, they center youth knowledge and voice, and provide them with multiple openings for reexamining, reimagining, and rebuilding worlds within and beyond the classroom. We pose the following elements of a Critical Speculative Design Pedagogy:

- **Consequential Concern**: Shifting learning purposes from individual to collective well-being, catalyzes youth to think broadly about justice matters of consequential concern impacting their communities and to design more just futures (Sanchez, in press). By situating learning within the entanglements of society and justice, young people are essential change-makers and stakeholders, which fosters community and cooperation to provide a legitimate sense of knowing and responsibility beyond themselves.
- **Kindred Relationality:** Building bonding relationships of reciprocal respect, love, and care through thick solidarity, while collectively mobilizing to reject oppressive and damage-centered narratives, nurtures learning and multiracial responsibility and thriving (Harjo, 2019; Liu & Shange, 2018).
- **Critical and Liberatory Presencing:** Leveraging ways to engage with the work of people who look like them, have similar histories and experiences as them, and do science in expansive ways can support youth's consequential learning in juxtaposition to problematic political projects (Sanchez, in press).
- **Constellar Youth Knowledges:** Youth dexterously traverse the cultural ecologies across their lives, grasping onto what speaks to them, to then develop a unique, connected repertoire of practices and transdisciplinary expertise. The constellation of resources comes from: (a) their specialized interests, relationships, and school engagements (Ito et al., 2013), (b) the familial capital from kin and cultural connections rooted across histories and lands (Kimmerer, 2013; Nxumalo, 2021; Moll, et al. 1992; Yosso, 2005), and (c) their intuitional felt resonances (Harjo, 2019). This learning occurs as movement across time, space, and activity as they span their expertise over the bounds of home, school, digital, and other learning environments focused on sustaining their cultural lifeways (Gutiérrez et al., 2017).
- **Futurity Play:** Rejecting the adultification of Black, Brown, and Indigenous youth, "social dreaming," through imagining and tinkering, can bring youth to make sense of and build worlds, and center play as a leading activity in social change (Espinoza, 2009; Gutiérrez, et al., 2017; Mitchell & Chadhury, 2020).

Methods

Context: Research-practice partnership & curriculum co-design

This social design research project (Gutiérrez, et al., 2020) partnered with two ethnically and linguistically diverse public middle schools in the Northwest United States during the height of the COVID-19 pandemic. The class demographics consisted of 65% self-identifying Black, Brown, and Indigenous youth and relatively even among those who self-identify male and female. We wove themes of community, anti-racism, liberatory expression, and civic engagement into the co-designed physics unit, pulling in principles of CSDP (see Theoretical Framework):

- **Consequential Concern:** Our designed science and social focused unit storyline traced the role of light in our lives, specifically centering the experiences and impacts Black, Brown, and Indigenous communities, with the driving question: "How can and does light serve some communities and not other communities?" The readings examined phenomena from a critical sociopolitical stance: (a) on light energy and technologies highlighting environmental and racial injustice through workplace inequities, (b) on melanin and medical racism with technologies using UV light detection, and (c) on racial bias in dermatology and in AI algorithms used to detect skin cancer.
- **Kindred Relationality:** As a teacher-researcher team composed of white and Brown women, we sought to refuse the white domination and racial neutralization and invisibilization forced upon students, while also fostering collective solidarity and agency with students. Especially in COVID-19 when closeness among classes is difficult to develop given a 28-minute weekly time period together, this unit occurred amidst highly publicized racial reckonings—communicating about emotional and political action brought them together to begin recognizing aspects of shared struggle and individual racialized struggle.
- **Critical and Liberatory Presencing:** Countering absent, misrepresented and/or abstract narratives of non-settler communities in curricular design, we prioritized the voices, experiences, and work from transdisciplinarians of color, like Ruha Benjamin, Joy Buolamwini, and Movement for Black Lives.
- **Constellar Youth Knowledges:** We developed lessons for students to engage with content related to justice topics (technology, environment, health), in various forms (readings, discussions, class lessons, videos), and pertaining to ranging interests (maps, graphs, technology, arts, pop culture). Rather than adhere to a strict standard of annotation, we encouraged students to express sensemaking with emotion and personal experience, which granted us insight into the heterogeneity of their conceptions of justice. Embedding the unit with cross-disciplinary learning engagements like the Visioning Board signaled a valuing of the intellectual and cultural epistemologies and ontologies of youth, which was oppositional to the domain specificity that situates knowledge as settled, zero-point epistemologies that perpetuate onto-epistemic supremacy (Warren et.al, 2020).
- **Futurity Play:** In the guidelines for the culminating activity of the unit, the Visioning Board, we aimed to center student innovation and experience, avoiding work that could be telegraphed by the teacher or constrained by curricular standards. The media and text would be tools for understanding expressions of their reflections, inquiries, fears, and introspections, where they could "grapple with their interiority through images and creating artwork" (Harjo, 2019, p. 206) and tinker with possible configurations of resistance and transformation (Gutiérrez et al., 2017).

Data collection

Over the course of two months of science classes, the duration of the lightwaves unit, we made ethnographic observations, recorded field notes, collected chat logs, and took screenshots of class presentations. We also conducted semi-structured interviews with the teachers to understand their backgrounds and contextualize their interactions with students over time. Given that this research study occurred in the midst of a global pandemic, our core data came from student work: annotations of reading assignments, online chat and discussion posts, and Visioning Boards. Students emphasized key concepts and paragraph summaries (PS) through highlighting, drawing, reinterpreting, and adding personal connections, questions, and emotional reactions. We also administered an exit ticket after the lesson on AI-driven dermatology, and a reflection form at the end of the unit to learn more about their process, inspiration, and more specific speculations regarding their Visioning Board.

We studied 158 students' learning pathways ethnographically, first identifying students whose Visioning Boards indicated a pointed interest in light/computer vision technologies, and then tracking their resonances throughout the unit across our field notes and their reading annotation assignments, online message board discussion posts, in-class participation logs, exit tickets, reflection forms, and interviews. For our analysis, we mainly concentrated on the students' Visioning Boards and their annotations of the readings as the most semiotically rich data types in the corpus. With COVID-19 significantly impacting attendance and synchronous class time, we found that their annotated readings afforded them more time to question, critique, and imagine with the critical data on. Thirteen students were identified with data representative of the learning pathway analysis.

Thematic analysis of pathways & ethnographic analysis of learner cases

We used *threading*, *weaving*, and *patternmaking* dimensions in our analysis for the 13 students to inductively identify thematic dimensions within and across those phases, categorizing students' work and noticings chronologically (Wolcott, 1994) in their (a) *threading*: making initial observations and beginning to form critical consciousness (expressing an emotional or other relational connection to the topic, highlighting the importance of a particular concept), (b) *weaving*: grappling with sensemaking around race through the application of their multiple ways of knowing (recognizing systemic rather than individual inequities, navigating ethics or morality, advocating for justice, perceiving white as a standard, noting racial invisibility), and (c) *patternmaking*: sharing their desired futures focused on collective thriving (racial justice in various industries; health in intellectual, physical, social, or spiritual ways). To analyze emotion, we examined students' syntactical choice (use of particular words, organization of words), punctuation (use of exclamation points, question marks, or ellipses), stylistic formatting (bolded, italicized, underlined, capitalized, or highlighted), and personal examples that may have revealed or suggested a particular emotional state. Taking a sociocultural lens, we followed the students' guided emotion participation, examining their representations of emotion in relation to their other enactments and interactions (Vea, 2020). We then synthesized the three phases across the 13 students. With the Visioning Boards, which represented their patternmaking phase, we took a critical media ethnographic approach, using interactions and prior writings from the threading and weaving phases to help interpret students' creations (Jocson, 2014).

We wanted to center and explore the brilliance of Black, Brown, and Indigenous youth to document liberatory possibilities of the approach through this analysis. This led us to interpret the unfolding learning pathways of two girls of color whose expressions of learning differed from western normative expectations of science and from one another. Developing ethnographic cases for these two girls allowed us to more closely understand the cultural pathway of their individual learning (Bell et al., 2012).

Findings

We share two ethnographic case studies of girls who engaged in this instructional unit. After setting the context around each main case, the accounts are organized as a chronological unfolding of threading, weaving, and patternmaking phases, highlighting how the elements of CSDP impact their learning journeys. We name students based on a synonym of their name's meaning and refer to them by those initials (ES and GS).

Case study of the Enlightened Student (ES)

Case context

The Enlightened Student (ES), who is part of the school's East African student community, fluidly makes connections between school and the real world, incorporating her multiple forms of knowledge and expression in science. According to her teacher, ES possesses an "innate drive with school" and a "hunger for knowledge." The relationship she built with ES and her family over the school year, through COVID-19 circumstances, surfaces in ES's openness in her annotations as well as her desire to discuss content outside of class time.

Threading

In the reading on solar energy, ES writes, "Having diversity is very good for an industry like this. Because there will be more buyers from different communities if they see diversity and their own people. ES indicates that diversifying a predominantly white industry would be beneficial because communities can buy from "their own people," suggesting that she places significance in cultural capital, in supporting the economic and professional gain of her "own people" (Yosso, 2005). As a form of political clarity (McKinney de Royston et al., in press), we take this as ES beginning to infuse personal experience and consciousness with her working understanding of bias in the solar industry, that the industry should be diverse not just for diversity's sake, but because this shift in the racial makeup of a workforce can potentially lead to a light technology benefiting more communities.

In ES's annotation on the melanin and medical racism article, she writes, "*LaToya's husband believes our black people are dying because … doctors practice and perfected healing whites skin and other skin that's like it, not the skin that's darker.*" We observe ES's felt resonance with the perspectives of Black people in the readings as she starts to develop awareness of injustices in healthcare and technology, and the overall well-being of their communities. Her comment expresses relationality and solidarity with the highly melanated people's experiences and voices. These emotional and familial resonances, as part of her *constellar knowledges*, serves as the initial catalyst that moves the readings from a detached assignment to a more personal, felt social alignment

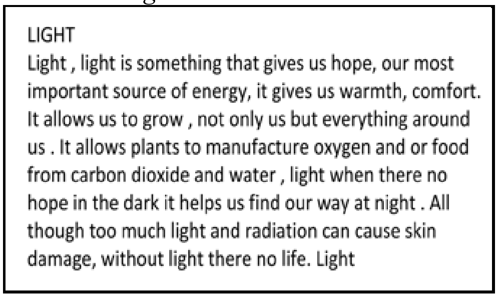
(Harjo, 2019). We see her perspective-taking through LaToya to make sense of the data. ES problematizes medical technology as unethical in its white prototypical design centering whiteness and white life (Browne, 2015). In referring to them as "*our* black people," she speaks as a student analyzing data and as a kin member, upset at how doctors prioritize the health and "perfected healing" of white and lighter skin people. Her feelings appear to be drivers of her sensemaking and move towards critical consciousness, setting up emotional configurations related to her histories, and motivating her to more clearly see the ethical wrongs in LaToya's situation in relation to herself (Vea, 2020). Her thinking-feeling response is based on the racial violence built into the algorithm, that the healthcare system is not built to support Black humanity as it is for white patients (Harjo, 2019; McKittrick, 2021).

Weaving

In her reflection after the lesson on racism in AI-driven dermatology, ES's Exit Ticket further demonstrates felt relationality with the highly melanated people referenced across the lessons. She writes*, "I have darker skin … I wonder if my skin is dark enough for the facial recognition to not identify me. I felt a little disappointing, simply because black people are always looked down upon in the system, and its hard when society's future in technology does not fit our features and our skin tone. Its literally 2022."* ES shows disappointment, impatience, and incredulity (e.g. "Its literally 2022") at the continued unjust treatment of people with darker skin through the use of "the system" and "always." In acknowledging the importance of racial equity in persistent technologies and the need to wrestle with associated systemic inequities, we perceive her to be questioning if and how people with her "features and skin tone" fit into that future. With mentionings of the lesson on AI-driven dermatology, ES advances emotional configurations she used for sensemaking in her prior annotation to give social meaning to her emotions, correlating skin color with her own potential racial invisibility and of others in the larger Black community (Vea, 2020). We see strong evidence of her new learning about environmental and medical imaging technologies and melanin entwining with her personal knowledge and emotional awareness of inequitable treatments towards people of color. ES sees that it is not the technology but rather people who perpetuate a white-dominated system of racism and reinscribe biased practices and technologies that ignore a more melanated humanity, and are violent to "Black livingness" (McKittrick, 2021). The statistics and stories of people who look like her bring her to confirm her own felt knowledge and see how racial inequities are built into society. ES makes vital scientific arguments by expressing political clarity around her racial equity concerns about technological functionality as a systemic issue involving a stance that dehumanizes Black people. In her thinking, we see these related strands of knowledge and purpose starting to coalesce—setting the stage for her speculative designs.

Patternmaking

Figure 1
ES's Visioning Board



LIGHT
Light , light is something that gives us hope, our most important source of energy, it gives us warmth, comfort. It allows us to grow , not only us but everything around us . It allows plants to manufacture oxygen and or food from carbon dioxide and water , light when there no hope in the dark it helps us find our way at night . All though too much light and radiation can cause skin damage, without light there no life. Light

Standard culminating knowledge forms for classroom science education—causal explanations, conceptual models, evidence-based arguments—cannot easily accommodate the radical speculative dreaming of students. Using her *constellar knowledges* as a guide, ES gravitates towards poetry in her Visioning Board (see Figure 1) and particular resonances from the readings to synthesize her interpretation and analysis of a more socially just future. Through a mix of repetition, metaphor, and science knowledge, she highlights *light* as a necessary tool for health and survivance for humans and nonhumans, while also cautioning against its misuse and excess.

ES's poem also acts as a declaration for racial recognition and mattering: with light, there is "warmth, comfort … without light there [is] no life." Her genre flexibility leverages her expertise in poetic expression as *futurity play*. Through this medium, ES freely communicates her stance on racial justice and tests out her theoried future, artfully remixing her learning with her own *constellar knowledges* (Gutiérrez et al., 2017). ES's poetry are speech acts of refusal of racism, piecing together the different woven strands that she has gathered from the readings and her own *constellar knowledges*, to understand racism as systemic and action as collective, and to claim bold movement and responsibility towards justice. ES surfaces her purpose in her speculative dreaming, in seeing her role in her community's care and thriving, while also recognizing that to fight against the wider systemicity of injustice, "everything" and everyone must work together. We take this poetic approach to social dreaming as a strong example of liberatory classroom science instruction.

Case study of the Gifted Student (GS)

Case context

For Black, Brown, and Indigenous youth, individualism and myths of meritocracy often falter and wane as motivation for academic engagement, as these ideologies and privileges are not aligned with their cultural and racial values and ways of being and mattering. This change did not go unnoticed by GS's teacher, who shared that her "best practice" is "building relationships with them and as a class, everything is different now, for all of us but especially my kids of color." GS had completed only one unit prior to our focal unit on lightwaves. Her teacher explained, GS "started the year off strong, then dropped off the face of the planet. Then, I called home and said some very motivational and genuine things and boom, she was back in the game...to the extent that I gave her the science award [for demonstrated excellence]." GS's teacher shared about her matriarchal team (including GS's mother and grandmother) as a trio of "badass" and "magical" women. As shown below, this powerhouse of intergenerational, Black expertise was core to the learning artifacts GS generated.

Threading

Analysis of GS's early learning artifacts showed that threading began as very one-dimensional, with complexity and vibrancy increasing as the learning moved through the increased CSDP into the unit. On solar energy, GS summarizes, *"Organisms that include our bodies and plants need energy to live."* Though she demonstrates competency in conceptual knowledge, we take this as a sign of disengagement and disconnect from the content. With the next reading on AI-driven dermatology, there was a marked shift in the elaborations and affective engagement in GS's annotations. In her paragraph summaries, GS mentions bias and an example of dehumanization through African American and Asian populations not being recognized by technology but rather being mistaken as gorillas. Her choice to include this specific experience in her notes over other broader concepts implies its influence on her understanding of algorithmic technology, and potentially leading to *kindred relationality*, and also feeding into GS's progression of political clarity through the reading. GS's visceral pulling from constellar, felt knowledges was evident with the calling out of *"Early technology adopters"* as lacking awareness of the consequences of using biased technologies and her refusal to maintain white dominance in the field of medicine, stating that *"research should include diverse samples across multiple populations"* and *"...there is not enough medical professionals of color nor enough medical information on marginalized communities."* Through her questions and colored highlighting of wonderings and key concepts, and her opinions of what "should" change, we see GS beginning to form critical consciousness, wading through sensemaking and displaying a desire to know more about the ethics and morality of biased and novel technologies (McKinney de Royston et al., in press). In her responses, we see acts of refusal, means of working to secure futurity (Nxumalo, 2021, p. 6), opening up space for Black, Brown, and Indigenous youth livingness in the next phase of their inquiry.

Weaving

This flow of activities and GS's annotations are necessary for the weaving of epistemic heterogeneity needed in STEM endeavors (Bang & Medin, 2010). GS grapples with illuminated diffractions of *dark matters* as seen through the aperture between the science of light and the politics of lightness, bolding her words to bring attention to her demands and suggest an urgency. As part of her paragraph summary, she writes, *"Melanoma and its mortality rates affect different classes of people at different levels. ...* ***The messages I have seen regarding sunscreen promotes its use by light-skinned people but not those of African descent. Public health groups should do a better job at promoting the dangers.****"* GS weaves in information from a reading about melanin as a defense against UV rays, with information from a separate reading about the risk of skin cancer for communities of color. GS uses facts to demand that public health groups do a better job at advertise, bring awareness, and protect dark skinned people. We believe the combination of statistics, felt knowledge, and personal experience in seeing advertising not designed for her likely leads GS to make this statement. GS's emotional configurations draws from her own life, attaching social meaning. We argue that this critical sociotechnical interpretation and commitments provides a humanizing stance for their speculative design engagement during patternmaking.

Patternmaking

An interview with GS's teacher revealed the essential living story taking place at GS's kitchen table with her grandmother related to her Visioning Board: "she seemed a bit nervous at first to tell me [that she and her grandmother worked together], probably because some teachers might see that as cheating … when I told her it was awesome that she made the board with her grandma, she beamed." Together, GS and her grandmother engaged in animated threading, weaving, and patternmaking as they spoke to and from their relational knowledge together. Contextualizing GS's previous work and her increased in-class participation with her Visioning Board, the shift in how bias is articulated illustrates the melding of GS and her grandmother's perspectives—a form of collaboration likely to have involved a coordination of intergenerational knowledges.

Figure 2
GS's Visioning Board

AI projects a false sense of a secure, holistic and fair search process while validating and deepening bias further in its algorithms.

Diminishing Bias in Artificial Intelligence

The current biased artificial intelligence(AI) systems have become a significant problem throughout the world and in multiple industries such as healthcare/medicine. In vulnerable populations, people have been hurt or suffered the impingement of their rights due to biased AI. Furthermore, in healthcare, racial minorities and those living in poverty often get substandard healthcare quality than non-Hispanic Whites and people with higher income and wealth. Algorithms trained on inaccurate, insufficient quality data will produce the wrong results, leading to inadequate care delivery.

Just as humans have to admit bias/racism to defeat it, so do machines, algorithms, and AI.

The Visioning Board (see Figure 2) maps her just future by providing a grounding text titled "Diminishing Bias in Artificial Intelligence," as a synthesis of content knowledge and onto-epistemologies curated between GS and her grandmother. This centering of *constellar knowledges* through intergenerational relations reinforces the importance of distributed expertise and collaborative sensemaking. Moving from left-to-right through the images of the Visioning Board, GS tells a proleptic narration of the weaponization of technoscientific innovations, calling out specific forms of bias and claims of universality in algorithms. There are refusals of bias in STEM fields "ranging from computer science to genetics." GS offers up contextual representation of Black medical and science professionals for the *critical and liberatory presencing* of diverse backgrounds reflective of their own identity. Through her textual explanations and curation of images, GS's Visioning Board indicates *futurity play*, re-creating what the future of AI could and should look like. GS's work provides a counter design to the normative physics unit, weaving in threads of ontological and intergenerational knowledges through their articulation of racial injustice and emphasis on eliminating bias, while proposing refusals as methodologies for patterning thriving Black futurities in our ever-increasing technoscientific society. This transdisciplinary form—with intergenerational collaboration—supported her speculative dreaming of a more just future with technology.

Conclusions & implications

This research focuses on informing how science learning environments can desettle traditional western science education and create spaces for liberatory dreaming and designing for Black, Brown, and Indigenous youth and their co-conspirators (Bang, et al., 2012). Returning to the unit's original question (How can and does light serve some communities and not other communities?), building capacity for thick solidarity towards collective thriving will continue to be a timely generative theme. The work we engaged with students signals a crucial opportunity for education in opening up possibilities for future generations to critique and reject racist sociotechnical systems, examine teaching practices, and enact agency for centering multiracial justice and the felt and relational implications of design. The materials, instruction, and student positioning that supported critically conscious inquiry and speculative design in this project-has broad implications to how science learning environments should be constituted for all youth—and specifically for Black, Brown, and Indigenous youth. Culturally expansive learning means accepting the multiple contexts and spaces that students engaged in threading, weaving, and patternmaking, and consciously distancing ourselves away from the westernized approach with science, with technology, and with one another. Speculative design science instruction shows promise for supporting youth in critical analysis and liberatory dreaming and realizing of more just and thriving futures.

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How Computational Thinking Can Become a Sensemaking Practice for Preservice Teachers in an Engineering Course

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Abstract: The role of computational thinking (CT) in science education presents an important challenge for teacher preparation, as CT and closely related concepts now appear in science standards in many regions. There is broad agreement that computation is an epistemic practice in science and engineering (e.g., Nersessian, 2008). However, supporting preservice teachers' (PSTs) understanding of CT as sensemaking practices in engineering design remains underexplored. We present a qualitative exploratory study in which we aim to support PSTs' participation in and recognition of CT practices in engineering design contexts within a semester-long science and engineering course. We present two themes that inform how CT became a sensemaking practice in engineering: (1) the design of learning environments in which CT is reflexive (Harel & Papert, 1990) with PSTs' own experiences in engineering design and (2) the central role of contextualization and addressivity (Bahktin, 1986; Sengupta et al., 2021) in CT in engineering education.

Introduction

During the past 15 years, many geopolitical areas have included CT and closely related ideas in the science curriculum (Braun & Huwer, 2022; NRC, 2012). However, prior research investigating science teachers' preparedness and motivation to implement computational thinking shows that teachers do not feel ready to integrate CT into their classes (Kang et al., 2018). To address this problem, researchers have integrated CT into university-level teacher preparation classes. This integration takes multiple forms, from integrating a CT module that takes a couple of hours (Walton et al., 2020; Yadav et al., 2011) to re-designing an undergraduate class to incorporate CT (Mouza et al., 2017). These approaches suggest moderate success in supporting pre-service teachers' understanding that CT can be taught in different disciplinary contexts, even without using computers (Yadav et al., 2011). However, results also demonstrate that PSTs usually made relatively superficial connections (i.e., based on keywords) between components of CT and science curricula (Walton et al., 2020) and they were largely unable to develop lesson plans that meaningfully incorporated CT with disciplinary content (Mouza et al., 2017). The PSTs' understanding of CT fell short of showing how CT supports science learning (Walton et al., 2020).

We propose several reasons for these challenges. One of the most common ways of integrating CT into science classrooms is for students to re-represent explanations of what they have already "figured out,"—an approach that masks the generative potential of CT as a *means* for sensemaking. Another common approach to integrating CT is to provide general experiences in introductory computer science in order to create new points of entry for more students, thus, broadening the computing "pipeline." It is not surprising then, that expressing how CT mediates disciplinary learning is challenging for educators, since common rationales for integrating CT with science and engineering do not offer any insight into how computational thinking practices are epistemic practices in the natural sciences and engineering (Sengupta et al., 2021). Additionally, many teacher learning experiences are compressed in methods classes and last only a couple of sessions. As a result, participants do not have prolonged and disciplinarily contextualized participation in CT practices, therefore, do not experience for themselves how disciplinary learning happens through CT. We describe an approach that advances PSTs' participation in prolonged and contextualized CT activities to support their understanding of how CT mediates disciplinary learning in science and engineering.

Theoretical and conceptual framework

Previous literature shows that computing is often a legitimate sensemaking practice in science and engineering. This is consistent with constructionist views that learning computing makes learning disciplinary concepts easier, known as *reflexivity* (Harel & Papert, 1990). For example, as argued by Farris et al. (2019), elementary science students learned to critically interpret their own data about motion through creating agent-based models of that motion, moving back and forth between the phenomena, their data, and their models. Following Odden and Russ' (2019) definition, participation in sensemaking requires "building or revising an explanation in order to "figure something out"... to resolve a gap or inconsistency in one's understanding." (pp. 191- 192). Our sensemaking stance has its roots in the epistemological frames (e-frames) theoretical construct and refers to the approaches learners take to an educational activity (Hammer et al., 2005). A sensemaking frame positions learners to participate in an activity in order to build a new explanation (Kapon, 2016). Furthermore, computational thinking provides a means of managing complexity (NRC, 2010). It is apt that CT can be leveraged in engineering design from complex problems towards solutions. However, little research has considered supporting PSTs to learn to use and recognize affordances of CT practices in the context of engineering design using physical science concepts.

Currently, enactments of CT in STEM classrooms often do not take up a sensemaking frame. It is common that programming environments are introduced so that students can reproduce or "posterize" (Windschtil & Thompson, 2013) what is already known about the phenomenon (e.g., creating a literal representation of some features of the solar system in Scratch (https://scratch.mit.edu/) at the conclusion of an inquiry about the solar system). In addition to side stepping sensemaking goals, educational computing frequently stays in the realm of a technocentric stance (Farris & Sengupta, 2016; Sengupta et al., 2021). Technocentric views typically fail to conceptualize children's computing in a broader context that goes beyond device-level engagement (Papert, 1980; Sengupta et al., 2021; Silvis et al., 2022). However, a more situated approach, rooted in Bakhtin's framing of language (including computer languages) as heteroglossic (i.e., multivoiced), invites us to think about the socio-material and dialogic work through which sensemaking occurs. Bakhtin (1986) proposed that utterances are shaped by real and imagined listeners, a phenomenon he termed *addressivity*. In this sense, the design of a computational artifact becomes a dialogue with potential users and the use contexts of that object. Learners' considerations of the user in the design process, including writing guidelines for them and interacting with them, can shape their computational design by making the designer better understand the relation between user action, elements of the code, and the output (Sengupta et al., 2021). We propose that a focus on how CT can support disciplinary learning goals in engineering must consider how computing is framed in broader contexts and positions learners as being responsible and answerable to real or imagined users and use cases (Bakhtin, 1986; Sengupta et al., 2021).

In this study, our central hypothesis is that development of CT in K-12 curricula can be synergistically supported by physical science and engineering design curriculum. In our study, PSTs engaged in epistemic engineering practices that are reflexive with CT across different modules throughout the semester. We regularly prompted PSTs to reflect on how CT practices were evident in their work as they explored a scientific phenomenon or iteratively improved design solutions. Our inquiry is guided by the following research questions: How does their understanding of CT's role in science and engineering evolve across the semester? What aspects of the learning environment mediated these changes?

Design

Our study took place in an introductory engineering course for elementary educators taught during Spring 2022 at a large research university in the northeastern United States. In this qualitative exploratory study, we take a microgenetic approach (Saxe, 2012) as our goal was to investigate how PSTs come to understand CT's role in science and engineering across the course of the semester. Twenty-three of the 25 enrolled students consented to participate in this study. These 23 students consist of one graduate student (Science Education) and 22 undergraduates (17 pre-major College of Education students, Elementary and Early Childhood majors). Twenty-one of 23 expressed a career goal to become an elementary school teacher. Most students were in the first half of their undergraduate career: five first year students, 11 second year students, five third year students, and one fourth year student). The graduate student was a former kindergarten teacher.

The class met twice a week for 15 weeks, each class meeting was 75 minutes long. This introductory and interdisciplinary course focused on physical science concepts, pure and applied science and scientific processes, engineering design principles, and associated technologies. The course is designed in four modules: structures, simple machines, electricity, and making and modeling with code. Based on previous literature (e.g., Nersessian, 2008), we conjectured that (1) engaging in course material and epistemic engineering practices throughout the course will authentically necessitate learners' engagement in computational thinking and (2) this engagement will support PSTs to express examples of CT that contribute to goals in engineering design. Each module involved multiple aspects of CT as a means to accomplish scientific and engineering sensemaking.

We, as the instructors of the course, intentionally highlighted and named the following components of CT: abstraction, decomposition, pattern recognition, debugging, and automation, and related these to the following CT practices (Weintrop et al., 2016): data practices, modeling and simulation practices, computational problem-solving practices, and systems thinking practices. These were overviewed during a presentation about CT during Week 1. When we observed students participating in these components, we named them in class discussions to help build a common language of CT practices and components in our collective engineering work. For example, in the structures module, preservice teachers *recognized patterns* in the number of diagonal braces needed to stabilize a polygon. Later, PSTs *used simulation* to help them build and improve their physical bridges. When they were building bridges, they drew on *abstraction* and *systems thinking* as they were focusing on individual members and joints and figuring out how they work together and how those affect the structure as a whole. In each module, students were asked to write about or reflect on how CT components and practices were evident in their engineering design or in elementary-aged learners' engineering design. Data includes preservice teachers' course assignments and instructor fieldnotes and communications. For this study, we selected five focal assignments (Table 1) from the data corpus. These assignments are ones in which pre-service teachers were explicitly asked to write about CT and are distributed across the course of the semester.

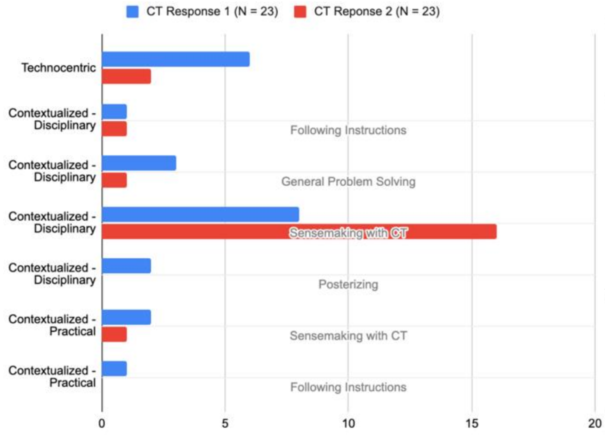
Table 1
Focal Assignments and Prompts

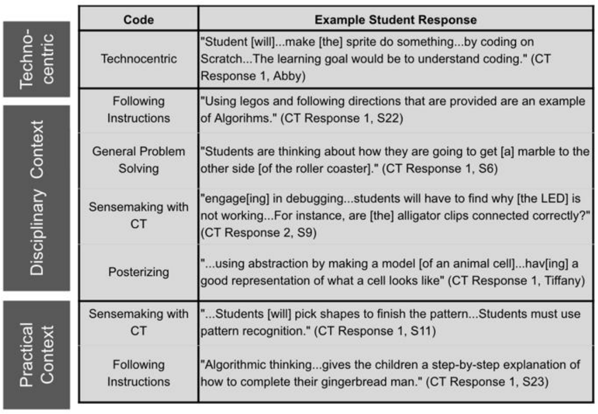
Assignment	**Prompt**
CT Response 1	Create an image that depicts elementary-aged students engaged in CT in science or engineering design activity. Write two or three sentences explaining how the activity in your drawing involves CT and supports learning.
Applications to Teaching	Consider whether you see examples of CT practices present in the lesson design. What examples do you see?
Quiz 1, Item 6	Identify two components or practices of CT that you have used in the structures unit. For each example, please briefly explain your thinking. How do you think using those CT components or engaging in those CT practices was helpful for what you were doing?
Micro:bit Design Project	Please give a visual and verbal description of the tool and the context you imagine it being used in. Describe any relevant components of CT that you have used and how they were evident in your project or the design process. In what ways are these components relevant for the (imagined) learners?
CT Response 2	The same as CT Response 1.

Analysis and findings

We first analyzed how participants wrote about the role of CT in science and engineering at the beginning and end of the semester. Participants' CT Response 1 and CT Response 2 were coded using open and axial coding (Strauss & Corbin, 1990). This process generated three top level codes: technocentric, disciplinary contextualization, and practical contextualization.

Figure 1
Counts for Each Code at CT Response 1 and 2 and Illustrative Examples for Each Code





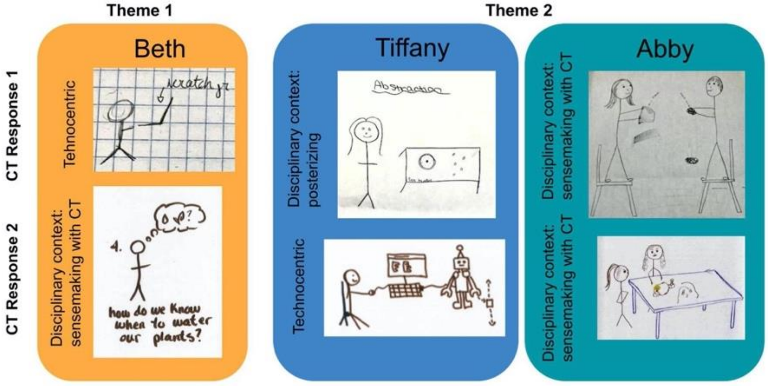
	Code	Example Student Response
Techno-centric	Technocentric	"Student [will]...make [the] sprite do something...by coding on Scratch...The learning goal would be to understand coding." (CT Response 1, Abby)
Disciplinary Context	Following Instructions	"Using legos and following directions that are provided are an example of Algorihms." (CT Response 1, S22)
	General Problem Solving	"Students are thinking about how they are going to get [a] marble to the other side [of the roller coaster]." (CT Response 1, S6)
	Sensemaking with CT	"engage[ing] in debugging...students will have to find why [the LED] is not working...For instance, are [the] alligator clips connected correctly?" (CT Response 2, S9)
	Posterizing	"...using abstraction by making a model [of an animal cell]...hav[ing] a good representation of what a cell looks like" (CT Response 1, Tiffany)
Practical Context	Sensemaking with CT	"...Students [will] pick shapes to finish the pattern...Students must use pattern recognition." (CT Response 1, S11)
	Following Instructions	"Algorithmic thinking...gives the children a step-by-step explanation of how to complete their gingerbread man." (CT Response 1, S23)

Technocentric responses indicate that the response focused on learners gaining familiarity with coding without contextualizing it into any context. Second, disciplinary contextualization indicates that the response incorporates CT into a disciplinary context in science or in engineering. This code also contains four sub-codes: sensemaking with CT, general problem solving, posterizing, and following instructions. We note that activities coded for "general problem solving" were too broad to be coded as sensemaking. The examples that received the code for "general problem solving" did not elucidate how any particular aspect of CT was used to solve the problem. The third top-level code is practical contextualization. Although the prompt specifically asked about a

CT integrated activity in science or engineering, some of the participants shared examples from everyday life which were not connected to science or engineering contexts, and these responses were coded using one of two sub-codes: sensemaking with CT or following instructions. See the quotations in Figure 1 for illustrative examples.

As shown in Figure 1, our analysis of CT Responses revealed a decline in technocentric framings of CT and CT for non-sensemaking means such as posterizing what is already known. We observed an increase in activities in which CT is used towards sensemaking goals in STEM contexts. Pre- and post- measures do not describe what mediated this change, nor the process of increasingly positioning CT as a sensemaking practice. We therefore conducted a microgenetic analysis (e.g., Saxe, 2012) to try to understand how students' positioning of CT evolved across the course of the semester, focusing on the data points shown in Table 1 and our field notes. From this analysis, we identified two themes. Each theme, following Braun and Clarke (2005), "captures something important about the data in relation to the research question and represents some level of *patterned* response or meaning within the data set" (p. 82). Theme 1 illustrated how learning about CT in elementary science and engineering became reflexive (Harel & Papert, 1990) with PSTs' own undergraduate-level experiences in engineering design, and we present Beth's work as a representative case (Yin, 2009). Theme 2 is concerned with addressivity (Bahktin, 1986). We use contrasting cases (Yin, 2009) from two additional students, Tiffany and Abby to illustrate how addressivity is essential for learners' positioning CT as sensemaking practices. Together, these two themes help to explain how the learning environment—firmly rooted in the disciplinary learning goals in engineering design and physical science concepts (Figuiredo, 2008) support the PSTs to recognize CT practices as sensemaking practices.

Figure 2
Participants' Drawings in CT Response 1 and 2



Theme 1: Learning about CT becomes reflexive with engineering design

To explain the Theme 1, we present examples from Beth's coursework as representative and explanatory case of the theme. Beth was in the fourth semester of her studies and expressed a desire to be an early childhood/elementary teacher. Before the course, Beth had no prior experiences with coding or physical computing.

Drawings analysis: Beth

At CT Response 1, Beth drew a figure of a student working on a laptop, with a "Scratch Jr." label on the screen (see Figure 2). In her written explanation, Beth wrote an example of how elementary-aged students would engage in CT "to make [the] sprite do something automatically by coding on Scratch." Beth wrote that this activity supports learning because "students are learning to code" and the main goal of the activity is "to understand coding." Beth did not mention a purpose of coding other than to learn to code.

At the end of the semester, Beth's CT Response 2 involved multiple drawings of students working on different design problems, including building simple machines to "make our lives easier" or making a potato circuit. For example, one of these drawings depicted a student imagining a raindrop and a plant and asking, "How do we know when to water our plants?" (see Figure 2). In her explanation, Beth wrote that the forms of activity in her drawings support learning because "students gain an understanding of the world around them" through participating in engineering to solve problems. Across CT Responses 1 and 2, Beth moved from a technocentric framing of CT to a framing in which CT is used in disciplinary science and engineering contexts to tackle problems. Beth's initial drawing illustrated a typical technocentric view (e.g., "learning to code", however, her final response illustrated how she is situating CT in disciplinary learning goals (simple machines make "work…easier").

Developmental analysis: Beth

What mediated Beth's movement from a technocentric perspective about CT to a sensemaking perspective? In Quiz 1, Beth reflected on how certain CT practices were helpful in the structures module. She wrote, for example, how modeling and simulation practices helped her to "visualize how structure[s] worked and how they can be improved." Beth reflected on how she used a CT practice in the context of engineering design to iteratively solve a problem.

In her Micro:bit design project, Beth re-mixed code to command the Micro:bit to measure the ambient temperature and report the output on the LED display. She shared different uses of the engineered tool from how to manage the water temperature in a fish tank to investigating how certain weather conditions impact temperature. Throughout the design process, Beth considered potential uses of the tool and what would be feasible for children. She wrote in the design report: "[I] searched for a project that seemed interesting and doable for young children." In the video included in her design report, Beth explained the relation between input devices (i.e., the temperature sensor) and output. She wrote that debugging and algorithmic thinking were salient CT components she engaged in as she was building the thermometer. Beth's Micro:bit design project illustrated how she engaged in coding, algorithmic thinking, and debugging to create a tool that can be used in solving problems, such as managing the water temperature in a fish tank.

We propose that Beth's experiences across the semester drove her shift from thinking about stand-alone coding activity "to make [a] sprite do something" (CT Response 1) to using a micro controller to solve an everyday problem such as knowing when to water the plants, via engineering a soil humidity sensor (CT Response 2). Our analysis of Beth's case suggests that through her first-hand experiences in engineering design, she recognized that CT can be helpful in solving engineering problems people face such as designing a stable truss bridge or building a device to manage the water temperature in a fish tank. In other words, Beth began to position CT and engineering practices as mutually reflexive. Beth's rationale for CT shifted from "learning to code" to "exploring the world around us" and she was able to contextualize instances of CT into problems and solutions in science and engineering contexts, with imagined users and human implications.

Theme 2: Fostering sensemaking requires contextualization and consideration of uses

Theme 2 concerns contrasting cases of Tiffany and Abby, both of whom planned to become early childhood/elementary educators. Tiffany was in the third semester of her studies, and Abby was in her second semester. Neither student had any prior experience with coding or physical computing. We contrast their work to illustrate the importance of designing for imagined uses and users.

Drawings analysis: Tiffany and Abby

Tiffany's responses in the CT drawing tasks stayed in the realms of posterizing (Windshitl & Thompson, 2013) a scientific concept and a technocentric framing of CT (Sengupta et al., 2021). In CT Response 1 (Figure 2), Tiffany drew an image of a student creating a model of an animal cell. She explained that this activity involves CT since the student uses *abstraction* to minimize "the complexity of the cell to show the key elements of what she is learning." Tiffany wrote that this activity supports students to have "a good representation of what a cell looks like" by making the model of the cell "bigger and more simple." The model does not offer any further exploration of the cell but rather a bigger and simpler representation of it. In CT Response 2 (Figure 2), Tiffany drew an image of a student working on a block-based coding software to program a robot and wrote that activity involves *automation* because students are "programming a robot to pick up and put down a block on its own." Tiffany's emphasis on programming became the primary goal of the learning activity, emphasizing "inviting [kids] to explore coding" and students' opportunities to "program many different codes..." Tiffany's CT Response 2 was therefore representative of a technocentric framing of CT since programming is at the center of the activity as she emphasized the learning goal is "exploring coding".

In contrast to Tiffany's drawings, Abby's drawings increased in their connectedness among CT and epistemic goals in engineering. In CT Response 1, Abby drew an image of two students testing if/how surface area and mass impact travel duration during free fall (see Figure 2). To Abby this activity involved *pattern recognition*—a component of the CT—since students "compare different types of materials and guess which will fall at a slower speed." In CT Response 2, Abby drew an image of "two students working on trying to figure out why this circuit is not lighting both of the light bulbs" (see Figure 2). To Abby, this activity involved debugging; she stated students will "not only need to figure out how to light the bulb but in the process, they need to figure out why." Abby wrote that the activity supports learning since "debugging pushed students to a deeper understanding of a [electricity] concept."

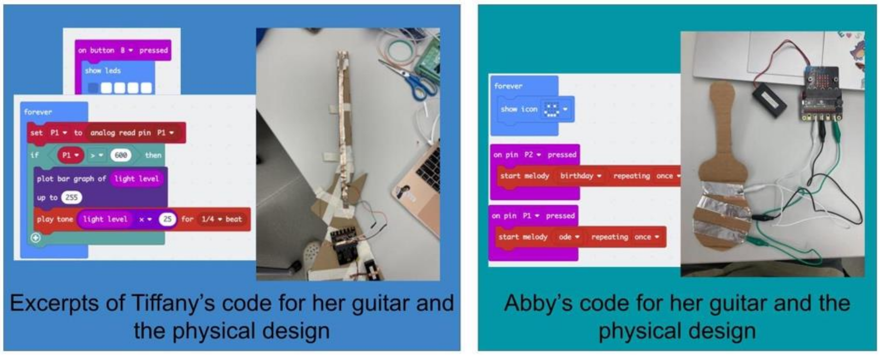
Abby's CT Response 1 and 2 were similar in the sense that both activities pursue disciplinary learning goals. However, we observe an important nuance between these two: In Abby's first response, CT was used towards gaining declarative knowledge about the relationships among mass, surface area and duration of travel. In the second response, CT was used to solve a problem in engineering design and explore electricity concepts (e.g., conductivity and polarity). In this sense, we identify an epistemically richer use of CT in the second response.

Developmental analysis: Tiffany and Abby

In order to better understand Tiffany's experiences across the semester, we examined her other assignments. In the Micro:bit design project, Tiffany found online instructions for an air guitar and selected this project. In the original project, the Micro:bit air guitar would play a different melody when different buttons on the Micro:bit were pressed. The code—freely downloadable as part of the project —specified the light level variable to control the pitch of the melody when pin 1 (P1) is pressed (see Figure 3 for the code). In her written work, Tiffany barely explained how the air guitar works. While she did specify have a use case (a music class), her explanation failed to demonstrate a worked-out relationship between the functionality of her project and the contexts in which it could be used: "My project was supposed to play different songs depending on the amount of light it receives" and she added that it "can be used to teach students in a music class about different notes and how to play songs."

Figure 3

Code and Physical Setup for Tiffany's (left) and Abby's (right) Micro:bit Air Guitar



```
on button B ▾ pressed
    show leds

forever
    set P1 ▾ to analog read pin P1 ▾
    if P1 ▾ > ▾ 600 then
        plot bar graph of light level
        up to 255
        play tone light level x ▾ 25 for 1/4 ▾ beat
```

Excerpts of Tiffany's code for her guitar and the physical design

```
forever
    show icon ▾

on pin P2 ▾ pressed
    start melody birthday ▾ repeating once ▾

on pin P1 ▾ pressed
    start melody ode ▾ repeating once ▾
```

Abby's code for her guitar and the physical design

As Tiffany worked on her project, we observed that she did not attend to the ways that inputs (e.g., when a button or pin is pressed) and outputs (e.g., playing music) were associated within the code. As she wrote, "When I first tested my project, it didn't play the songs it was supposed to play, unless I pressed one of the buttons on the Micro:bit." The Micro:bit code could have been slightly altered to meet her desired goal, that is, playing something without pressing any button or pin. Instead, Tiffany made changes to the physical guitar by permanently connecting P1 to the GND pin so that the circuit is closed, and as a result P1 is continuously stimulated without any input (see Figure 3). In the design report she wrote, "After trying a couple of different things, I was able to improve my project a little bit so that it would play a song without a button being pressed." She did not report that she tried adjusting the code in any way toward meeting her desired design goals. We observe that the code was isolated from the design process and stood by itself as a "received" and immutable object, and therefore, it was an end in itself, rather than a means for meeting disciplinary goals. We propose that Tiffany's experience of the code for the air guitar contributed to her technocentric stance, and her perception of the code blocks as a received and unchangeable object, rather than an understanding of code as language to accomplish desired design goals. Rather than working on her physical design in tandem with the code, she hacked the physical mechanism of the guitar to overcome the challenges in her code.

We contrast Tiffany's work with Abby. In the Micro:bit design project, similar to Tiffany, Abby also designed a Micro:bit guitar. Abby's guitar was coded and set up to play a different melody depending on the pin pressed (see Figure 3). She faced challenges knowing when her code had been sent to the microcontroller, so she adapted the code to show an icon on the Micro:bit display as a means of confirming it was running the code (Figure 3). In the project report, Abby explained how the user can use the guitar: "When placing a finger on 1 piece of foil connected with either pin 1 or 2 and then another finger on the foil connected to the GND pin, you complete an electrical circuit by letting a small electric current pass through you." She continued her guidelines by explaining the interplay between the circuitry and the code: "This triggers the code on the Micro:bit and starts playing a song." Abby also shared a detailed explanation of the context of use: "This touch sensitive project can teach students about external inputs and how to complete an electrical circuit by using touch inputs and [the] GND pin."

How could teacher educators help Tiffany and others in similar positions? Although both Abby and Tiffany were asked for a detailed description of the engineered tool and the context they imagined it being used, the ways they answer the question were quite different. Tiffany broadly wrote about how the designed tool works without addressing how the parts (code, pins, circuitry) interact with each other and wrote that the project could have been used in a music class. In contrast, Abby gave an elaborate description, intended for a user, explaining what kind of user input creates a desired output and why. Abby also explained the imagined context for the tool thoroughly. We propose that the difference between these cases is partially explained through considering the degree to which Tiffany and Abby were able to contextualize the engineering goals in meaningful contexts, and the role of engineering design as addressive (Bahktin, 1986) for whom the designs are for. Abby's detailed description of the tool for the user, and her addition of features may shape her understanding of the interplay between input, the code, circuitry, and the output. Knowing the relationship among these components, Abby recognized how her production and modification of code, as well as the physical inputs can be altered to meet her design goals. In other words, she recognized how CT can be leveraged to solve an engineering problem. Overall, Abby's case illustrated how CT (for example, debugging a circuit in her CT Response 2) can become a sensemaking practice to generate a solution to an engineering design problem with attention to users' experience of the tool, unlike Tiffany, who took the code's role to be immutable in her own work and the ultimate end goal of the activity in CT Response 2.

Discussion and contributions

We have demonstrated how PSTs learned to participate in CT as practices *in service of* science and engineering goals. Our analysis indicated an important shift in the way in which participants talk about CT in contexts of teaching and learning. Their initial foci were on technocentric learning activities and "posterizing" (Windshitl & Thompson, 2013) what is already learned, and their end-of-semester responses described activities in which CT is positioned as a sensemaking practice in science learning and engineering design. For 16 students, their final CT responses revealed enactments of CT that serve epistemic goals in contexts of engineering design and scientific inquiry. Our findings contribute to a more worked out understanding of how teachers frame disciplinary learning in relation to CT, a need noted by existing research (e.g., Mouza et al., 2017; Walton et al., 2020). We argue that moving to a more contextualized and reflexive understanding of CT as a sensemaking practice at the university level can support teachers to integrate CT into their future pedagogy, rather than perpetuating technocentric goals. This framing of CT is complementary to a pedagogical emphasis on scientific and engineering practices and ameliorates perceptions of CT as an extra teaching burden on top of science and engineering content.

When CT practices are routinely positioned as ways that PSTs figure things out in an undergraduate course, the PSTs adopted a more epistemically oriented view of CT practices in their pedagogy. Our microgenetic approach focused on how the learning environment mediated the shift from technocentric and isolated framings of CT to more contextualized and epistemically embedded framings: Beth's case illustrated how one PST's learning about CT became reflexive with her own undergraduate-level experiences in engineering design over the course of the semester. This is important since even though scholars have long acknowledged the overlap between CT and engineering design (e.g., Nersessian, 2008; NRC, 2010), supporting PSTs' understanding of CT in engineering design is largely underexplored. The second theme illustrated how contextualization, especially addressivity in engineering design, supported sensemaking. Tiffany and Abby's contrasting cases showed that the PSTs' imaginings of a user and a use context of their designs are intricately connected to their understanding of the relationships among components of computational artifacts.

Our study illustrated the deeply intertwined relationships between sensemaking practices and addressivity in contexts of CT and engineering. We extended prior arguments about dialogism in design (Sengupta et al., 2021) to demonstrate the affordances of learners' attention to real or imagined users in the context of pre-service teacher education. This process of contextualization generates a more dialogic approach to engineering, overcoming the tendency of technocentrism in CT-engineering design activities, such as the Micro:bit work we share here. We illustrated how the epistemic work of making sense of the relationships among code, microcontrollers, and the physical inputs and outputs was supported by imagining *how* the tools would be used. We argue that recognizing the interrelation among computing and other components of design, including physical inputs and outputs through the addressivity in design processes supports a more nuanced understanding of how CT can be leveraged in engineering design. This shift results in a deeper conceptualization of CT as a sensemaking practice of engineering, as evidenced in CT Responses 1 and 2. Our paper is a step toward understanding how to make the connections between computing and engineering design meaningfully present in the lived experience of PSTs, thereby positioning CT practices as closely connected to disciplinary learning goals in engineering and science, and helping to re-orient conceptions of preservice teachers' computing work towards a more humanistic stance focused on the users of technological artifacts.

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Designing for Equity: Moving Project-Based Learning From Equity Adjacent to Equity Infused

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Abstract: Project-based learning (PBL) is an inquiry-based approach that aims to engage students in challenging, active, and meaningful experiences connected to the world outside the classroom. However, PBL's student-centered approach has not always explicitly focused on educational equity. The goal of this paper is to provide a PBL curriculum design framework that goes beyond creating engaging curriculum to providing experiences that are equitable, relevant, and meaningful to each and every student, while supporting students' learning and identity development. To do so, we examined recent PBL curricula and related literature to identify the PBL design features leading to impactful and equitable year-long K-12 curriculum. We present cross-cutting PBL curriculum design principles and lenses to interpret design principles.

Major issues addressed

Given the learner-centered focus of Project-based Learning (PBL), it has always been uniquely positioned to advance educational equity; however, PBL has not always been explicitly part of the pedagogical approach in schools (Tierney, Urban, Olabuenaga, & Paulger, 2022). This paper presents a design framework for designing equitable PBL curricula that engages each and every student in meaningful learning experiences that are relevant to the world beyond the classroom, affirm and sustain all students' identities, and focus on the development of the whole child.

PBL is an inquiry-based approach that aims to engage students in challenging, active, and meaningful experiences connected to the world outside the classroom (Barron & Darling-Hammond, 2008; Krajcik & Blumenfeld, 2006; Tierney et al., 2020). The goal of education is not solely to prepare students to pass a test but to foster learning in a way that is transferable to their personal, cultural, academic, professional, and civic lives. PBL encourages students to develop the skills and understanding needed for the long-term retention and application of what they have learned (Strobel & van Barneveld, 2009). Importantly, this goal of deeper learning attends to the application of content knowledge and problem solving as well as the inter- and intrapersonal domains – which include communication and collaboration skills – and metacognition and learning to learn (National Research Council, 2012). Further, focusing on deeper learning means challenging students to take ownership of their work, engage in rigorous content, and develop skills and ideas that will have a positive impact on many areas of their future lives (National Research Council, 2012).

Project-based learning can improve student performance on traditional measures of academic achievement, build social and emotional learning skills, and engage students in deeper learning. This form of engagement focuses on higher-order thinking and skills that will help students succeed in college, their future careers, and their lives as active members of their communities. The alignment of PBL and deeper learning is supported by a growing body of evidence that PBL has a significant positive impact on student learning and other outcomes associated with deeper learning (Boardman et al., 2021; Deutscher et al., 2021; Duke et al., 2021; Krajcik & Schneider, 2021; Saavedra et al., 2022; Tierney et al., 2020). Further, this paper also seeks to more closely examine the link between the design of PBL curriculum and educational equity.

The persistent achievement gap between groups of students in the U.S. shines a light on the need to create deeper-learning experiences for all students. Ladson-Billings (2006) reframes the achievement gap, focusing instead on the educational debt that has accumulated from decades of inequitable education for those in historically marginalized groups, such as students of color, economically disadvantaged students, and multilingual learners. In her call to action, which is all the more relevant today, Ladson-Billings argues that the societal disparities, both historic and current, require that we, as part of the education system, use our expertise to alleviate these inequities. To truly address the educational debt, equity must be an explicit priority in the design of classroom experiences and throughout the education system (Paris & Alim, 2017).

The goals of PBL, therefore, go beyond deeper learning to providing experiences that are equitable, relevant, and meaningful to each and every student while supporting the development of not only students' academic learning, but also their social, emotional, and identity development. For this paper, we refer to this as a whole-child approach, acknowledges that supporting learning is dependent on the multidimensionality of a student's life. This means teaching and learning must focus on academic and cognitive development alongside social, emotional, and identity development. Given the learner-centered focus of PBL, it has always been uniquely positioned to advance whole-child development and educational equity; however, PBL curriculum has varied in how explicit, in design, the focus on equity has been and who has had access to PBL curriculum in public education (Deutscher et al, 2021).

In developing equitable PBL curricula, it is important to understand the principles that guide the design of PBL curriculum. A number of frameworks that define PBL (Condliffe et al., 2017) have informed the design of PBL curricula over the years. One of the challenges of designing PBL curriculum is the many choices that need to be made, not just about curricular content, but also the roles of students and the connections to the world outside of the classroom. These choices necessitate curricular design principles to guide the many choices that need to be made. Design principles have long been used in curriculum design to help guide curriculum designers as they make choices on the structure, content, assessments, and the roles of learners within the curriculum (Fishman, Penuel, Allen, Cheng, & Sabelli, 2013; Reiser, Novak, McGill, & Penuel, 2021; Tierney et al., 2020).

While there exists previous valuable work that has documented PBL curriculum design, and specifically PBL design principles (Krajcik & Blumenfeld, 2006), this work is often targeted to individual teachers who are designing their own projects, tends to focus on the principles of designing a single project, and predates recent PBL research on rigorous PBL positively impacting student outcomes and learning, specifically focused on year-long K-12 PBL curriculum (Boardman et al., 2021; Duke et al., 2021; Deutscher et al., 2021; Krajcik & Schneider, 2021; Saavedra et al., 2022; Tierney et al., 2020). This paper seeks to examine this recent body of literature to identify the PBL design principles leading to such impactful year-long K-12 curriculum. In order to bring clarity and coherence to the important work of developing high quality PBL curricula and increase their prevalence, this paper seeks to define a set of features and criteria to aid in the development of and analysis of yearlong PBL curricula.

We write this paper with the perspective that PBL, in its design and implementation, is at an inflection point. Here we can simultaneously recognize the impressive learner-centered work that has occurred thus far in PBL writ large and specifically PBL curriculum work, while also elevating learner's cultures and educational equity as a more explicit feature of PBL moving forward. High-quality PBL curricula, alongside sustained professional learning, supports larger-scale shifts in educational systems (Condliffe et al., 2017). Carefully designed curriculum materials that embody PBL with equity at its core can support teachers in providing students with deep and equitable learning experiences. In this paper we explore the following research questions: 1) What educational commitments and theoretical lenses can support the creation of equitable PBL curricula? 2) What PBL design principles lead to positive student outcomes and learning?

Potential significance

This paper describes the key Design Principles and Critical Lenses required to develop project-based learning curricula. These principles, divided into three categories, describe PBL curricula that have (1) learner-centered approaches to support purposeful, authentic learning that values students' voices and encourages collaboration and reflection; (2) course structures that deeply integrate coherent and authentically assessed content in projects; and (3) curriculum supports for students and teachers to enable the deep learning and practice shifts needed.

While Design Principles provide guidance for curriculum design, developers can often interpret and enact the Design Principles in a variety of ways. Therefore, the Critical Lenses align the pedagogical commitments needed to interpret the principles in a way that promotes the goal of equitable, deeper learning that attends to the development of the whole child. Designers should consider the perspectives they use as they design a curriculum for deeper learning and equitable development of the whole child. The perspectives designers use become operationalized in the developed curriculum, influencing the ways teachers implement the curriculum and, therefore, what students will experience in the classroom. To help illustrate this idea, imagine a photojournalist tasked with capturing an event. The intended audience, the photojournalist's personal style and perspective, and the context of the event all shape both the content and composition of the end results. This is similar to the work of curriculum designers, whose experiences, values, and pedagogical knowledge all influence – intentionally or not – the curriculum they create. In this paper, we present the Critical Lenses to support designers as they interrogate their process and approach in PBL design, helping designers become more purposeful in designing for educational equity.

Creating a PBL curriculum that perfectly captures all aspects of each Design Principle and Critical Lens is challenging, especially when developers must also take into account specific priorities and contexts for their curriculum. For example, while the principles as described here have strong evidence that they are effective in science, English language arts, and social studies classrooms, it may be that PBL in a mathematics classroom would require somewhat different interpretations of the principles. However, regardless of its contexts, a curriculum that prioritizes deeper learning and equity must draw on all the principles and lenses as they encompass pedagogical best practices and draw on evidence of how students learn.

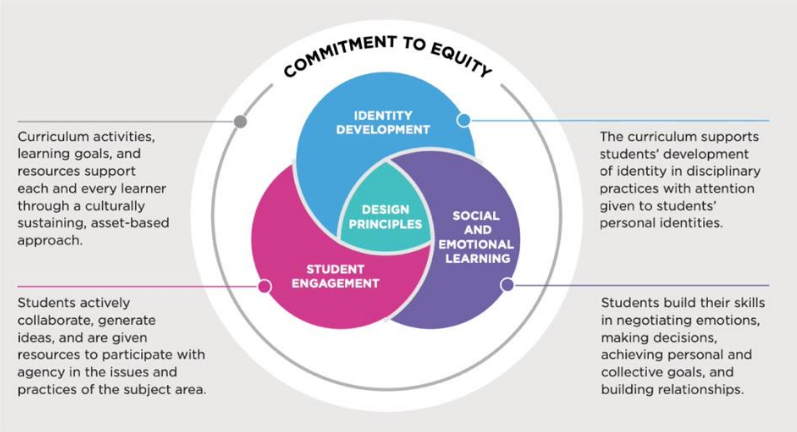
Designing a curriculum that embodies equity and deeper learning requires designers to push on the traditional structures of education. Indeed, one motivator for designing PBL curricula is large-scale systems change. For example, while curriculum designers may not have the power to change required content standards, they may push beyond standards by prioritizing deeper learning and whole-child development and by deemphasizing standards that are problematic and perpetuate historic inequities. We hope this paper ensures that regardless of who the curriculum designers are or their specific context for writing, there will be a shared understanding about the goals of creating PBL curricula that supports the development of all students and provides equitable experiences in deeper learning.

Theoretical perspectives

Creating a PBL curriculum that allows for deep and equitable learning is a complex and challenging task. Our theoretical framework for this paper acts both as lenses from which we identified and examined PBL design principles, but also, we believe, lenses for researchers, designers, and practitioners to enact PBL design principles. Regarding the latter use, while design principles embody values, they can still be interpreted in numerous ways. This matters deeply when seeking educational equity. The intent that is applied to design principles makes or breaks the extent to which the principles work in the service of educational equity or not. For example, a design principle focused on student agency (broadly, students' ownership of and engagement in their learning – a more specific definition is offered later in the paper) can be interpreted and used to promote student-centered curriculum but may not support the creation of equity-centered curriculum. In this way we name the theoretical framework of this paper as critical lenses to be used to interpret PBL design principles, ensuring that all students are valued, engaged, and included. These commitments provide a frame through which curriculum developers can interpret the Design Principles to ensure they are not producing or reinforcing inequities. We name these pedagogical commitments as Critical Lenses both for their essential place in design and to denote the role of critique in curriculum design.

The four Critical Lenses that make up our theoretical framework for this paper are: Commitment to Equity, Identity Development, Student Engagement, and Social and Emotional Learning (Figure 1).

Figure 1
Relationship of Four Critical Lenses for PBL Design



Curriculum activities, learning goals, and resources support each and every learner through a culturally sustaining, asset-based approach.

The curriculum supports students' development of identity in disciplinary practices with attention given to students' personal identities.

Students actively collaborate, generate ideas, and are given resources to participate with agency in the issues and practices of the subject area.

Students build their skills in negotiating emotions, making decisions, achieving personal and collective goals, and building relationships.

These interconnected concepts and pedagogies support the development of the whole child, and we present them as a set of pedagogical commitments curriculum developers should use to create a PBL curriculum that represents the valued outcomes of the PBL approach. As illustrated in Figure 1, all of these lenses overlap and come together to define how to enact the Design Principles in curricula, while Commitment to Equity also encompasses the other three, representing the constant eye toward equity that should occur in PBL design.

Identity development refers to the process of people understanding who they are as they participate in the world. This process, which is ongoing as an individual changes over time, is not solely internal but also embedded in social interactions that are influenced by societal norms, stereotypes, and power relationships (Holland et al., 1998). *Student Engagement* refers to the multifaceted way in which students interact with their learning environment, including how they participate, react emotionally, and invest in their learning and school community (Fredricks et al., 2004). Engagement can be defined at multiple levels, from moment-to-moment interactions with ideas and peers to involvement with school and subject areas across classes and academic years. *Social and emotional learning (SEL)* is the process of negotiating emotions, making decisions, navigating challenges, expressing empathy, achieving personal and collective goals, and establishing and maintaining relationships (Jagers et al., 2019). Finally, *Equity-committed design* calls upon curriculum designers, as well as teachers and the broader educational system, to embrace and enact a series of anti-oppressive, culturally sustaining, and asset-based approaches that center on students, their identities, and their experience (Gay, 2018; González et al., 2005; Paris & Alim, 2017). These equity-committed approaches in PBL design include but are not limited to: instructional approaches supported through curriculum, curricular content, and the selection of valued skills and dispositions embodied in the curriculum.

Within the broader scope of equity-committed design, we include a number of approaches: culturally sustaining/revitalizing pedagogy (Paris & Alim, 2017), culturally responsive pedagogy (Ladson-Billings, 1994), funds of knowledge (González et al., 2005), historically responsive framework (Muhammad, 2020), culturally responsive teaching (Gay, 2018; Hammond, 2015), Indigenous and land-based perspectives (Bang et al., 2014; Barajas-López & Bang, 2018), and culturally and linguistically relevant pedagogy (Hollie, 2011). Valuing, amplifying, and celebrating students' identities and backgrounds are central to all these approaches. These include, but are not limited to, students' racial, cultural, historical, linguistic, gender, ability/disability, community, and family identities and backgrounds.

Methodological approaches & data sources

This paper is a mixture of curriculum review and a review of related literature and theory. We first analyzed a subset of PBL curricula focused on year-long K-12 curricula that showed positive impacts on student outcomes and learning, then turned to the educational theories and literature that informed the relevant design principles. We then iterated on this process to identify design principles, critical lenses, and approaches to design. For the purposes of this paper, which is focused on design of course-long K-12 curricula, we pulled data as well as design principles and frameworks from five courses where the entire course was built around PBL (Table 1). These courses have a strong body of evidence demonstrating significant outcomes on both student learning as well as other positive student measures across income (Boardman et al., 2021; Duke et al., 2021; Deutscher et al., 2021; Krajcik & Schneider, 2021; Saavedra et al., 2022; Tierney et al., 2020).

Table 1
Design Principles Course-long K-12 PBL Curriculum

Knowledge in Action	*AP U.S. Government and Politics and AP Environmental Science courses—Two Advanced Placement courses for high schoolers co-designed by researchers at the University of Washington and high school teachers (Lo & Tierney, 2017; Nolen, Wetzstein, & Goodell, 2020; Parker et al., 2011, 2013; Saavedra et al., 2022; Tierney et al., 2020).*
Multiple Literacies in Project-Based Learning	*Science courses for third, fourth, and fifth graders that integrate math and English language arts designed by researchers at Michigan State University and the University of Michigan (Krajcik & Schneider, 2021; Miller & Krajcik, 2019).*
Compose Our World	*Ninth-grade English language arts course developed by researchers at the University of Colorado at Boulder (Boardman et al. 2021; Garcia et al., 2020; Polman et al., 2018).*
Project PLACE	*A Project Approach to Literacy and Civic Engagement—Second-grade curriculum integrating social studies and literacy developed by researchers at the University of Michigan and Michigan State University (Duke et al., 2021; Halvorsen et al., 2012).*
Learning Through Performance	*A yearlong science course for sixth graders developed by researchers at Stanford University (Deutscher et al., 2021; Holthuis et al., 2018).*

To identify the collection of principles for this paper, we looked at these aforementioned year-long K-12 PBL curricula and identified principles that repeatedly occurred or were particularly important to aligning fully with the theoretical framework/ critical lenses described earlier in the paper and achieving equitable learning for each and every student. From there, we explored related literature referenced by the PBL curriculum projects as central to the design principles used in the curriculum design. In the curriculum review, we explored the nuanced differences of how the common features of PBL were represented in each curricula creating a set of the design principles that applied writ large. An example of this is Content Coherence, a design feature of all the curricula we examined and one of our design principles. To further refine our collection of design principles and their definitions, we reviewed literature from both project-based practices and cognitive psychology as it relates to how people learn. This allowed us to both strengthen the case for principles identified in the curriculum review and raise up minor or yet-to-be included aspects of the principles. Oftentimes, principles were identified and their definitions refined because of their important role in advancing educational equity. An example of this type of design principle includes the authenticity of projects. While authenticity exists in all of the reviewed PBL curriculum, the implementation of it with the expressed purpose of lifting up students' context, identities, and communities changes the definition of the principle. For each of the design principles, we will define the characteristics, describe related seminal publications, and highlight the ways that the design principle supports this type of learning and engagement across multiple disciplines and grades.

Major findings

Design principles are often used as a tool to help curriculum designers organize and center qualities they would like the developed curriculum to embody. In PBL, design principles have been used to emphasize aspects such as student agency, authenticity, and collaboration (Tierney et al., 2020; Tierney, Urban, Olabuenaga, Paulger, 2022). We describe a set of Design Principles that can support the creation of content-rich, student-centered experiences. The Design Principles presented in this paper fall into three categories: 1) Learner-Centered Approaches, 2) Course Structures, and 3) Curriculum Supports (Table 2). The order in which we present these categories does not imply a sequence to the design process, nor does it suggest levels of priority. In addition, while we present each principle as a distinct idea, there is a significant amount of overlap between them.

We begin with the *Learner-Centered Approaches*, which focus on how students experience the curriculum. Project-based learning that attends to the development of the whole child and deeper learning places students at the center of learning in ways that value and build upon what students know, the skills they have, and what they care about. The principles in this first category answer these questions: "How do students engage with the project and their learning?" and "How do learners experience the project and course?" The Design Principles in this category support the development of PBL curricula that are authentic to students and integrate the Critical Lenses. These principles attend to engagement, connect to students' lives, value student voice, allow students to develop fundamental cognitive skills, generate understanding collaboratively, promote independence, and support success in college, career, and life.

The second category, *Course Structures*, contains principles concerning the scope and sequence of the content and supporting a coherent learning experience. While the previous category applies to how students experience individual projects, here we address what happens at the course level. This category of PBL Design Principles answers the question, "How are the course content and skills chosen, designed, and organized?" The principles outlined in this section are essential for a tightly designed PBL curricula that attends to how content is approached and organized across projects in the course (i.e., the scope and sequence of content, as well as the structure of each project) and integrates the ideas of the Critical Lenses.

The last category, *Curriculum Supports*, includes principles that help students and teachers navigate the course and their learning. Teaching PBL is complex. It involves deep content-area expertise, pedagogical knowledge, and a commitment to equity, which requires supportive curriculum materials. Similarly, students need supports and structures embedded in curriculum materials. This final category of PBL Design Principles answers the question, "How do the materials support teachers and students?" While the other principles can describe the experience of PBL in the classroom more broadly and independently of curriculum materials, these final two principles are unique to curriculum design.

Table 2
Design Principles for PBL Curriculum

Principle	**Short Description**	**Key Literature**
Learner-Centered	**How do students engage with the project and their learning? How do learners experience the project and course?**	
Purpose for Learning	Projects provide students with a reason for learning by engaging them in experiences that connect their own ideas to the project's problem or question before deeply exploring the content.	Parker et al., 2011; Schwartz & Bransford, 1998
Authenticity	Projects are relevant to students' lives, families, and communities and connect to the world outside the classroom, especially to tasks, roles, and practices of the discipline.	Krajcik & Blumenfeld, 2006; Parker et al., 2013; Polman et al., 2018

Student Agency	The course design allows students to make substantive and consequential choices in their projects as well as to apply the work and learning to their daily lives.	Calabrese Barton & Tan, 2010; Nasir & Hand, 2008; Tierney et al., 2020
Collaboration	Throughout projects, students work together on problems in purposeful and supported ways and create a community of active learners that includes students and their teacher.	Barron & Darling-Hammond, 2008; Blumenfeld, et al, 1996
Metacognition	Students have opportunities to build and use metacognitive skills to reflect on what and how they have learned, including disciplinary ideas as well as other skills and practices.	Fusco & Fountain, 1992; McCormick, et al. 2012
Course Structures	**How are the course content and skills chosen, designed, and organized?**	
Centrality of Projects	The projects are integral to learning by framing the entire process of and purpose for learning. A PBL course embeds all content in projects.	Condliffe et al., 2017; Parker et al., 2011
Integration of Rigorous Content	The curriculum integrates projects with core disciplinary ideas and practices. It also specifies learning goals aligned with standards as well as other essential content, such as literacy, social and emotional learning, and equity.	Krajcik & Shin, 2014 Parker et al., 2013
Coherent and Purposeful Content	The content of a PBL course is strategically sequenced to deepen understanding as students' progress through the course, revisiting and connecting ideas across projects.	Parker et al., 2013; Schwartz & Bransford, 1998
Assessment	The curriculum provides ongoing opportunities for assessing learning of disciplinary, social and emotional, and other essential skills and ideas that are performance based and authentically embedded in the work students are doing.	Parker et al., 2013; Taylor & Nolan, 2008
Curricular Supports	**How do the materials support the teachers and students?**	
Curricular Supports for Student Learning	The curriculum provides appropriate scaffolds and tools to support learning, with access points for all students, including explicit framing for lessons, scaffolds for disciplinary and social and emotional learning, and multimodal content.	Engle, 2006; Engle et al., 2012; Puntambekar & Hubscher, 2005
Curricular Supports for Teacher Learning	The curriculum materials support teachers in deepening their disciplinary, pedagogical, and equity understanding in ways that embed the resources in a teacher's daily practice and allow teachers to effectively adapt to their own contexts and students.	Davis et al., 2017; Nolen, Wetzstein, & Goodell, 2020

In order to move PBL from equity adjacent to equity infused, we argue that it is not enough to simply add equity as another design principle. Instead, we highlight pedagogical commitments, or Critical Lenses, for designers to consider to ensure that all students are valued, engaged, and included. These commitments provide a frame through which curriculum developers can interpret the Design Principles to ensure they are not producing or reinforcing inequities. The four Critical Lenses presented in this paper include: Commitment to Equity, Identity Development, Student Engagement, and Social and Emotional Learning. All of these lenses overlap and come together to define how to enact the Design Principles in curricula, while Commitment to Equity also encompasses the other three, representing the constant eye toward equity that should occur in PBL design.

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Professional Development of Teachers in Online Contexts: Differences in Learning Engagement and Relevance of Achievement Goals

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Abstract: University teachers are required to learn and improve their teaching competencies for their own development and to facilitate successful learning experiences for students. Online professional development courses represent an important learning opportunity for this, yet teachers differ in how well they learn from them. We investigated whether teachers' motivations and engagement explain these differences. Using an achievement goal approach, we assessed mastery goals (task and learning goals), as well as performance approach and avoidance goals. We developed an online course on pedagogical-psychological informed teaching and 67 university teachers completed assessments of their goals before the course, a knowledge test at the beginning and end of the course, and their implementation intentions after the course. Through learning analytics, we modelled learning engagement based on 8 indicators concerning usage of different course elements. Structural equation modelling showed that task goals were beneficial for learning engagement, and consequently, implementation intentions.

Introduction

University teachers are required to continuously learn and improve their teaching competencies to meet evolving educational demands and equip students with knowledge and skills needed to compete in today's job market. Professional learning opportunities play a crucial role in facilitating effective teaching; however, they also require persistent motivation (Shulman & Shulman, 2009). In terms of delivery formats, online professional learning courses have gained prominence as a central means of university teachers' professional development (Castro & Tumibay, 2021; Wynants & Dennis, 2018). Research indicates challenges in online learning, including lower completion and participation rates (Ng, 2016; Simpson, 2013; Wynants & Dennis, 2018). Thus, gaining a better understanding of the factors that contribute to university teachers' engagement and learning in online courses represents an important research direction (see also Liu et al., 2009).

Online professional development courses differ from face-to-face formats in terms of the nature of interactions, supplementary information availability, and non-linear design of the learning experience (Dettori et al., 2006). Moreover, participants often have more autonomy in online contexts, and as such, require increased self-regulation for effective learning (Azevedo & Cromley, 2004). Participants can therefore be expected to differ in how they learn in online courses, where personal characteristics, such as their motivations in the form of their achievement goals, might play an important role (Daumiller et al., 2022). Due to systematic differences, previous findings on face-to-face learning contexts cannot be readily transferred to online contexts, warranting further investigation. Exploring online learning contexts offers the opportunity to objectively analyze participants' engagement, as opposed to relying solely on self-report measures (see Daumiller et al., 2021). Specifically, using learning analytics, the medium of learning in online courses can be leveraged to objectively assess differences in learning engagement and associations with initial motivations and post-course learning gains. This can shed light on the relationship between teachers' engagement in online professional development, its impact on learning outcomes, and how teachers' motivations can enhance effective online learning.

Teachers' professional learning and relevance of their achievement goals

Teachers' professional learning encompasses continuous educational experiences tailored to enhance their teaching practices and outcomes. This process spans diverse forms, methods, and structures (Desimone, 2011), with professional learning courses emerging as a pivotal avenue. While limited research has addressed the topic of learning in online courses among university teachers, the significance of teacher professional learning for teaching engagement, practices, and student learning outcomes is well-established (Shulman & Shulman, 2009). Notably, increased financial investments and regulatory changes fail to consistently yield anticipated benefits for teacher practice and student learning (Hill et al., 2013). Consequently, it is necessary to identify ways to support teachers in their professional development.

Fullan and Hargreaves (2012) emphasize that professional learning is about aiding teachers in self-directed growth; it respects individual goals, not external demands. Teachers enter professional learning courses as self-directed learners, bringing with them individual goals and learning expectations (Tannehill, 2016). Furthermore, professional learning opportunities, especially in online course formats, are characterized by high autonomy and self-initiative. Thus, focusing on teachers' motivations represents a meaningful approach to understanding what drives them to engage in professional learning.

We draw on Achievement Goal Theory to characterize teachers' motivations and explain interindividual learning differences. Achievement goals constitute cognitive representations of end-states that individuals seek to approach or avoid in achievement settings (Elliot & Hulleman, 2017). This theory has been successfully used to describe teacher motivation, linking different goals to affective, cognitive, and behavioral patterns. Although achievement goals have been associated with differences in teachers' professional learning, this research is limited, with learning having been operationalized by loosely-connected aspects, such as attitudes towards helps-seeking (e.g., Butler, 2007), number of attended trainings (e.g., Fritzsche & Daumiller, 2018), number of magazines read (e.g., Nitsche et al., 2013), time spent on professional learning (Hein et al., 2020), and use of feedback (Hein et al., 2021; Kunst et al., 2017). However, few studies have considered differences in learning engagement, which are important for understanding differences in professional development (Daumiller et al., 2021).

Learning engagement in online courses and its relevance for learning gains and implementation intentions

Engagement denotes time and energy invested in purposeful learning activities (Kuh et al., 2005). Higher engagement has been associated with improved learning for students and teachers (Daumiller et al., 2021; Froiland & Worrell, 2016), which can help foster knowledge gains and intentions for knowledge transfer. Online courses offer an opportunity to capture a more reliable understanding of learning engagement and its linkages with motivations and outcomes by use of learning analytics and log data (e.g., views, clicks, posts, scrolls). These objective indicators can measure learners' actions in a more direct, minimally disruptive way, mitigating limitations and biases associated with self-report measures conventional for motivation research.

Numerous studies highlight the value of objective engagement indicators in research on student learning in online courses (Bonafini et al., 2017; de Barba et al., 2016; Pursel et al., 2016). These objective forms of engagement have been linked to diverse learning outcomes, including learning gains (for a summary see Daumiller et al., 2022). This research highlights the benefit of considering engagement as a latent variable to capture the overall psychological engagement construct rather than just individual indicators.

A clear consensus on the usefulness of different objective learning engagement indicators has yet to be reached (Agudo-Peregrina et al., 2014). To obtain comprehensive and reliable insights, simultaneous examination of multiple indicators is essential. Thus, based on the indicators that are commonly reported within studies investigating objective learning engagement in online courses (see Daumiller et al., 2022, for an overview), we measured learning engagement using page and lesson views, clicks on buttons and links, access of supplementary materials, and use of questions and answers.

Achievement goals and learning in online courses

Encompassing "different ways of approaching, engaging in, and responding to achievement situations" (Ames, 1992), achievement goals energize and direct competence-relevant behavior. As such, they should matter for university teachers' learning experiences and behaviors in online courses. Given the dynamic and context-specific nature of motivation, it is important to consider the motivations that teachers hold regarding upcoming courses as opposed to broad motivational characteristics. Instead of studying *why* teachers decide to participate in professional development, we were primarily interested in differences in *how* they are motivated for this learning context.

More specifically, achievement goals are defined as cognitive representations of competence-related end states in achievement contexts that individuals are committed to approach or avoid (Elliot & Hulleman, 2017). Different types of achievement goals with which participants approach an online course can be distinguished (de Barba et al., 2016). These goals are directed at what individuals want to reach at the end of their learning and act as a motivational basis for the interpretation of learning situations and self-regulation therein. Thus, close links with learning engagement and learning outcomes are plausible and have been empirically documented, including linkages with self-regulated learning (e.g., Adesope et al., 2015), learning engagement (Daumiller et al., 2022; Froiland & Worrell, 2016), and academic achievement (Church et al., 2001).

Following Achievement Goal Theory, different types of goals are posited to be relevant in achievement contexts. While further distinctions have been discussed (see Daumiller et al., 2019), at least three fundamental types of goals should be distinguished: mastery, performance approach, and performance avoidance goals (Elliot & Hulleman, 2017), which have been meaningfully linked to differences in learning engagement. Although these linkages are largely based on student populations and may not transfer to online learning, they can still meaningfully inform our expectations regarding how these goals should matter for teachers' engagement in professional training online courses.

Mastery goals are characterized by a focus on task mastery and improvement. They can also be further distinguished (see Daumiller & Zarrinabadi, 2021; Elliot et al., 2011; Hulleman et al., 2010; Korn et al., 2019) depending on whether an individual is oriented towards conducting tasks right (labelled *task goals*) or improving competencies (*learning goals*). Teachers have been found to distinguish between these two goal types (Daumiller et al., 2019; Mascret et al., 2015), where both are proposed to be functional for engaged learning and learning gains, given their focus on increasing competence by acquiring knowledge or skills (Daumiller et al., 2021; Murayama et al., 2012; Payne et al., 2007; Wolters, 2004). Nevertheless, emerging evidence indicates that task and learning goals might operate differently, with task goals enfolding particularly adaptive effects for learning engagement (Daumiller et al., 2022). Task goals might be superior to learning goals, as learning goals might distract learners from covering the full breadth of content to be learned. As the research and practical implications drawn from these findings can differ substantially, further investigations into the different facets of mastery goals are necessary.

Aside from mastery goals, *performance approach goals (1)* entail strivings aimed at wanting to be better than others, while *performance avoidance goals* are focused on avoiding doing worse than others. Combining a favorable approach-orientation with a focus on performance that serves to keep performance efforts channeled toward normative standards, performance approach goals are often linked to high levels of performance (Murayama & Elliot, 2019). However, this might distract from deep learning, as reflected in a meta-analysis by Payne et al. (2007), where no associations with learning gains were found despite increased (adaptive as well as maladaptive) learning processes (e.g., Harackiewicz et al., 2000; Senko & Dawson, 2016). Combining two negative aspects (focus and valence), performance avoidance goals render clearly negative effects, as reflected in increased anxiety, task distraction, and helpless engagement patterns (e.g., Elliot & Church, 1997), reduced learning gains (e.g., Payne et al., 2007), as well as more procrastination, surface processing, and disorganization (e.g., Diseth, 2011; Wolters, 2004). Performance-based goals are still little understood in online learning contexts, where studies have either omitted them altogether (e.g., de Barba et al., 2016), or have not considered them relevant in remote learning contexts due to a lack of contact with peers (Sachs, 2001). More research is needed to determine their significance, especially as concerns about what others do may still be prevalent despite others not actually being present.

The present research

Our study aimed to better understand how teachers differ in their motivations and learning engagement in online courses, and how these differences matter for learning outcomes. Overcoming limitations of past research, we considered university teachers' learning engagement in an online professional learning course using a broad array of objective learning indicators concerning how they interacted with the online course.

Based on this, we aimed to identify differences in participants' learning engagement, analyze how these differences matter for learning outcomes, and study their relationships with achievement goals. To this end, we considered achievement goals by distinguishing task and learning facets of mastery goals and including performance approach and avoidance goals. Based on the presented theoretical notions and prior empirical research, we formulated the following hypotheses:

Hypothesis 1: Learning engagement positively predicts knowledge gains and transfer intentions.

Hypothesis 2: Task and learning goals are positively associated with learning engagement.

Hypothesis 3: Performance avoidance goals are negatively associated with learning engagement.

Given the unclear nature of performance approach goals, we did not formulate a directed hypothesis for this type of goal. Further, we presumed both task and learning goals would result in positive effects but tested for potential differences on an explorative level.

Method

To answer our research questions, we constructed an online course on pedagogical-psychological issues underlying effective teaching (including motivating lessons, feedback from students, different types of learning activities). We offered this course as a professional learning course within the professional development in teaching framework offered by the respective university. Answers of all participants were anonymized using a self-generated codeword. We provide the online course used as an open educational resource and provide all data and code underlying this research in an open repository: https://osf.io/wmb37/.

Participants and procedure

Participants included 67 university teachers (M_{age} = 40), of which 42 were women; 11 had less than 1 year of teaching experience, 13 between one and two years, 13 between two and five years, 12 between five and 10 years, and 16 more than ten years. The most prominently taught subjects included education (12%), psychology (10%), science and engineering (10%), sports (9%), math and statistics (9%), and languages (7%).

The online course contained 3 lessons (including 10, 3, and 9 pages of learning content, respectively), 3 videos, 7 pages of additional information, 16 quizzes, and 3 end-of-lesson assessments. It was constructed based on an earlier online course that we piloted regarding understandability, content relevance, and ease of use. The average time spent on the online course was 71 minutes (*SD* = 34). When accessing the online course for the first time, participants completed a survey assessing their achievement goals and baseline knowledge. During the online course, we measured their learning engagement in the form of log data corresponding to eight different indicators based on views, clicks, and interaction with course materials. Directly after completing the course, participants were required to complete another knowledge test covering the topics within the course to gauge their learning gains, and subsequently rated their intentions to transfer learned content into teaching practice.

Measures

Following the item stem "In this online course…", we measured task approach (4 items; e.g., "my goal is to fulfill the different requirements very well"; internal consistency: McDonalds Omega ω = .94), learning approach (4 items; e.g., "my goal is to expand my knowledge as much as possible."; ω = .89), performance approach (4 items; e.g., "my goal is to be better than the other students."; ω = .88), and performance avoidance (4 items; e.g., "my goal is not to be worse than the other students"; ω = .97) goals using the university teacher motivation achievement goal scale by Daumiller et al. (2019) answered on a scale from 1 (*do not agree at all*) to 8 (*agree completely*).

As indicators of participants' engagement during the course, we used log data concerning (1) total pages viewed, (2) total buttons clicked, (3) total links clicked, (4) amount of clicks within course pages, (5) amount of clicks within supplementary course materials, (6) amount of core lessons accessed, (7) number of answers submitted in quizzes, and (8) amount of additional information accessed. We modeled residual correlations between closely corresponding and partly dependent indicators (e.g., link views with lesson clicks). A CFA confirmed the presumed one-dimensional structure and supported modelling engagement as a latent factor (CFI = .973, TLI = .950, SRMR = .089).

Participants' content knowledge in the course was measured using a self-created multiple-choice test containing 5 questions with 4 answer options each before the start of the course, as well as the same questions along with 9 further, more difficult questions after finishing the course. We subsequently computed the residual change scores between these two knowledge test scores to describe participants' learning gains. Given that the post-test was more difficult than the pre-test, it should be noted that the change scores do not reflect the absolute amount of learning gains for each participant, but rather differences between the participating teachers regarding their learning gains.

Finally, transfer intentions were measured with 5 items slightly adapted from Daumiller et al. (2021), for example, "I will try to integrate the content of this course into my own teaching" (ω = .91). All items were answered to on an 8-point Likert-type scale ranging from 1 (*do not agree at all*) to 5 (*agree completely*).

Analyses

We used structural equation modelling to investigate our research aims: Learning engagement was modelled as a latent variable based on the eight indicators, learning gains and transfer intentions were included as dependent variables, and achievement goals were included as predictors. We estimated the direct effects as standardized partial regression coefficients and obtained indirect effects by combining the specified coefficients for direct effects; their statistical significance was tested with *z*-tests. The model was estimated in R version 4.2.2 (R Core Team, 2022) using the lavaan package version 0.6-12 and MLR as an estimator.

Results

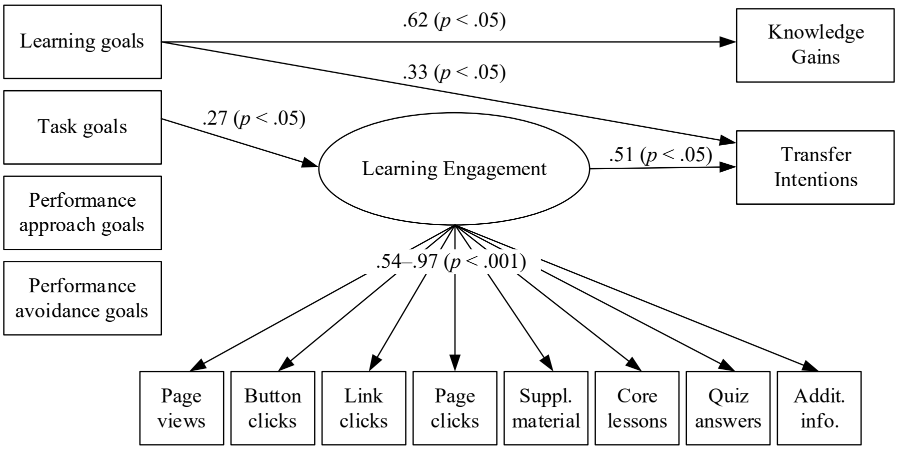
Descriptive statistics and bivariate correlations are presented in Table 1. In line with prior research, we found high levels of task and learning goals and lower levels of performance goals. All goals contained substantial intra-individual variability, indicating that participants started the course with different goal compositions.

Table 1
Descriptive Statistics and Bivariate Correlations

	M	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13
Achievement goals															
[1] Task approach goals	5.48	1.65													
[2] Learning approach goals	7.58	0.56	.43												
[3] Performance approach goals	2.08	1.30	.16	-.01											
[4] Performance avoidance goals	3.20	1.82	.18	-.05	.66										
Learning engagement															
[5] Page views	44.06	27.48	.11	.04	-.22	-.06									
[6] Button clicks	49.16	31.01	.14	-.05	-.19	-.20	.67								
[7] Link clicks	46.70	31.12	-.02	.04	-.29	-.17	.68	.62							
[8] Clicks within pages	57.51	36.57	.20	.04	-.20	-.22	.69	.97	.65						
[9] Supplementary materials	6.22	5.56	.08	-.07	-.34	-.23	.75	.57	.69	.62					
[10] Core lessons accessed	28.76	20.72	-.07	.02	-.23	-.14	.54	.54	.97	.57	.55				
[11] Quiz answers	48.69	31.13	.15	-.06	-.19	-.20	.67	.67	.62	.97	.57	.54			
[12] Additional information	3.39	3.36	.13	.01	-.28	-.29	.72	.52	.49	.53	.63	.39	.52		
Knowledge gains	6.81	0.95	.41	.69	.04	-.04	.02	-.16	-.11	-.10	-.03	-.15	-.17	.11	
Transfer intentions	6.37	1.55	-.25	.03	-.16	-.06	.38	.33	.34	.37	.40	.26	.31	.23	.13

Note. All |*r*| > .30 statistically significant at $p < .05$.

Figure 1
Results of Analyzing the Associations Between Achievement Goals, Learning Engagement, and Learning Outcomes; Note. Only statistically significant effects are visualized. Residuals and their correlations are not presented.



The results of the structural equation model (CFI = .96, TLI = .93, SRMR = .08) are visualized in Figure 1. Task approach goals had a positive, statistically significant effect on learning engagement, while learning approach goals and the two performance goals did not. Engagement had a positive, statistically significant effect on transfer intentions, however, not on learning gains. According to Acock (2014) both effects can be considered moderate in size. Further, there was a small, statistically significant indirect effect from task goals via engagement on transfer intentions ($\beta = .14$). While learning goals were not statistically significantly related to learning engagement, they had direct associations with knowledge gains and transfer intentions that were not mediated through learning engagement. As such, this illustrates differences in how learning and task goals matter for the teachers' learning processes and outcomes in the online professional development course.

Discussion

As professional development of university teachers is paramount for successful educational process, and online courses represent an important, yet little understood, form of educational delivery, we aimed to investigate differences in university teachers' engagement in an online course and how they were related to achievement goals and learning outcomes. Following an achievement goal approach, we distinguished between two mastery goals, namely task and learning goals, and also included performance approach and avoidance goals. Besides offering a detailed view on potential differences between goals, we expanded prior motivation research that primarily relied on self-reports by combining traditional data collection methods and novel learning analytics techniques, measuring learning engagement based on a broad variety of objective indicators. Our finding that especially task goals are beneficial for learning engagement, and in turn, learning gains, extends prior literature on differences between these two types of mastery goals and paints a more nuanced picture of how mastery goals matter and form a relevant premise for successful online learning.

Contrasting prior findings (e.g., Bonafini et al., 2017; de Barba et al., 2016), we did not find that learning engagement measured via objective indicators within the online course mattered for learning gains. However, learning engagement was significantly linked to transfer intentions (Hypothesis 1). It should be acknowledged that our measure primarily focused on behavioral aspects of engagement; an increased relevance of engagement for knowledge gains might have been found had we also considered cognitive and affective aspects. This highlights the importance of designing online courses in ways that spur engagement, as well as considering the role of personal learner characteristics that might impact learning engagement.

One such personal learner characteristic is university teachers' achievement goal pursuit. In terms of linkages with engagement, like other studies conducted within online contexts (Daumiller et al., 2022), task goals were found to matter more for engagement than learning goals (partial support for Hypothesis 2). Aside from replicating prior findings and lending support towards the relevance of task goals, this provides insights into learning goals: We found learning goals to directly matter for knowledge gains and transfer intentions instead of through engagement. This implies that learning goals may not necessarily go along with greater quantity of learning engagement (as assessed in the present study via the objective indicators), but rather greater quality (see Daumiller et al., 2020). For example, teachers with stronger learning goals may not have visited many pages within the course but may instead have deeply focused on pages that were relevant for their specific learning needs. Teachers with task goals, however, might have been particularly concentrated on interacting with all aspects of the course to thoroughly complete it and do a good job. Our findings therefore lend support to both task and learning goals being adaptive in terms of learning but enfolding different mechanisms. Our findings render first indications to this end; however, further research is required. Specifically, research that disentangles different forms of learning engagement by including more qualitative aspects of cognitive and affective engagement processes is needed (see Ben-Eliyahu et al., 2018).

Aside from this, we did not find support for Hypothesis 3 regarding performance avoidance goals being negatively linked with engagement; the same was true for performance approach goals. This may signify that the online course did not include enough opportunities for normative comparisons between participants. As such, performance goals may not have been a relevant motivational driver in the context of the present study. While this could be followed up on by designing course features in a way that provides more opportunity for comparisons between the participants (e.g., leaderboards), it should be considered that our course was designed in a similar manner to most other professional development courses for teachers (see Daumiller et al., 2021). Opposed to course settings where normative elements cannot be fully avoided (e.g., students requiring grades to pass a course), the point that normative comparisons matter less for university teachers within professional development courses can be deemed helpful in terms of being able to focus more on the mastery orientation of these settings (Karabenick & Noda, 2004) and fully profit from the potential that strengthening participants' task and learning goals may have.

Overall, our study entailed several strengths including the implementation of a micro-longitudinal design, the use of a knowledge test to assess learning gains, as well as the integration of objective indicators of learning engagement. Nevertheless, several limitations should be considered when interpreting our findings. First, we assessed the present relationships with respect to a single online course, limiting generalizability of findings. Future research should incorporate different online courses with different designs. Second, our study only focused on objective indicators of engagement. Thus, assessing other forms of engagement that have been identified within the literature would offer a more holistic approach and the opportunity to further validate the present findings. Despite these limitations, first practical implications can be drawn from our study: Course instructors and designers should be made aware of the importance of task goals for online learning experiences in university teachers and focus on encouraging participants towards these goal strivings, as well as designing courses in a corresponding manner. This may be facilitated through (1) directly influencing these goals by scaffolding and stressing the importance of task mastery and putting the goals into writing (reminding participants of their goals and aspirations); and (2) supporting the respective goal pursuit by an arrangement of contextual features emphasized in the online course (stressing mastery goal structures, see Lüftenegger et al., 2014).

Endnotes

(1) Similar to mastery goals, performance goals can be further distinguished based on whether they are directed at normative comparisons regarding performance (normative goals), or at competence demonstration (appearance goals). For theoretical and conceptual clarity, we focus exclusively on normative comparisons (in line with Elliot & Murayama, 2008; Elliot et al., 2011).

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When is an Owl More than an Owl? An Interaction Analysis of a Computer Science Co-Design Conversation on Cultural Relevance

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Abstract: The learning sciences community is currently exploring new ways to enact productive and equitable co-design research-practice partnerships that are sensitive to all the concerns and needs of stakeholders. The paper contributes to that still-growing literature through an interaction analysis of a co-design discussion involving school district partners that unfolded about cultural relevance and sensitivity in relation to the use of a specific image in an elementary school coding lesson. The episode involved looking moment-by-moment at how district educators recognized and acknowledged that a specific design decision could be harmful for a minoritized population of students enrolled in the district. However, once a key change was made to be more culturally responsive and considerate, new and unexpected pedagogical challenges appeared. This case serves to illustrate some of the unexpected tensions that can appear in real-time when unanticipated questions about cultural relevance are foregrounded during lesson and materials co-design.

Introduction

Given already full curricula and numerous standards, a set of design strategies are emerging that move away from introducing computer science ideas to students as a standalone topic in schools. This appears heavily in what is sometimes referred to as "STEM+C" (STEM plus Computing") approaches, whereby computer science and computational thinking are used pedagogically to support other expected content and practice learning goals, while also helping students develop in their computational thinking proficiencies. For example, computational thinking has been introduced as a way to understand natural selection in high school biology classes through algorithmic explanations (Peel et al., 2019). While some generative new frameworks (e.g., ibid, Weintrop et al., 2016) are appearing on how to integrate computational thinking with STEM content, there are still a number of other practice-based considerations and decisions that need to be made to support STEM+C integration in schools, many of which are still only partially known to learning scientists. Thus, learning scientists have been embracing research-practice partnership and collaborative design ("co-design") with classroom teachers and other school-system partners (e.g., school district coordinators, students, school librarians) (see Severance et al., 2016 for an example) in order to develop and refine STEM+C integration approaches.

This current paper originates from a research-practice partnership that involves co-design of STEM-C integrative lessons and resources with district and school educators. The goal of this larger project has been to design activities and materials (in the form of lesson plans, computer programs, and artifacts for teachers and other school educators) that could integrate specific elementary mathematics topics as they are treated in the district's adopted mathematics curriculum with district-required computer science instruction for elementary students. The paper focuses on an event that occurred during co-design activities in which an important conversation unfolded about culture and a minoritized group of students enrolled in the partnering school district. This episode was recorded on video and noted immediately by one of the researchers as a notable and extended (i.e., lasting several minutes and reappearing a second time on the same day) explicit conversation about cultural awareness and sensitivity. The purpose of this paper is to illustrate how that conversation about culture was laced with multiple underlying tensions. As will be illustrated below, the tensions relate to how different stakeholders responded to an explicit call for cultural sensitivity; some individuals were immediately concerned, and others needed more time. Another tension in this episode related to how the decision to make changes in the design of instruction to be more sensitive culturally were complicated by how the mathematics content and computational thinking were to be integrated as well.

Literature review: Cultural relevance and computing education

Above, we situated the work of this research-practice partnership co-design project as orienting toward integration of mathematics and computational thinking in elementary school and designing supports for paraprofessional educators who lead instruction in the computer lab. The district schedule allows for one computer lab lesson per week. However, through an approach informed by the theory of expansive framing (Engle et al., 2012), our co-design and partnership is organized to create and link multiple contexts of mathematics and computing and the classroom and the computer lab. For now, we turn to a body of literature that pertains to this analyzed episode is the intersection of cultural relevance and computing.

First, we assert that culture is already omnipresent despite it not often explicitly foregrounded in conversations about computer science, computing, or computing education. We follow Rogoff (2003) and others (Nasir et al., 2020) in asserting that all human activities are inherently cultural in nature. Current models of professional computer science and computing professions are already inherently cultural, but they center the experiences, preferences, and values of specific populations who tend to be more heavily represented in computing professions and computing coursework; often, it is the group that is racialized as White and (cis)gendered as male (National Academies of Science, Engineering, and Medicine, 2021). Observations of how computer science and computing education have been highly gendered have been made repeatedly over the years. Turkle and Papert (1992) made a call for epistemological pluralism in how students learn to do computer programming and relied on (White) feminist critiques of epistemological styles that are often associated with gender (e.g., planning vs bricolage). Kafai, Richards, and Tynes (2017) have also explored issues of computing and gender, noting ways in which women, across races, are not always provided the same forms of access to computational communities. One approach to change that has been to emphasize different practices and artifacts that can integrate computing that are not necessarily associated with masculinized norms of computing (such as robotics). One notable example in learning sciences research is electronic textiles (Buechley et al., 2013), through which computing and computational thinking take place in the context of creating and enhancing fabric crafts. Others include recognizing gendered craft activities such as weaving or knitting as already using computational thinking (Keune, 2022; Lee & Vincent, 2019).

In addition to gender, computing education can also be reimagined along ethnic and racial axes. First, computing education experiences can be designed so that they take reside in online and physical spaces that are designed specifically to welcome and empower historically minoritized racialized groups. *Digital Divas* (Pinkard et al., 2017) and *COMPUGIRLS* (Scott et al., 2013), along with nonprofit organizations such as *Black Girls Code*, are all compelling examples that are intersectional and speak to both gender and race. Race and ethnicity can also be made an explicit part of computer science education by helping minoritized youth to recognize and critique inequitable social structures that tend to align with race and ethnicity. This approach can create opportunities for students to raise their critiques and develop counternarratives (Vakil, 2018). Another way that race and ethnicity have been considered, especially in US-based work, has been in the intentional linking of computing with heritage practices. For example, Searle and Kafai (2015) have embarked on work with indigenous communities in the United States to combine Native craftwork with computing. Similarly, Eglash and colleagues (2006) have sought to elevate ethnocomputing by recognizing the rich computational reasoning that resides in practices such as cornrow hair braiding and beadwork.

These aforementioned projects provide aspirational models of what could be culturally relevant and responsive designs for computer science learning environments and learning tools. Our current paper is slightly different in emphasis in that we ask: what tensions arise within a research practice partnership when working together to resolve an issue of culturally relevancy within the context of a co-design session? Where we add to this literature is from the perspective of co-design and from the real-time encounters and engagements with cultural relevance and responsiveness as they appear during design conversations. The phenomena we analyze and share here provides a vivid image of what actual conversations about cultural relevance and sensitivity looked like and what were some of the underlying tensions related to both cultural sensitivity and the integration of math and computing content.

Theoretical framework

The interpretive and theoretical framework informing this paper is situated in what Philip et al., (2016) has called racial-ideological micro-contestations. Racial-ideological microcontestations (heretofore shortened to 'microcontestations') are an ontological innovation (diSessa & Cobb, 2004) from design-based research that names a class of interactional phenomenon during which the learning of disciplinary content knowledge is an overarching concern, but issues of race are invoked such that there are multiple simultaneous stances invoked including those that are epistemic, affective, and moral. They are moments when fluency on matters of race and matters of disciplinary content are simultaneously and prominently raised. Microcontestations have been presented in the context of a data literacy activity in a high school classroom that directly involved students of multiple racial identities and discussions of how data and their referents accord with racial dynamics related to geographies and media preferences. Specifically, in the source example, a high school class discussed a geographic data visualization and a conversation ensued about why there was a difference and how it was associated with a neighborhood that consisted heavily of one historically-marginalized racial group. At various times, students tried to provide explanatory stories around the data visualization on the basis of what they knew from their own racial membership and express solidarity. The teacher intervened and made attempts to redirect conversation to respond to some emergent tensions. In that source case, the lens of microcontestations revealed some missed opportunities that could have shifted the interactional dynamics between students and between teacher and student were noted. By making issues of race and content prominent in interaction, this lens serves to spotlight some tensions and complexities that learning scientists must consider and respond to in the design of learning experiences.

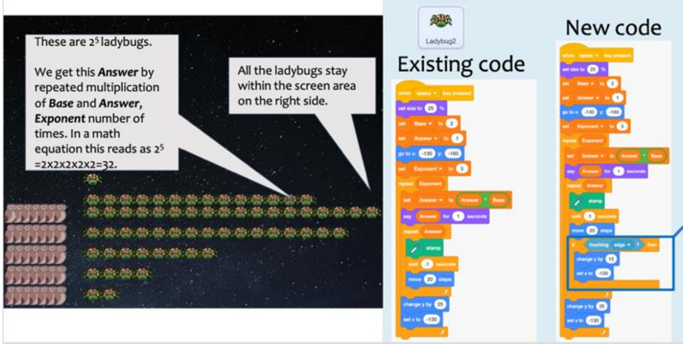
Methods and data sources

The co-design research-practice partnership

The larger project is a multi-year research-practice partnership in which a university-based team is working with a rural-serving school district to develop supports for paraprofessional educators who are tasked with teaching computer science as part of their computer lab responsibilities. The computer lab specialists (their official title) had historically been responsible for overseeing instruction on matters like basic computer literacy, internet safety, keyboarding, and search. With the adoption of statewide computer science standards for K-12, districts throughout the state have explored a range of approaches to address those standards while recognizing that instructional time was already full and that budgets could not be expected change to allow for new permanent full-time teaching staff to be hired.

As a partnership, this project is of the co-design variety. In preparing for and enacting co-design, a number of discoveries are being made about optimal design arrangements. Of specific note is that “design” was a loaded term that needed to be re-examined when district partners saw this as more comfortably viewed as “adaptation” (Lee et al., 202). Design is a valued and highly-involved practice, especially in learning sciences. A tacit ideal of co-design is that the collaborative aspects of design work occur under the presumption of simultaneity and equal participation. That is, co-design is thought to be a time for all parties to meet and invest equal amounts of time to develop common vision and mutually worthwhile solutions. District partners, while enthusiastic about the project, were very limited on time given so many other responsibilities for their schools and classrooms. This was especially true for the classroom teachers and computer lab specialists who were part of the co-design team. Given that, joint sessions were done as periodic meetings with all parties present, sometimes via zoom and sometimes in person depending on circumstances (note: this project began in the remote work portions of the COVID-19 pandemic). A sequence had been developed and agreed upon that the university and district participants would generate together ideas for where there were the most content needs and what were the existing constraints (schedules, pre-requisites, availability of technical resources) and ideate on what could be intersections of computational thinking and the identified mathematics topic. For example, the topic of interest to the episode below is exponents. Teachers noted that students regularly mixed exponents with multiplication, and that this was a challenging topic for their students. Through co-design conversations, the decision was made to address this by working with Scratch-based visualizations of exponents as repeated multiplication and that multiplication can be thought of as repeated addition, with these having very different effects (see Figure 1 below).

Figure 1
Depictions of Scratch elements that show repeated addition and repeated multiplication.



Once this was identified, the university team would work separately with the involvement of district personnel providing intermittent feedback on the creation of the materials and artifacts. In this example, it was Scratch programs, slides, posters for the classroom and computer lab, and lesson plans. When another simultaneous design meeting was held when the classroom teachers and computer lab specialists could also attend, the material drafts were provided and discussed. One important activity to help evaluate this was role-play by which classroom teachers and computer lab specialists taught the lessons to each other during the sessions and offered commentary or suggestions. It was during this role-play that the analyzed episode appeared.

The region where this project is set is, according to 2020 Census records, about 85% non-Hispanic White. Hispanic/Latinx individuals (White and non-White identifying) make up about 11% of the local population. Less than 2% is of Asian ancestry and all other Census-tracked racial groups were less than 1% each of the local population. All of the district personnel and teachers on the co-design team are White. The local research team was predominantly White, with two of four graduate research assistants present who were international students of South Asian origin. Political preferences were not discussed, but the region had historically voted for conservative candidates in local and national elections by a 2:1 ratio (e.g., in the 2020 US presidential election, the region voted about 65% for Donald Trump and 28% for Joseph Biden). Two other research personnel from a different institution and region were present as well for the observed design activity. These other individuals (East) Asian and Black respectively.

Interaction analysis

Interaction analysis is a methodological approach that appeared early in the learning sciences literature (Jordan & Henderson, 1995). Basically, it leverages the availability of interactional records such as video and audio recordings and focuses on short time-scale moments (often on the scale of a few minutes). These interactions typically involved speech between multiple individuals and the use of various artifacts and nonlinguistic modes of interaction (e.g., gesture, body position, etc.). The aim of it was to understand social meanings as they were expressed and negotiated in real time. Because of the complexity of human interaction, the standard techniques for conducting interaction analysis as a form of inquiry involved reliance on various forms of transcription and multiple iterative group reviews of the original video footage. Techniques such as competitive argumentation and progressive hypothesis refinement have been offered for supporting the interpretive work. While it is more involved, these will all involve many iterations of review, applying and challenging interpretive lenses, and identifying observable evidence or warrants for interpretations that persist. The validity of an interaction analysis is based on its reporting with transparency provided on the interactional episode, the interpretation, and the justifications for those.

Consistent with that approach, we iteratively reviewed, transcribed, re-transcribed, and intensively discussed the episode and video footage in several ways (watching it without sound, watching it focusing on a single person, etc.) over a period of multiple months with multiple trained analysts to generate the interpretations offered below. Of note for this reporting, we are being intentionally vague about the individuals' specific roles within their schools, district, or universities to further reduce risk of reidentification.

Results

The analyzed episode took place during a design meeting that involved district personnel, classroom teachers from multiple participating schools in the district, computer lab specialists from multiple schools, and researchers. The entire group of participants were split into two with one half congregating at one table and the other congregating at another. A stationary video camera was placed at one end but not controlled by a researcher. Given that, the angle and audio quality was not ideal – some speakers could only be seen from behind or leaned in and out of camera view - but the quality was sufficient for this analysis. At the table were multiple classroom teachers and computer lab specialists, one central district office employee, and members of the research team hailing from two universities. For ease of reading, the episode is broken into three sequential "scenes".

Identifying the concern

Prior to this meeting, a set of materials including lessons, slide decks, and a *Scratch* program had been prepared by a member of the local the university team. The local university team had not been aware of the specific potential cultural insensitivities prior to this meeting with the teachers, specialists, and district personnel. The concern is that the choice of Sprite in the Scratch program could cause discomfort for a group of students.

The episode took place in the midst of one of the school district team members, Lisa, role-playing instruction using the Scratch program that had been developed to represent repeated addition and repeated multiplication. She had been asking others at the table who were role-playing as students to open the pre-developed Scratch program (see Figure 1, above) and to begin making specific edits to explore multiplication and exponents when another school team member, Daphne, interjected. Her register and posture changed to indicate she was not role playing as a student but speaking as a colleague. Eleanor also worked in the school district. Alex and Taylor were members of the university team.

1. Daphne: You know the problem with the owls, is we have Navajo students, and owls in the Navajo-
2. Eleanor: yes
3. Daphne: -are like really bad luck, and like, like it's intense, it's a like a big thing.
4. Lisa: (turns to the left where university team members are sitting, sighs) Did you hear that?
5. Alex: Yeah?
6. Lisa: (to Daphne, hands raised, palms up): wait but you can't-
7. Daphne: -Like they freak out over it
8. Lisa: -you, can't (raises pitch and punctuates words with beat motions) you find something wrong with every kind of creature? (drops hands on desk)
9. Daphne: -Yeah
10. Lisa (laughs, looking left towards university team members): I don't know
11. Taylor: Oh, we probably should change that.

In this transaction, Daphne changed the interaction to be one of educators and designers. She expressed immediately that in the student population at the school district, there were indigenous students who were part of the Diné/Navajo nation. In line 3, Daphne stresses this is something for the group to be aware of, stating three times ("really bad luck", "it's intense", and "big thing"). This was apparently new to Lisa who was surprised and turned to the university team members. The reason for this could be that this was a correction to note for revision of the materials. However, after, she does express an initial objection (line 6) to Daphne ("wait but you can't"). Daphne was still continuing to stress the seriousness of the use of the owl sprite (line 7).

This was the first known instance in which race or ethnicity had appeared as a topic of discussion during the day. While this was the first mention of a topic explicitly related to a racially minoritized population, the initial response was surprise from Lisa. Her initial responses (lines 5 and 7) were to suggest that this might be something that need not be modified ("you can't..."). She then added in a slightly higher linguistic register as if channeling an exaggerated voice that it would be possible to "find something wrong with every kind of creature". This was not stated with any markers of anger but more of disbelief. The higher linguistic register, accompanied a slightly exaggerated slapping of hands on the desk, making this statement appear as ambiguous regarding whether it was mock frustration for humor or an invitation for solidarity from others who might feel similarly.

Again, the political preferences of individuals were not known. However, the initial response from Lisa bore resemblance to what some of the interaction analysts noted was common in political discourse in the United States about matters of inclusion and equity in the country – that one observation related to race be immediately generalized ("something wrong with every kind of creature"). Specifically, the sensitivities that are urged in order to be more inclusive of historically marginalized communities are seen as unnecessary additional asks for others to accommodate or anticipate. It is also possible that Lisa was expressing frustration on shifting topics to the sprite selection when she was trying to role-play teaching, and this was an interruption.

Seen as a contestation, what was at odds here was whether the racial and cultural concerns that were raised and marked by Daphne were important enough to merit changes. There was a tension with respect to whether this was a concern, but it was expressed in a partially exaggerated way, allowing for this to be dismissed as a comment or as an entry for someone else to express their solidarity in thinking this was not a matter requiring a response. It was mock generalized to "every kind of creature". If sprite selection was indeed a problem for everyone, then it may seem like responding to this instance was prioritizing one group over another. For members of the university team, however, this was seen as something that required response and correction (Line 11).

Elevating the concern

Shortly after, Lisa was seeking clarification on the implications of what would need to happen next. The role play had been halted, and she leaned toward Daphne to ask the following before Daphne interrupted again.

12. Lisa: So, does that mean we have to-
13. Daphne: Yeah, no, like I had t- take um, I had one in my class this year that was Navajo. Um…[student name]
14. Lisa: Ohh (tilts head to the side)

15. Taylor: I guess one suggestion is that-
16. Daphne: And then remember when I had-
17. Daphne: maybe you weren't here when I had [another student] and she was like Navajo.
18. Taylor: What do you guys think of about a [alternative] sprite. What animal do you think would be good?
19. Eleanor: (turns to educator on her left) Because in their tradition owls are bad omens, and it's like a curse if I understand it correctly.
20. Daphne: (looking towards Eleanor and then back to computer): Yeah, it's - I don't know all the details on it, I just know it's like a big thing.

In line 13, Daphne then expresses a personal connection. She adds that she had a Diné/Navajo student in her "class this year". Lisa seemed to recognize the name of the student and change tone with "Ohh" (line 14). At that moment, her arm that is upright then bends at the wrist as if any tension being held with the erect arm just dissipated, and Lisa tilted her head sideways in what appeared to be an expression of understanding and empathy.

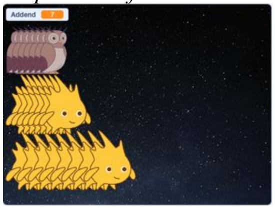
Some side conversation also took place from a university team member who is trying to find another sprite to use (line 15 and 18). During this time, Daphne has some overlapping speech (line 16) and also adds another point of personal connection when she "had [another student] and she was Navajo." At this point, Lisa looks down and appears to accept this is a matter that can be addressed. At the other end of the table, Eleanor overheard this and turned to the educator sitting to her left to explain that "owls are bad omens". Daphne, who was not being addressed but could hear Eleanor speak, turned and added that she did not know much about it. What she did know it was important ("a bi:::g thing", line 20).

This portion of the exchange suggested that once a specific individual was identified (line 13), Lisa had been engaged and stopped remarking. This was a marked change from the earlier response to the caution that this was potentially problematic for a group of people. Also, what was revealed was that the need for sensitivity was shared, but the exact reason for *why* it was a sensitive matter was not widely shared. Eleanor seemed to know some, but no one knew immediately why it was potentially harmful.

Discovering unexpected ramifications

Several minutes (not included here for space) were then spent with different individuals at the table suggesting alternative sprites and offering opinions (such as whether they liked them, if it was cute in appearance). Eventually, a sprite ("Gobo") was selected to replace the owl in the Scratch program and the lesson role-play continued. However, the next interruption that involved stepping out of the role play was initiated by Lisa.

Figure 2
Depiction of the Owl and Gobo sprites



21. Lisa: So far on this sheet, if we go with this one, can we have it move 20 steps versus 10 steps because they're just kind of so close together. So, I just changed mine to 20 just to see what it would look like it
22. Alex: The problem with that could be is they are going to change to a number to [inaudible]
23. Lisa: That's right
24. Daphne: you could change it later, after, like for this particular one, you could do 20 and then
25. Lisa: But see I would do this then..I'd tell them [inaudible] it gets erased
26. Daphne: I get what you're saying

The concern that Lisa raised was that the Gobo sprite (see Figure 2) was wider. When it was stamped, the Gobo overlapped whereas ("they're just kind of so close together") when it was the owl, there was no occlusion on sprite stamps. Lisa suggested that the number of steps to move laterally should change from 10 to 20 so that there would be no overlaps when stamps were made. However, Alex then observed that this was going to be a problem for later parts of the lesson. When there were larger values for the number of stamps, they would not fit on the stage in Scratch. Lisa (line 23) realizes what Alex was saying would be a problem if this was a permanent change. Daphne suggested it be done temporarily, "you could change it later..." (line 24). However, Lisa expressed that this could be counter to what they intend for students as the change could be made for the one example, but then "it gets erased" so that they could complete the other examples. Daphne acknowledges that this is a problem (line 26).

As far as the contestation goes, a change had been made once it was agreed that this change in sprite was appropriate. However, this created the new tension of how the pedagogical strategy and Scratch program were designed to link the mathematical idea of exponents as repeated multiplication as demonstrated by Scratch code would be represented. While the change to the Gobo sprite responded to the need for cultural sensitivity, it ended up challenging the pedagogical and integration strategy as represented in the curriculum material being developed and tested.

Discussion

The entire episode is longer and has more discussion of sprites and sharing what was discovered about the meanings of owls in Diné/Navajo communities, which will need to be reserved for a longer paper. However, this microcontestation episode as presented spotlighted some concerns that learning scientists and research practice partnerships involving design should consider for future work.

First, is that it is very possible for designer ignorance and general assumptions that given tools were sufficiently appropriate factored into this. No members of the university team had been a priori aware of the importance of owls as a bad omen, and there was also little awareness of how many students of Diné/Navajo background would be in the school serving a predominantly White student body. As demonstrated by Taylor in her response, it is something that, once discovered, is a matter that would be taken up immediately and seriously. However, why did this situation come about? Because this was in Scratch, a well-known tool for introducing computer programming, a blanket assumption seemed to have been that the tool was already vetted enough. The added responsibility to think about tools meant to increase issues of exclusion as having potential shortcomings was not in immediate awareness. The research community is still recognizing how educational technologies that are meant to be neutral or safe to use can still end up embodying mechanisms of exclusion (Litts et al., 2021). It is a caution worth keeping in mind.

Second, this did not appear to be a concern that produced a uniform response across design team members. Daphne had seen this as a point of immediate concern whereas Lisa needed some more time to see that this was a pressing concern. We caution the reader to exercise restraint in how different actors are viewed in this episode. We firsthand had seen how Lisa is generous and helpful in a range of interactions and in this project. Her initial response was compelling not because it was her that had expressed it, but it is very likely the same one that large segments of people in the broader geographic region and nation would have. This is not to be accepted as how we may wish things should be, but it is how things are currently. If partnerships and collaboration are a priority for our work, we have the opportunity to recognize this and find productive ways forward. In this case, it appeared a key turning point was when Daphne connected the impact of the owl symbol with a specific student that both she and Lisa knew. Once it was a specific person for whom all were invested in educating and supporting, the seeming reluctance to making changes in the sprite eased.

Third, while it was known as a cause for concern and should be acknowledged, the reasons for why it was a concern were not fully known. Daphne could confidently assert that the owl was problematic, but Eleanor needed to introduce why it was problematic. This was a key learning moment for all to understand the owl's meaning to the Diné/Navajo. The question this raises is what level of knowledge we want educators to have that equips them to be inclusive and sensitive to matters of cultural diversity, exclusion, and harm. We are not equipped to know the long-term impact of this incident for the actors involved. We can assert that the sprite has been changed, but it is unknown if how work around issues of culture and historically marginalized communities will be understood or centered. It could be possible that simply new behaviors are put in place to respond to immediate concerns, but the underlying matters and thoughts about race and racism that limit progress are not being addressed. Rather, they are just becoming harder to see in public in some settings.

Finally, there was an entanglement here that the math and computing integration had with the owl. While the sprite selection may have seemed arbitrary and interchangeable, it turned out that its precise size on the screen supported specific uses in line with pedagogical intent. The owl was small enough to appear a certain number of times in the space given and help to illustrate repeating processes represented computationally. What the owl selection serves to illustrate here is that whether or not the harm or risks are known, the infrastructure in which something as simple as a screen sprite is placed and which it supports quickly become intertwined. It is not simply a matter of cosmetic change in response to cultural concerns. Rather, it implicated many other changes that had to be made.

Thus, in a brief moment when a Scratch program was being built in service of a co-design, a seemingly neutral owl was selected as a sprite to help realize a model of computation and mathematics. However, an interaction analysis of a computer science co-design conversation about how it would be problematic showed us that the selection of an owl had far more below the surface than had been anticipated.

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Using the Adaptive Cycles Framework to Conceptualize the Temporal Dimension of Teacher Learning

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Abstract: Attending to when and where teachers are with respect to change and learning—the temporal aspects of teacher learning—can yield more effective, timely, and responsive professional development (PD) efforts. Toward this end, we conceptualize phases of learning in a PD program, and how these phases are shaped by different resources and levels within teacher learning ecologies. Conceptually, we build on the Adaptive Cycles framework (Gunderson & Holling, 2002) and empirically, on video-based teacher conversation from a partnership with a PD-organization (PDO). We describe the learning of two school-based teams in the PD through the four phases of the Adaptive Cycles: problematization, reorganization, growth, and conservation. Findings show how the teams differed in their starting point, learning trajectories, and external resources invoked by participants. These findings strengthen our call for centering temporality and provide conceptual tools for doing so in research and practice, towards greater responsiveness to teacher learning ecologies.

לַכֹּל, זְמָן; וְעֵת לְכָל-חֵפֶץ, תַּחַת הַשָּׁמָיִם (קהלת ג' א')
To everything there is a season, and a time to every purpose under the heaven (Ecclesiastes 3:1)

Objective

For more than two decades now, sociocultural research on teacher learning highlighted its social and contextual nature, and as a result, portrayed quality PD as collaborative and situated in teachers' instructional contexts (Ball & Cohen, 1999; Horn & Garner, 2022; Kazemi & Hubbard, 2008). At the same time, empirical findings from such PD designs also point out several impediments to learning within teacher conversations (Borko et al., 2008; Horn et al., 2017; Vedder-Weiss et al., 2018), underscoring the need for ever more nuanced theories of teacher learning to inform teacher educators' responsive work (Cochran-Smith et al., 2014; Ehrenfeld, 2022; Horn & Garner, 2022; Opfer & Pedder, 2011; Stengel, in press). In this paper, we contribute this line of research by arguing that responsive PD efforts require a conceptualization of the temporal dimension of teacher learning.

We show why and how temporality matters by framing teacher learning as a *phased affair* with teachers open to various sorts of resources and interventions depending on where they are in their learning cycles. Theoretically, we take inspiration from sociocultural, ecological, and complexity theories and their guidance to (respectively) understand (1) teachers as agentic sensemakers; (2) within the context of their learning ecologies; (3) through phases of change and learning. Conceptually, we adapt and use the adaptive cycles framework (Gunderson & Holling, 2002). Empirically, we use data from Project SIGMa (Horn & Garner, 2022) to illustrate these temporal aspects of teacher learning. Project SIGMa was a research-practice partnership with a PD organization, and, as a central part of our joint work, we used video-based conversations to support secondary mathematics teacher teams in improving their practice. Here, we look at two school-based teams and ask: *How do different resources within teachers' learning ecologies interact in different phases of their learning?*

Theoretical and conceptual frameworks

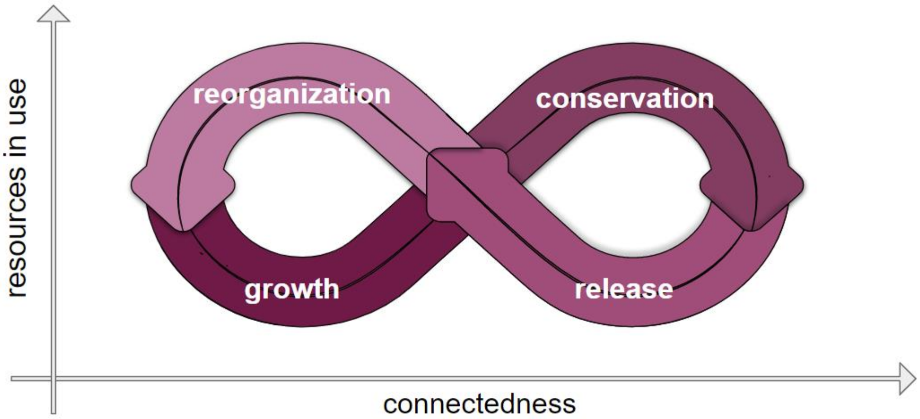
This work is rooted in a sociocultural, ecological, and complexity perspectives on teaching and teacher learning. *Sociocultural research* on teacher learning informs our approach of privileging contexts and conversations, and positioning teachers as agentic learners and sensemakers (Horn & Garner, 2022; Lefstein & Snell, 2013). *Ecological theories* foreground the fact that learners are simultaneously involved in many settings and ask questions about the ways learning emerges from the interactions between these settings, as well as other resources and levels of teachers' learning ecologies (Bronfenbrenner, 1979; Cobb et al., 2003; Ehrenfeld, 2022). Finally, in line with ecological theories, a *complexity theory orientation* seeks to identify systems that interact towards the emergence of teacher professional learning (Cochran-Smith et al., 2014; Opfer & Pedder, 2011). In addition, models rooted in complexity theories also guide us to look at phases of change in ways that, we argue here, are useful for understanding teacher learning trajectories. An example is Gunderson and Holling's (2002) adaptive cycles framework.

The adaptive cycles framework

In traditional environmental ecology, processes of change within ecosystems (such as forests) were described as linear with two phases: growth towards an end point or climax, and conservation, the state the system would reach if not disturbed. However, in adaptive cycles, the climax, or the conservation phase, becomes a transition phase in a continuous cycle, proceeding through phases of release (later in this paper described as problematization), reorganization, and then again growth and conservation. In the forest example, the phase of release can be thought of as triggered by forest fires or drought. Then, in the reorganization phase, nutrients become available for new pioneer species to capture opportunities towards the following phase of growth. Finally, the framework also describes differences between the phases in terms of the level of resources in use, and the connectedness of components in the system (see Figure 1).

Figure 1

The four phases of the adaptive cycles



Note. The cycle reflects changes in two properties: (1) The y-axis represents accumulated resources in use (originally described by Gunderson and Holling as *potential*); (2) The x-axis represents connectedness of elements within the system. The behavior of loosely connected elements is largely influenced by external variability. The behavior of highly connected elements is mostly influenced by their inward relations, which strongly mediate external variability.

Adaptive cycles in the case of teacher learning

In the case of teacher PD, a focus on temporality helps us think about different phases in the teachers' learning trajectories and how they are supported by different resources (see Table 1).

Table 1

Four Phases of Adaptive Cycles in Forests and Teacher PD

Phase	Forest Analogy	Teacher PD
Growth	Competitive processes lead to a few species becoming dominant, potentially previously suppressed vegetation.	**Experimenting** with the new professional arrangement.
Conservation	Nutrient and biomass resources become bound with existing vegetation preventing others from utilizing them.	New practices are **consolidated,** and teachers are proficient with a new professional arrangement.
Release	Forest fires, drought, or intense pulses of grazing.	**Problematization** of institutional practices and teaching norms.
Reorganization	Nutrients become available for new pioneer species to capture opportunities.	**Navigating** tensions between institutional logics and teachers' pedagogical goals. Renewal, **planning**, and **recruitment** of new arrangements and practices

Growth is the longest and slowest phase and represents what Gunderson and Holling called *incremental learning*, where, in our case, teachers are experimenting with new teaching arrangements, adapting or rejecting practices according to their needs and sense of agency, until the arrangement becomes relatively stable. *Conservation* represents the phase when practices are consolidated, and teachers become more proficient with their professional arrangement. *Release* represents the *problematization* of current institutional logic and teaching practices, and often involve external agents as PD facilitators, or a new policy introduced to school (note that we renamed the release phase in the context of teacher learning as problematization). In the case of video-based PD, video-based reflection can also disrupt existing teaching and learning arrangements. Then, *reorganization* can represent navigating tensions between institutional logics and teachers' pedagogical goals, inherent conditions of teacher learning (Horn & Garner, 2022). Just as the reorganization phase in the forest is where nutrients become available for new pioneer species, teachers' reorganization phase is about renewal, planning, and recruitment of new arrangements and practices. Gunderson and Holling (2002) describe this phase as "the engine of variety and the generator of new experiments" (p. 74). At this point, transition to *growth* (experimenting with the new professional arrangements) and back to *conservation* may represent what Gunderson and Holling called *transformational learning*. Importantly, adaptive cycles also guide teacher educators' responsiveness to different phases of teacher learning. In the case of teacher learning, the x-axis in Figure 1 (and later with more elaboration in Figure 2) represents connectedness of resources and teaching arrangements within the system. Within the reorganization and growth phases, when resources and teaching arrangements are loosely connected, new invoked external resources are expected to be more salient in promoting change. In contrast, within the conservation and release phases, internal processes such as video-based reflection are more likely to be salient in promoting change. This distinction in central to our analysis and discussion of how different phases of teacher learning calls for different support.

Methods

Research context

This study is part of a larger research-practice partnership where the research team collaborated with a Professional Development Organization (PDO) to support the participating teachers' development of ambitious and equitable mathematics instruction. Through this partnership, we worked with teachers from six schools. All participating teachers had five or more years of experience and were affiliated with the PDO. Together, we co-developed a video-based formative feedback (VFF) intervention to provide teachers with timely information about their classroom instruction and help them make sense of problems of practice.

Data collection

During the 2017–2018 and 2018-2019 school years (Year 1 and Year 2 of our partnership), we worked with six school-based teacher teams, each ranging from two to five people. We visited and filmed teachers in each team one to six times over the course of the year. To film lessons, we used two cameras. Camera 1, a tablet camera on a robot tripod (Swivl), captured the whole class with a focus on the teachers' movements. Camera 1 also captured conversations from four student groups through four separate microphones placed at their tables. Camera 2, a point-of-view camera (GoPro), was mounted on the focal teacher's head, shoulder, or chest to approximate what they saw as they moved through the classroom interacting with students. In addition to these recordings, our classroom data included fieldnotes, lesson artifacts, photos of whiteboards and student work. The data also included fieldnotes about or recordings of conversations with the teachers before and after instruction, as well as texts and email exchanges with the teachers about the classroom activities. To film debrief conversations, we used the same wide-lens tablet camera and a recording of the researchers' laptop screen to document what teachers and researchers watched at any given time. In addition, debrief data included fieldnotes, photos of whiteboards when used, and fieldnotes about or recordings of informal conversations with the teachers before and after the formal debrief. All 32 debrief conversations were initially transcribed by an external transcription service and then finalized by Project SIGMa team members.

Focal cases

Within this larger group of well-supported and experienced secondary math teachers, we focus here on the Rees Middle-School team (Ezio and Veronica) and the Noether High-School team (Brad, Marisa, Abigail, and Greg). These two school-based teams had a similar leading concern, which remained relatively stable across our partnership. Both teams had the explicit goal of promoting student collaboration. This goal typically included a focus on teaching conceptual math content and supporting social inclusion. Notwithstanding their similarities, the two teams perceived their institutional contexts in significantly different ways. At Rees, tensions between the teachers' personal commitments and school practices were significantly more contradictory. In contrast, at Noether, between Year 1 and Year 2 of our partnership, one focal teacher (Brad) was appointed as department chair. This shift implied that he had greater agency around issues like curriculum design and even purchasing classroom furniture to better support student collaboration. Another difference between the two teams was the length of our partnership. By the end of Year 1, one of the two teachers from Rees moved schools and our partnership ended. However, our work with Noether continued to Year 2, with a one-time Member Check visit in Year 3. Year 1 with the Rees team included three VFF cycles. Year 1 and Year 2 with the Noether team included six VFF cycles. Secondary data include interviews with the participating teachers.

Data analysis

The overarching goal of this data analysis was to understand the teachers' learning was in different phases of the PD, how their "phasing" impacted what resources they are bringing to bear, and what they accounted for because of where they are. We looked at learning trajectories across all meetings we had and described the teams' learning at the PD through the lens of the adaptive cycles. For each of the phases of *problematization*, *reorganization*, *growth*, and *conservation*, we asked whether and where do we recognize conversations that are associated with this phase. First, for the phase of problematization, we searched for and analyzed instances where teachers problematize either institutional practices and norms, or aspects of their own instruction. Second, for reorganization, we focused on instances where teachers discussed planning and recruitment of new ideas, including the tensions between institutional context and their own pedagogical goals. Third, for growth, we focused on instances where teachers tried out relatively new ideas and professional arrangements (in and out of classroom.) Finally, for the phase of conservation, we focused on evidence that teachers became proficient with new professional arrangements, to the extent that these arrangements were consolidated and stable within teachers' routine practices.

Notably, we quickly learned that instances that represent the four phases were usually mixed across the data, that many episodes can be seen as representing multiple phases, and that phases were never really "done" but more or less salient at different points of the conversations. In other words, while these categories are analytically distinct, real life is messier. We tried to consider this messiness in our analysis and be explicit about it. This nuance in and of itself led to some interesting findings. For example, when the Rees team mostly coordinated resources in light of institutional contexts, we considered it *reorganization*. When the Rees team mostly tried out these new resources, we considered it *growth*. However, we noticed that while the main focus of the formal video-based conversations became the growth, our informal conversations with the teachers were still a space for teachers' sensemaking about their reorganization, highlighting how formal and informal dimensions of the PD were interrelated.

Finally, we explored the guidance provided by adaptive cycles to consider the influence of external variability on different phases of learning. Adaptive cycles suggests that within the reorganization and growth phases, invoked external resources will be more salient. In contrast, in the conservation and release/ problematization phases, internal processes such as video-based reflection will be more salient. The temporal analysis is reported in the following section.

Findings

In this section, we describe our partnership with the two teams through the lens of the four phases. First, we show that our work with the Rees team centered on the *reorganization* and *growth* phases. Then, in contrast to Rees, we briefly describe how our work with the Noether team can be seen as a *full adaptive cycle* across all four phases. We conclude by considering implications to designers' and facilitators' responsiveness to teacher learning by using the lens of temporality.

Rees: The PD focused on the reorganization and growth phases

Several years before our partnership began, Ezio and Veronica moved to Rees High-school from the same previous school. Veronica moved first. She was displaced from their old school as the youngest teacher in the department, with less than 5 years of teaching experience at the time. Ezio joined her shortly after, with more than 15 years of experience. When they re-joined forces at Rees, Ezio and Veronica had a strong collegial relationship and collaborated as much as their schedules allowed. This collaboration strengthened when they joined the PDO as a team, which bought them an official shared planning time during their school day. As a team, Ezio and Veronica shared two main goals. First, they wanted to change their lessons to support more student collaboration. In an interview in Fall 2017, they described supporting student collaboration as a topic they tried to grow the most that year. Ezio described not having a lot of experience with student small groups and mentioned he was working on leading students to the answers instead of simply giving answers. Veronica described groupwork as being "outside her comfort zone," and yet she was willing to take "big risks" and try new practices in her classroom. Second, Ezio and Veronica felt a commitment to work towards making their school more equitable. Both teachers were frustrated by the distribution of resources within school, which they felt was favoring affluent families. These families were either newcomers to the school's gentrified neighborhood, or students who were recruited to school's magnet program from other neighborhoods.

Problematization of school routines happened before the PD

Using the terminology of the adaptive cycles, the phase of *release* — the *problematization* of their school routines and of their own teaching — mostly happened before our intervention. Specifically, Ezio and Veronica had grown concerned about the unofficial tracking in their department. For them, tracking was not just about differentiating levels of math classrooms but extended to other activities (such as electives) and created what Ezio called a "sharp divide" between different groups of students. In other words, Ezio and Veronica started our partnership with relatively clear articulations of issues that bothered them in their classrooms as well as in their school. The phase of *reorganization* represents the generating of ideas to address these problems, navigating tensions between institutional practices and their personal commitments.

Reorganization and growth phases

The phase of *growth* involves experimenting with new ideas and instructional practices. Our work with Rees across three VFFs focused on these two phases. Rees VFF 1 illustrated their preliminary reasoning with regards to groupwork facilitation, and the recruitment of ideas towards supporting more equitable student collaboration (i.e., *reorganization* phase). For instance, in Rees VFF 1, Ezio and Veronica made a strong connection between their grouping strategies and their institutional concerns about stigmatizing groups of students. When it came to grouping strategies, they noticed that purposeful grouping amplified the consequences of tracking in the shape of labeling kids as "dumb" or "awesome" — even if teachers did not explicitly state their grouping scheme — while random grouping disrupted it. Then, the following two VFFs were mostly focused on experimenting with and consolidating instructional practices such as random grouping, re-grouping, and rotating groups (i.e., *growth* phase). For example, Veronica started incorporating the aforementioned random grouping into her teaching routine. In this case (Rees VFF 2), Veronica implemented it by the book, with limited flexibility and discretionary judgment. Trying out these new practices constituted experimenting. The debrief offered her an opportunity to hone her flexibility and consider overriding the randomness to attend to the specific teaching situation, which allowed her to consolidate some of her understandings of her experiment. For another example (Rees VFF 3), Ezio incorporated the instructional practices of rotating-groups, another experiment. This new practice introduced to Ezio and Veronica by their PDO coach. The debrief offered teachers several opportunities to consolidate the practice. The idea was that when groups were rotating, they left (by design) their whiteboard scribes to the following groups to reflect on. However, in watching the clips of his classroom, Ezio realized that when he addressed the groups, he talked to the students as if they wrote the scribes next to them, which resulted in some type of miscommunication.

Notwithstanding the analytic distinction between the two phases, the reorganization challenges in light of the school context were never fully resolved. Even though the formal video-based conversations shifted to focus on experimenting with new instructional practices, Ezio and Veronica continued to mention their concerns about school in interviews and informal conversations, and our team used these opportunities to support them on this end. For example, one of our team members described to Ezio Rochelle Gutiérrez's argument of why teachers need political knowledge and creative insubordination (Gutiérrez, 2016). This example calls attention to seeing the VFF cycle — and PD in general — as an activity that happened both on the formal "front stage" (the video-based conversation) and on the informal "backstage" (Goffman, 1959).

Conservation: No evidence for a stable phase

Throughout our partnership, Ezio and Veronica demonstrated instructional growth, however, we cannot describe these new instructional arrangements as stable. Using the terminology of the adaptive cycles, Ezio and Veronica did not reach the phase of *conservation* with their new practices. Rather, our work with the Rees team was centered on reorganization and growth. In contrast, the case of the Noether team illustrates a full adaptive cycle.

Noether: The PD entailed full adaptive cycle toward stable changes

The Noether team included four teachers: Brad, Marisa, Greg, and Abigail. The four teachers had different backgrounds and years of experience. For Brad, Noether was his first teaching job. He was there for over five years, and at the end of the first year of our partnership, he was appointed department chair. Marisa was new to the school and was Brad's collaborative planning partner. This section mostly focuses on them as a subgroup within the Noether team. Abigail arrived at Noether the same year as Brad, after teaching at another school for two years. She had a close relationship with Brad and Greg, who both described her as someone who helped them become better teachers. Greg was the most experienced teacher on the team with more than 20 years experience, all at Noether. Brad himself was inspired by Greg's commitments, as a veteran teacher, to shift his teaching and focus more on students' thinking and discussions. In sum, the team was supportive and collaborative, committed to improvement, and included a variety of backgrounds and experiences.

Problematization: Seeing where instruction falls short through video-based reflection

Notwithstanding the team's collaborative and committed nature, the Noether team did not show signs of arriving at our partnership with a sense of urgency, neither with regards to their institution nor their teaching. in contrast to the Rees team, *problematization* of some aspects of their instruction, and of institutional norms, emerged within the PD as a result of the video-based reflection. The three VFFs in Noether Year 1 often included problematization of the teachers' practices. By problematization in this case, we mean that we discussed central aspects of instruction aligned with the teachers' stated goals, and yet, were still not recognized by them as possible avenues of growth in their teaching. These aspects included, for example, refraining from providing students with answers and instead directing students to each other as resources of mathematical knowledge.

Reorganization: Planning new teaching arrangements

Toward the end of Year 1, it became evident that Marisa and Brad were not only reflecting on and problematizing their practice, but also considering ways to *reorganize* their teaching arrangements. Noether VFF 3 signaled this shift. After watching a video clip of Brad's groupwork facilitation, the research team pointed out the gap and possibility of further directing students' questions to each other within the group. Marisa then invoked her experiences teaching a problem-based curriculum in her previous school to suggest that the constraints of supporting student collaboration are stemming from the culture of their classrooms and school. In later interviews, we found further evidence that these discussions pushed Brad and Marisa to reorganize their classroom and units. Indeed, in the following year, Brad and Marisa used their common planning time to restructure their curriculum and to experiment with new lesson structures.

Growth: Experimenting with groupwork

During Year 2, Brad and Marisa restructured their classrooms to have students work in small groups daily over a five-week unit on statistics. This was the context for Noether VFF 6. At this point, Brad had become department chair and therefore had greater agency in curriculum design. Brad and Marisa took advantage of the new design to "dive in full" into groupwork experimentation in the way Marisa pushed to in the previous year. Brad's classroom design and interaction with student groups in Noether VFF 6 included changes that echoed Marisa's previous experiences with the problem-based curriculum that she invoked frequently. Their experiments with these ideas (e.g., directing students to each other when asking questions) represented a phase of *growth* towards the following phase of consolidating the new arrangements into relatively stable practices

Conservation: New teaching arrangements consolidated into a stable practice

Until now, we described how Brad and Marisa's learning trajectory spanned across the three phases of problematization, reorganization, and growth. Our argument in this last section is that Year 3 illustrated a full adaptive cycle towards a new stable practice. The new stable practices were supported by a variety of resources and levels in the teachers' learning ecology: VFF video resources, together with their shared analysis, external resources like curricula and conferences, and institutional resources such as Brad becoming the department chair. All of these supported Brad and Marisa in the adoption of new structures and practices around the notion of groupwork. In February 2020 of Year 3, our team members visited Brad's classroom for a Member Check. (At this point, Marisa had moved to a new school for family reasons.) Coincidentally, they arrived a day after Brad received new group tables to replace his individual desks with obstructive arm trays that made groupwork difficult. He had completely built the lessons they observed around student collaboration, and our team members noted in their fieldnotes that students seemed used to it (which Brad confirmed in the interview). Importantly, our team also noticed several instructional moves we had discussed during past VFFs: (1) quiet circulation in the classroom listening to groups; (2) asking what students were talking about; (3) directing students to each other rather than giving them answers; (4) using student roles. In the interview after the Member Check observations, Brad recalled this learning process:

> I remember you guys came and observed somebody and it was like we had been very new into doing groupwork. [...] And I just felt like the kids needed to talk more and needed to work together more and that I just needed to change things up [...] So, I did all year group work, fall

> to spring and then Geometry. I only started last spring. So they're used to working in groups […] highest level kids that are used to just being A students and don't need the other three end up valuing group work by the end of the year. So... so I've just dove in full on to having all my classes work in groups.

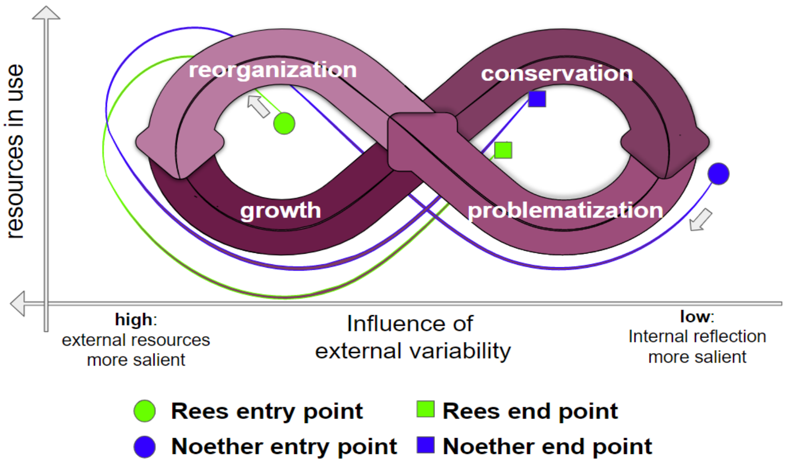
Overall, there was a lot of evidence in Brad's classrooms that he has developed more strategies, structures, and awareness about setting up and supporting effective groupwork. Even more, Brad recalled how these arrangements started with *problematization*/*release*, when he "remember you guys came and observed… I just needed to change things up." They then shifted to *reorganization* and *experimentations*, during which he and the kids got used to work in groups, and side by side with their frustrations, students are seeing the affordances. Eventually they seemed to arrive at a stable phase, which we argue is a new *conservation* phase.

Summary and comparison of the two cases

In this analysis we used temporality as an analytic tool to view teacher learning as a phased affair, with teachers open to different support depending on where they are in the adaptive cycles (see x-axis in Figure 2). Ezio and Veronica from the Rees High School were mainly concerned with establishing new professional arrangements, experimenting with them, and coordinating their work with school norms and policies. In other words, our work with them centered on the reorganization and growth phases (see green line in Figure 2). In addition, there is evidence that at the end of our partnership their new teaching arrangements did not yet stabilize and reached another phase of conservation. In contrast to Rees, we described our work with the teachers at Noether as spanning almost across all four phases (see blue line in Figure 2). For Noether, we used the metaphor of release to describe the phase of acknowledging and reflecting on the gap between the teachers' pedagogical goals, and the ways their teaching often played out in the classroom and fell short with regards to student learning. Then, transitions from problematization to reorganization represents navigating tensions between institutional norms and teachers' pedagogical goals towards renewal. A main institutional resource in this phase was Brad becoming the department chair. At this point, the transition from reorganization to growth included experiments with the new visions of collaborative learning, towards a well-established new arrangement we found in a Member Check in Year 3, that can be described as nearing conservation.

Figure 2

Revisiting the adaptive cycles in the cases of Rees and Noether



Discussion: Responsiveness to different phases of teacher learning

Responsiveness to different phases of teacher learning calls for different support. As a general guidance, this example suggested that in the conservation and problematization phases, internal reflection has more potential to promote change. This was particularly evident in the case of Noether VFFs in Year 1, where problematization mainly stemmed from reflection on video representations of teaching. In addition, these examples suggest that in the reorganization and growth phases, acknowledging and providing a variety of external resources has more potential to promote change. Within the reorganization phase, the focus should be on reconciling these resources with school context, and in the growth phases on experimenting and consolidating them into practice.

Temporal analysis and comparison between the Rees and Noether VFF cycles resulted in several more insights. First, while the phases in Figure 2 are analytically distinct, in real life, they are interrelated. For example, while Ezio and Veronica were experimenting in the growth phase, they kept making sense of their school contexts and coordinating external resources (reorganization phase). Relatedly, this analysis also highlighted how formal and informal dimensions of the VFF cycles were interrelated, as when the informal conversations with Ezio and Veronica provided additional opportunities to provide resources and support. This insight extends the meaning of responsiveness in PD, from facilitation of the formal video-based conversation to the ongoing formal and informal communication and relationship building.

As we work towards more nuanced theories of teacher learning, we call to centering responsivity for teacher learning trajectories and their temporality in the sense of time that Erickson (2004) referred to as *kairos*, which in modern Greek means *opportunity*, or "a brief strip of the right time." (Erickson, 2004, p. 7). It is the qualitative aspect of time as humanly experiences. It is not simply duration (as often time is discussed in literature of teacher learning) or the sequential *chronos* from point A to point B, but rather a lens for supporting teachers with responsibility and attention (Stengel, in press), providing them the right resources at the right moment.

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How Can Computational Modeling Help Students Shift Their Ideas Towards Scientifically Accurate Explanations?

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Abstract: This paper explores how MoDa, an integrated computational modeling and data environment, enabled students to express their ideas about diffusion and shift them toward canonical ideas. Drawing on data from an 8-day unit with two 6th-grade science classes, we analyze students' utterances in presentations, drawings, and written responses to document their diverse ideas about diffusion We present three case studies to illustrate how engaging with computational modeling in MoDa and the unit around it enabled students to shift from non-canonical ideas towards more canonical explanations of diffusion. In particular, we identify three factors that helped in shifting students' ideas: the availability of code blocks to represent a diverse range of ideas including non-canonical ones, consistent access to video data of the phenomenon, and model presentations to the whole class. The paper illustrates how a computational modeling tool and curriculum can make students' diverse ideas visible and shift them toward canonical explanations.

Introduction

Scientists tightly integrate computational modeling and real-world data analysis; they develop and evaluate multiple theories to explain a phenomenon before converging on a single explanatory account (Chandrasekharan & Nersessian, 2002; MacLeod & Nersessian, 2013; Nersessian, 2002). Similarly, in science education, students come to the classroom with diverse ideas to account for how the world works (Rosebery et al., 2005; Smith III et al., 1994). Computational modeling tools can surface students' diverse ideas and make them available for exploration and critique (Linn and Hsi, 2000; Wilkerson, Gravel and Macrander, 2013; Sengupta, Dickes and Farris, 2021). However, computational modeling environments have largely been used in science education to confirm canonical ideas rather than for students to explore multiple, possibly non-canonical theories. Hence, little time is spent allowing them to design explanatory models or showing them the evidence for the model. Moreover, integrating real-world data into the modeling process provides learning opportunities that do not arise when students focus on models alone (Bumbacher et al., 2018). However, opportunities for students to explore and analyze real-world data and to design computational models based on evidence remain largely disconnected. Existing work that integrates computational modeling and data analysis relies on curricular activities outside the modeling environment to link the two (Blikstein et al., 2014; Blikstein et al., 2016; Fuhrmann et al., 2014).

This paper investigates how MoDa (Eloy et al., 2022; Fuhrmann et al., 2022; Wagh et al., 2022), a computational, block- and agent-based modeling environment that integrates model design and real-world data analysis, enabled students to express and refine their thinking about diffusion. Drawing on an 8-day computational agent-based modeling unit on diffusion with two 6th grade science classes, we analyze students' utterances in presentations, their drawings, and their written responses. We illustrate three different non-canonical ideas that students expressed while designing a MoDa model for diffusion and trace how these ideas shift over time. In particular, we identify three features of the MoDa unit - the availability of code blocks to represent a diverse range of ideas including non-canonical ones, consistent access to data through the modeling activity, and whole class model presentations - as contributing to shifts in students' thinking toward canonical explanations of diffusion. Our findings suggest the value of integrated modeling and data analysis activities for both surfacing students' diverse ideas and shifting them towards scientifically accurate explanations.

Theoretical background

We first briefly review the literature on computational modeling, focusing on domain-specific block-based modeling in particular and how it has been incorporated into science classrooms. We then contextualize this study within work that emphasizes the link between data use and scientific model construction.

Block-based, computational, agent-based modeling

Designing computer models combines the advantages of traditional modeling with computational literacy, opening new possibilities for inquiry-based learning (White & Frederiksen, 1998). Agent-based computational modeling environments, in particular, simulate the actions and interactions of autonomous agents (e.g., individual organisms, particles, molecules) in order to understand the behavior of a system. Domain-specific block-based programming environments provide students with a limited library of blocks related to the target phenomenon (Wilkerson et al., 2015) and significantly lower the threshold for students to program and test their theories about scientific phenomena (Hutchins et al., 2020; Repenning, 2017). The domain-specific nature of programming can align with students' existing ways of thinking and provide a language to articulate their scientific ideas (e.g., Aslan et al., 2020). It also supports students' developing conceptual understanding and mechanistic reasoning (Wagh & Wilensky, 2018). In the last two decades, innovations in agent-based, and domain-specific, block-based computational modeling technologies have enabled learners to create their own models using visual and block-based (as opposed to script-based) programming in environments such as NetTango (Horn et al., 2014), Deltatick (Wilkerson-Jerde et al., 2015), ViMap (Sengupta et al., 2021), and Much.Matter.in.Motion (Saba et al., 2021).

One design tradeoff of relatively small block libraries is the more limited opportunities for students to explore non-canonical ideas. In some cases, students are asked to use or manipulate a model from existing blocks that only present "canonical" scientific explanations of phenomena. Students miss the opportunity to engage in iterative model building: to articulate and test out an initial idea, identify its limitations, and try out different ideas and explanations. We study the intentional inclusion of non-canonical blocks in MoDa's block library to study the implications surfacing and understanding students' ideas about scientific phenomena.

Using data to design models

Modeling and data practices are tightly intertwined in professional scientific work (Nersessian, 2002). Scientists use data from real world phenomena to both design and validate computational models to build explanatory theories about those phenomena. However, model-based learning approaches in the science classroom predominantly focus on model-based and data-based practices separately (Bumbacher et al., 2018). The Bifocal Modeling framework (Blikstein et al. 2016; Fuhrmann et al., 2014) suggests integrating real-world data collection with computational modeling to enable real-time comparisons of simulated and real data. Juxtaposing data and modeling enables students to notice and attend to discrepancies between models and data, bringing noise, uncertainty, and intrinsic differences between them (Blikstein et al., 2016; Gouvea & Wagh, 2018). Such comparisons create new learning opportunities, enabling students to develop conceptual understanding and meta-modeling competences (Blikstein, 2014; Fuhrmann et al., 2018), deeply explore the underlying features of a phenomenon (Schwarz et al., 2013), and make decisions based on data to think critically and evaluate models (Holmes et al., 2015). Besides designing classroom activities that enable and emphasize this integration, learning environments can also highlight for students the links between real-world data and computational modeling (e.g., Bumbacher et al., 2018). Without available tools, it is difficult to engage students in the explicit coordination of computational models and real-world data for theory building and to study the types and conditions of learning that arise from comparing real-world data and computational models.

Building on these research traditions of integrating data and modeling, we explore two research questions: (1) How do students use a block- and agent-based computational modeling environment to express their initial ideas about diffusion? (2) How do students' ideas about diffusion shift over the course of the unit?

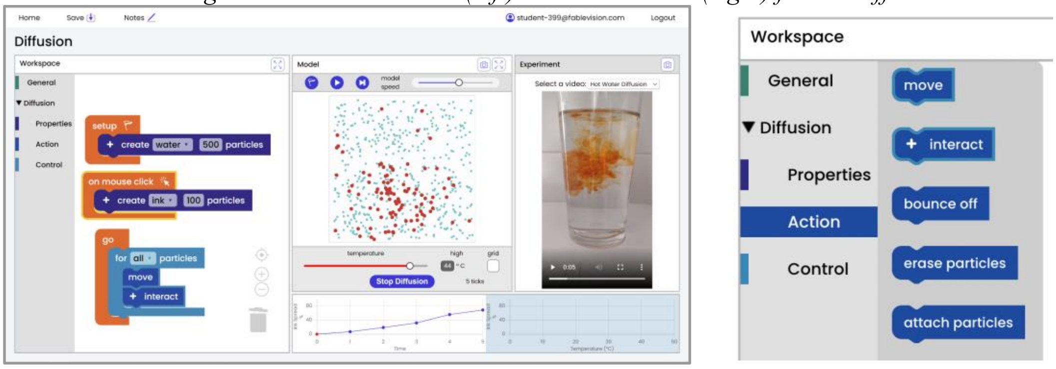
Materials & methods

MoDa: The modeling and data environment

The block- and agent-based, domain-specific computational modeling environment used in this study is MoDa (Eloy et al., 2022; Fuhrmann et al., 2022; Wagh et al., 2022), which was designed for middle school students and teachers to use in science classrooms. MoDa combines computational models using domain-specific code blocks (Wilkerson-Jerde et al., 2015) with the Bifocal Modeling framework, in which learners compare their computational models with real-world data (Blikstein, 2014; Fuhrmann et al., 2018). MoDa consists of a modeling area (built using Google's Blockly library), in which students can drag and drop blocks to program agent-based models that run on the NetLogo engine (Wilensky, 1999). It also includes a real-world data area with videos serving as visual data. In the unit described in this paper, this area includes two videos of ink spreading in hot and in cold water (Figure 1, left). The simulation area includes phenomenon-relevant parameters (e.g., temperature) that students can adjust to evaluate their models. The code library includes blocks for the canonical explanation (i.e., the "bounce off" block that changes heading on collision) of diffusion and typical non-canonical student explanations such as “attach” that makes two particles stick together and “erase” that deletes a particle (Figure 1, right).

Figure 1

The MoDa modeling and data environment (left) and code blocks (right) for ink diffusion in water

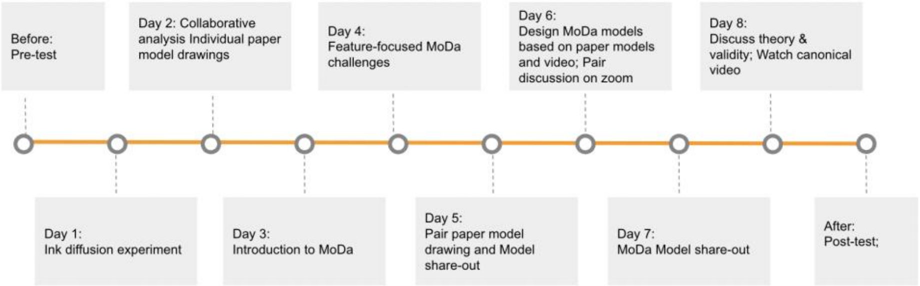


Participants, settings, and instructional sequence

Participants were 6th grade students in a private school in California. Across two classes with the same teacher, 16 students consented to participate (8 girls, 6 boys, and 2 non-binary students). They conducted a diffusion experiment to compare the rate of ink spread in hot and cold water and drew paper models to explain the difference in the rate of spread across the two conditions. Students used MoDa to program computational models to explain their observations and shared both their models with the class for feedback. On the last day, students discussed the validity of their models and watched a video of the canonical explanation for diffusion. All names are pseudonyms. The science teacher has been part of this project for 2 years and participated in professional development and co-design sessions with the project team. The unit occurred over eight class periods and included activities to explore ink diffusing in hot and cold water (Figure 2). Although diffusion is an important concept in science curricula (NGSS, 2013), it can be challenging for students to learn. Diffusion is the net movement of any substance from a region of higher concentration to a region of lower concentration as the result of individual molecules bouncing off one another during the course of Brownian motion. Diffusion occurs faster at higher temperatures because temperature is expressed, molecularly, through an increase in Brownian motion. The science classes did not meet every day of the week, so a few days passed between days of the instructional sequence.

Figure 2

The diffusion unit’s instructional sequence



Data sources and analysis

To identify students’ different explanations for diffusion, we analyze videos of students designing MoDa models (Day 6) and of students presenting their models to their classmates (Day 7). We then trace these explanations back to their origins in earlier data sources (pre-test responses and drawings on Days 2 and 5, respectively) and to their conclusions in students’ post-test responses to construct progressions of students’ explanations through the unit. We marked moments in which students either changed or articulated having changed their explanations and we identified what factors contributed to the shift. This analysis was done independently by the first author and two other co-authors. The above data sources were coded using grounded coding (Corbin & Strauss, 2014) to identify factors that led to students’ shifts. We construct three cases that typify both the non-canonical ideas that students shared and their trajectory toward a shift to a canonical understanding of diffusion.

Results

Our analysis revealed that students were able to express a range of ideas to explain how diffusion works through their computational models. In total, we identified nine kinds of explanations about diffusion expressed in code. We identified three factors that played a key role in shifting student thinking towards more canonical explanations: the availability of domain-specific blocks to model non-canonical ideas, consistent access to the phenomenon through the video data within MoDa, and model presentations to the whole class. Below, we illustrate three initial non-canonical ideas that students expressed while designing a MoDa model for diffusion: the barrier model, the attach model, and the density model. For each idea, we present examples of how students stated, drew, and coded it in MoDa, and how their ideas shifted towards the canonical explanation.

The barrier model

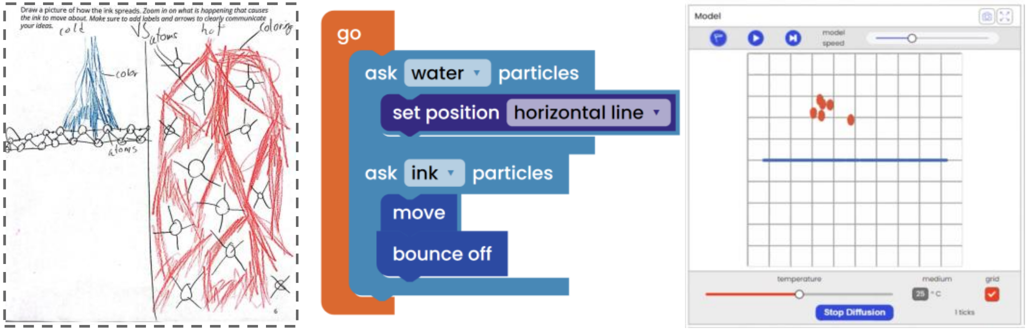
In their first non-canonical model, Johana and Ted had cold water particles create a barrier or border that blocks the ink particles from spreading throughout the glass (Figure 3, left). By the time they created the pair drawing on Day 5, Johana and Ted had expressed the canonical effect of temperature on ink and water particles ("When the water or ink molecules are warm, they move/spread faster. When they are cold, they move/spread slower.") but maintained a non-canonical explanation of particle interaction. While creating their MoDa model on Day 6, Johana and Ted coded the barrier model.

> *Ted: We need to fix that horizontal line thing.*
> *Johana: Is it supposed to be like a barrier or something?*
> *Ted: Yes, I bet it can still pass it through.*
> *Johana: If we make it so they have to bounce off, then it won't be able to pass through it.*

In creating their barrier model, Johana and Ted included the canonical "bounce off" particle interaction to prevent the ink particles from passing through their water barrier (Figure 3, middle). By adding drops of ink above this water "barrier," the students kept the ink at the top of the simulated beaker (Figure 3, right).

Figure 3

The barrier model: Johna and Ted's model drawing (left), the code (middle) and simulation (right).



Draw a picture of how the ink spreads. Zoom in on what is happening that causes the ink to move about. Make sure to add labels and arrows to clearly communicate your ideas.

```
go
  ask water particles
    set position horizontal line
  ask ink particles
    move
    bounce off
```

After a few more revisions to their code, primarily focused on the ink particles' movement, Johana recognized an important discrepancy between their simulation and the video data.

> *Johana: Even if we get this to work, if the border is on the top, it won't let the ink go to the bottom, right? And doesn't, every time when we see it [in the video], it comes down towards the bottom? Maybe here, let me try something. [...] So, our initial idea was to create a border at the middle, then we realized that even if we programmed that, we would have to program them to bounce off, right?*
> *Instructor: Yes*
> *Johana: So they would be staying at the top, and that is not what it looks like in the actual thing [the video].*
> *Instructor: Oh so you revised your model.*
> *Johana: So now I am more, leaning towards the bounce off model.*

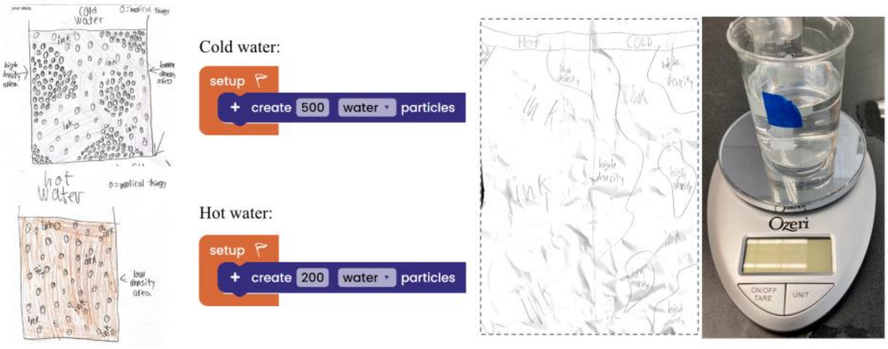
In the whole classroom model presentation on Day 7, Johana and Ted had not yet finalized their code but emphasized that *"we had a border [barrier] and we are going to take that away. So it's just they are bouncing off* *of each other and, again, if something is moving quickly and it bounces off, it is going to travel further. If something is moving slowly, and even if it bounces off, it is not going to travel as far."* They explained the reduced spread in cold water solely as a result of temperature, in line with canonical science.

The density model

Introducing the variable of weight to the system, Miguel expressed the idea that hot water particles were lighter than cold water particles. As early as his Day 2 drawing, he explained that *"The ink in the cold just sank to the bottom of the glass. It might have lower density, so there is more space for the ink. It might have been the only place it could move into."* In his drawings (Figure 4, left), Miguel's "density theory" implies pockets of heavier, more densely packed cold water particles, where ink has minimal open paths ("places") to spread. In contrast, he understood hot water to be uniformly less dense, allowing the ink to diffuse everywhere throughout the glass.

Figure 4

The density model: Miguel and Wade's model drawing (left), code (middle) and experiment (right).



Cold water:

setup
+ create 500 water particles

Hot water:

setup
+ create 200 water particles

On Day 5, when Miguel and Wade coded their density model, they created more water particles for the cold water condition and fewer particles for the hot water condition (Figure 4, middle). In Day 6 pair drawing, they created a density model, but after a discussion with the teacher, Miguel decided to test his dense theory by using the scale in the classroom (Figure 4, right). When he learned that the hot and cold water beakers weighed the same, Miguel balled up his paper model and threw it in the trash (note the wrinkle lines in Figure 4). Still, he maintained the density theory going into the Day 6 computational model presentations.

> *Miguel: First set it to 203 [particles]… this right now is hot water … I basically modeled density by the amount of water particles on the grid… I know hot water has a lower density than cold water, so there are less particles to model a lower density.*
> *Instructor: (plays simulation and video; class notes discrepancies) How can we model the cold water diffusion?*
> *Miguel: Set water particles to 500.*
> *Instructor: (plays simulation and video; class compares) … What are you thinking about density based on what we just saw? (7 second pause) Did you notice a huge difference between hot and cold when you changed the density?*
> *Miguel: Uhh, yeah, it… one seemed… I don't know, not really.*
> *Instructor: I didn't either! I didn't notice too much of a difference, and I think that's really important information. What about anyone else? (solicits individual students for reactions)*

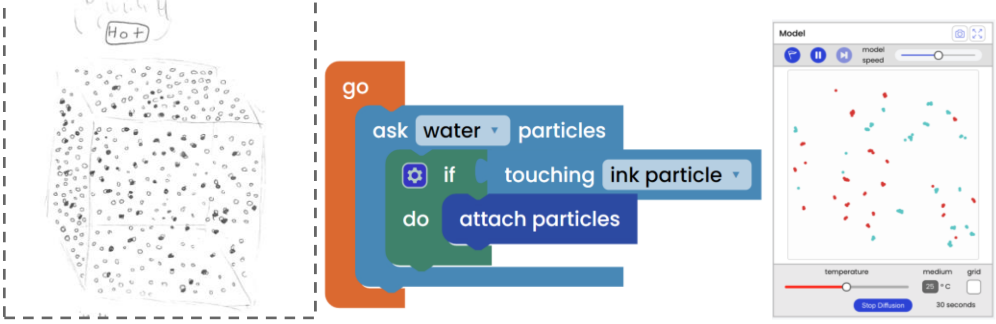
After the whole-class presentation comparing the fit between his hot and cold models with the other students' presentations and the corresponding videos, Miguel started to doubt his density theory ("I don't know, not really."). By the post-test, Miguel expressed the canonical theory for diffusion that *"since particles move faster in hot water, they will bounce off more things in a certain amount of time."* Wade, Miguel's partner who joined class remotely for the Day 6 model presentations, maintained the density theory through the post-test, explaining the difference between cold and hot water diffusion as "*cold has density, hot has air bubbles*."

The attach model

Qahira expressed the attach theory, the idea that the ink spreads in water because the particles "pick up" or stick to one another. Though Qahira didn't articulate the attach model on her pre-test or Day 2 drawing, she clearly expressed it in her Day 5 pair drawing with Rachel (Figure 5, left), which she captioned *"In the hot water the water particles move faster, as they move they pick up the ink particles around them spreading the ink faster. In the cold water the water particles move much slower than in the hot water so they pick up the ink and spread them much slower."* She then coded this model on Day 6 using the "attach particles" block (Figure 5, middle), which made the particles clump together (Figure 5, right).

Figure 5

The attach model: Qahira and Rachel's model drawing (left), code (middle) and simulation (right)



```
go
  ask water particles
    if touching ink particle
    do attach particles
```

As Qahira and Rachel stated while presenting their model on Day 7, they eventually changed their minds about the attach model.

> *Qahira: We realized that ink particles attached more than one ink particle to the water particles and making clumps and moving around like that. That wasn't really what we saw at all in the video. And, therefore, comparing real life with the model, we were able to figure out that one was not the right one.*
> *Instructor: Explain your thinking about this bounce off.*
> *Qahira: Well, our thinking was, if the particles of water are moving slowly in the cold water, they're not gonna hit the ink particles as fast. Therefore the ink particles have time to fall to the bottom and then, like, so, yeah. It will kind of look good, I guess, in the model, similar to what the water does in hot water and cold water [in the video].*

By coding their non-canonical attach theory and comparing the simulation to the video data, the students realized their theory wasn't accurately capturing the diffusion phenomenon. Qahira noticed a better fit between her simulation and the video when using the bounce off model. She maintained this canonical understanding through the post-survey, where she explained *"the hotter the water, the faster the water particles move. When the ink and water particles collide, they bounce off of each other."*

Discussion

Our findings highlight three key points. First, students brought a diverse range of ideas about the mechanisms underlying ink diffusion in water, some of them canonical and some of them not. Although limited in number, *the collection of domain-specific blocks available in MoDa* enabled students to express these diverse theories and test them by creating a diverse set of models. In contrast to the drawn paper models, which students completed before modeling their theories in MoDa, the dynamism of computer models seemed to prompt students to refine their non-canonical models in ways not afforded by drawing static models. Consistent with the literature on model-based learning, students began to shift away from non-canonical theories once they saw how those theories played out in action. Also consistent with conceptual change research (Smith III et al., 1994), students may have been more willing to change their ideas away from non-canonical explanations after seeing why those ideas don't function in the way they expect, in contrast to simply seeing why a canonical theory works. Second, *students' consistent access to video data* of the ink-in-water experiment within the modeling environment seemed crucial to their evolving theories of diffusion. Aligned with our previous work (Fuhrmann et al., 2018), comparing their models with experimental data highlighted discrepancies between the data and models, leading students to shift towards other, canonical explanations. For all students presented in this paper, the lack of alignment between the video data and their coded model (e.g., the simulated barrier blocking ink in ways that did not occur in the video, particles clumping in the attach simulation and not in the video data) led to a shift in student explanations towards canonical ideas.

Finally, *computationally representing their theories in code to the whole class* turned students' ideas into concrete artifacts available for consideration and critique by the class community. Computational models can serve as critical artifacts for sense making at the level of the classroom (Wilkerson et al., 2017). In presenting to the whole class, students shared their own ideas and listened to other students' ideas. The models presented by students in these whole class presentations led to students shifting their explanations and revising their models to reflect canonical ideas. Though not a focus of this analysis, we suspect the concrete yet dynamic representation of students' thinking afforded by MoDa also enabled the teacher to guide both individual and whole-class instruction toward disciplinary norms. Further work is needed to validate this assumption.

Conclusions

To conclude, MoDa and the unit described in this paper was used by these classes as an inquiry tool that enabled students to express, explore, and develop their ideas about a scientific phenomenon. Acknowledging students' existing ideas early on in the unit through the design of blocks in MoDa and accompanying activities supported students in developing a range of models including non-canonical models. Having access to real-world data to notice discrepancies through comparison with the model as well as presenting their ideas and computational models to the whole class supported students in iteratively refining their models to represent a more canonical explanation of diffusion.

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Recommendations from a Critical Landscape in the Field of Communication Sciences & Disorders

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Abstract: Systemic oppression impacts access to equitable opportunities and leads to barriers in learning from each other through meaningful communication. A recent scoping review of peer reviewed texts on how the field of Communication Sciences and Disorders (CSD) is identifying and challenging systemic oppression was conducted through the application of a critical analysis. The following paper aims to discuss the nine recommendation categories informed by the final 39 articles included in the review.

Introduction

Communication is powerful as it connects people to each other (Abrahams et al., 2022). However, communication binaries in terms of what is considered normal and pathological in the context of systemic oppression have led to a division between people. This has contributed to communication breakdowns, challenges in collaborative learning, and a crisis of connection (Way et al., 2018). The field of Communication Sciences and Disorders (CSD) has contributed to this systemic oppression. This is evidenced by the fact that our professional title has the world "pathologist" in it (i.e., speech language pathologist, SLP) and that our goal is effectively to simultaneously normalize and pathologize ways of communicating and learning. As a means to challenge this reality, CSD professionals can learn from literature recommendations that employ a critical analysis in order to subvert current power imbalances and work towards learning and communication equity.

Purpose

The purpose of this paper is to discuss the recommendations that resulted from a scoping review of peer reviewed literature using a critical analysis in the CSD field (Hussain et al., 2023). The goal of this paper is to discuss and learn from these recommendations to work towards communication equity.

Methods

A scoping review was conducted using the PRISMA Extension for Scoping Reviews (Tricco et al., 2018) to systematically map peer-reviewed literature from six electronic databases. The primary research question for the scoping review that gave rise to the recommendation categories discussed in this paper was as follows: what CSD literature applies a critical analysis? A critical analysis in the field is defined as work that: a) identifies and challenges systems of oppression, hierarchy, power relations (Collins, 2017; Sajnani, 2013), and "domains of power" (p. 27, Collins & Bilge, 2016). In turn, these power relations and domains of power re/produce inequity, exclusion, and dominant discourses within the field (Bianchi 2009; Dominelli, 2002); b) aims to understand marginalization as a function of social constructs (Pesco, 2014) rooted in systems like capitalism, colonialism, and cis-heteropatriarchy that perpetuate inequity. This includes "intersecting systems of power" (Collins & Bilge, 2016, p. 27) leading to a simultaneous culture of disabling and unjust institutions with systemic barriers and inequitable access to services, research opportunities, and professional training. This impacts those who are marginalized as a function of dis/ability, race/ethnicity/religion, age, gender, sexuality/sexual orientation(s), class/socioeconomic status, and/or intersecting systemic marginalization (Collins & Bilge, 2016; Crenshaw, 1989, 1990); c) provides recommendations to counter oppressive relationships and systems towards transformative change and social justice within the field (Asakura et al, 2020; Corneau & Stergiopoulos, 2012; Pesco, 2014; Rudman, 2018). This paper focuses on the latter, providing recommendations to counter systemic oppression towards transformative change and social justice. Recommendations are thematized into nine recommendation domains across the final 39 articles included in the review. While recommendation domains are identified and discussed separately, some domains overlap with each other and they are included in the quantitative portion of the analysis.

Results

Nine common related domains of recommendations were identified across the final 39 scoping review articles: 1) Identifying and countering colonialism (n = 22, 56% of 39 articles), 2) Indigenous epistemologies (n = 4, 10% of 39 articles), 3) advocating for the implementation of critical theories and critical conceptual frameworks (n = 17, 44% of 39 articles), 4) critically examining the construction of disability (n = 9, 23% of 39 articles), 5) trust and relationship building (n= 14, 36% of 39 articles), 6) changes to assessment intervention protocols (n= 10, 26% of 39 articles), 7) changes to the curriculum (n= 15, 38% of 39 articles), 8) awareness/changes in clinician's attitudes, values, and/or behavior (n= 18, 46% of 39 articles), 9) systemic and policy changes (n= 12, 31% of 39 articles). Identifying and countering colonialism is the highest-ranking recommendation domain.

Analysis and discussion

Identifying and countering colonialism

22 articles address colonialism. Some of these articles provide recommendations on decolonization, cultural safety, cultural responsiveness, countering the pathologization of Indigenous languages/Indigenous variations of English, and/or language policy in the context of the colonialism faced by Indigenous and/or Black people in Australia, Canada, Aotearoa/New Zealand, South Africa, and the U.S.A (Allison-Burbank, 2016; Brewer, 2017; Gillipsie, 2016; Gould, 2008; McLellan et al, 2014; Peltier, 2008; Pesco, 2014; Purdy, 2020; Zingelman et al. 2020). Several articles specifically discuss recommendations for clinical services for Indigenous people with acquired brain injury, including as a result of stroke (Penn et al., 2017; Armstrong et al., 2019; Brewer et al., 2016; Brewer et al., 2020; Penn & Armstrong, 2017), in the context of ongoing consequences of colonialism that inform health outcome disparities (Brewer et al., 2020). Other articles provide recommendations when addressing colonialism. They highlight the importance of acknowledging discrimination and racism as integral features of apartheid, western imperialism, and colonialism, which constructed/continue to construct the profession's whiteness, English language cultural imperialism, and the belief that white western cultures are superior to others (Khoza-Shangase & Mophosho, 2018; Kathard & Pillay, 2013; Pillay & Kathard, 2015; Pillay & Kathard, 2018; Pillay 1998; Pillay, 2003; Moonsamy et al., 2017; Pascoe, et al., 2020).

Applying indigenous epistemologies

Four articles assert the importance of incorporating (pan-) Indigenous perspectives, frameworks, research, and epistemologies (Brewer et al., 2016; Brewer 2017; Purdy, 2020; Zingelman et al., 2020) to facilitate SLPs' effective engagement with culturally responsive practices. Furthermore, studies highlight the importance of implementing Indigenist methodologies while collaborating with Indigenous peoples with the aim that the research will be decolonizing, transformative, and beneficial for Indigenous peoples (Brewer et al., 2016).

Advocating for the implementation of critical theories and critical conceptual frameworks

17 articles recommend that the CSD field implement specific critical theories and conceptual frameworks as a means to work towards social justice: a) active citizenship as a concept to counter dominant cultural narratives of disability and rehabilitation by focusing on relationships and community belonging (Pound, 2011); b) anti-racist, anti-oppressive, and social justice education as a way to go beyond cultural responsiveness when teaching CSD students to examine economic and social inequalities and respective manifestations of disparities at global and micro levels of daily interactions (Pesco, 2014); c) concepts associated with critical social theory to provide relevant and responsive services around the world (Hyter, 2014); d) critical science and decoloniality as a way to confront colonial and hegemonic global north practices which have shaped the field. More specifically, political consciousness and the relationship of laboring affinities (RoLA), whereby SLPs use equality and social justice as a lens for transforming practice (Karthard & Pillay, 2013) and shifting from dominant views of the global north with respect to health care delivery from individualized health care to transformative practices that are embedded in the communication context informed by social, relational, cultural, historical, linguistic, and political realities (Pillay & Kathard, 2018); e) critical paradigm and curriculum of practice in the context of cultural imperialism impacting training, policy and research practice particularly as it impacts Black South Africans (Pillay, 1998; Pillay & Kathard, 2015); f) critical speech language pathology to adopt contextually relevant methodologies (Penn 2004); g) epistemic disobedience by South African CSD professions to counter capitalist, colonial, and heteropatriarchal scripts and to re-imagine their own Afropolitan scripts (Khoza-Shangase & Mophosho, 2018); h) frameworks focusing on language and power such as critical social science for inciting change in problematic report writing and clinical practices in schools (Ng et al., 2014) and language ideology to describe the intersectionality of factors that lead to the exclusion of people in need of an AAC in multiple languages (Tönsing and Soto, 2020). Furthermore, Gould (2008) emphasizes the importance of understanding health policy as it

relates to language policy (versus the two being separate) in the context of the medicalization of non-standard language systems in existing power imbalances between Indigenous and non-Indigenous people; i) public health approach focusing on structural racism and inequities faced by Indigenous people in a colonized society, thereby addressing issues such as power, racism, and equity (Brewer et al, 2020); j) intersectionality as a lens to work with people's agency navigating sociolinguistic interactions in the context of macro-social structures leading to oppression based on social identities such as race, class, disability, and gender (e.g. Guerrero-Arias et al., 2020; Donaldson et al, 2017). Intersectionality is also recommended in tandem with the International Classification of Functioning, Disability and Health (ICF), gender-affirming services to ensure that family and social support systems can provide a holistic lens for the benefit of transgender individuals and their health (Jacob & Cox, 2017). It is important to note, however, that the ICF is critiqued because it does not address disabling conditions such as poverty and it is recommended to be combined with social and human rights models of disability (Kathard & Pillay, 2013); k) Universal Design for Learning to enhance speech language pathologists' practice with a strengths-based approach (Rappolt-Schlichtmann et al., 2018).

Critically examining the construction of disability

Nine articles specifically critique the field's approach to disability by recommending a shift from a deficit-based to a social model of disability and strengths-based approaches (Pound, 2011; Donaldson, 2017; Rappolt-Schlichtmann et al., 2018), critically examining the construction of disability such as stuttering (Watermeyer & Kathard, 2016), and reconstructing social roles after aphasia (Penn, 2004). Guerrero-Arias et al. (2020) specifically discuss the construction of disability identity at the intersection of other social constructs such as race, gender, and socio-economic status that have been borne from relations of power and power imbalances. Similarly, Gould (2008) challenges the disabling of Indigenous children who are second dialect/language learners. Meanwhile, Kathard and Pillay (2013) shift the concept of disability to the disabling contexts of poverty, exploitation, and oppression. They argue for the need to apply social and human rights models of disability. Ng et al. (2014) invite clinicians to critically examine language use in report writing with respect to disability and normality. They discuss how notions of normality, disability, failure, and success actively shape and impact a child's identity and opportunities. They assert the need to nuance how language is understood.

Trust and relationship building

14 articles recommend focusing on building trustworthy relationships between [non-Indigenous] clinicians and Indigenous clients, their families, and communities in order to decolonize and transform practice. This includes: listening to Indigenous clients' stories (Brewer, 2017), establishing and maintaining relationships with family and community members while being self-reflexive about the history of colonial intergenerational trauma experienced by Indigenous peoples (Gillispie, 2016; Brewer et al., 2020), addressing power differences (Brewer et al., 2016), building relationships with Indigenous health colleagues providing cultural support (Brewer et al., 2016), and building a strong and affirming therapeutic relationship shaped by the SLP's appreciation of the extended family, the person's worldview, the therapy setting, and resources used (McLellan et al., 2014). In some cases, the recommendations such as culturally responsive intervention are grounded in the needed recognition that mistrust towards colonial education and health systems exists among Indigenous peoples due to colonial trauma, including intergenerational trauma related to boarding/residential schools (Allison-Burbank, 2016; Gould, 2008). [Settler] clinicians and researchers are also recommended to decolonize attitudes and practice when working with Indigenous peoples, including recognizing that Indigenous peoples are best placed to work within their own communities (Penn et al., 2017). The term "settler" is added as a qualifier here to distinguish between settler and Indigenous clinicians/researchers. Pillay and Kathard (2015) highlight that traditional CSD curriculum typically entails disrupted and disconnected relationships with populations (e.g., site placements). They argue that longitudinal engagement with populations is important to facilitate a sense of belonging. Similarly, Pound (2011) discusses strong, reciprocal, and healthy relationships (including the importance of friendships), and community belonging while exploring the concept of active citizenship to support user-led projects and leadership of those who have a communication disability. This is echoed in Purdy's (2020) article about Māori culture focusing on lasting relationships, and therapeutic relationships being centered around co-constructing goals, as opposed to the healthcare provider having all the power. Jacob and Cox (2017) discuss the importance of familial and social support in the lives of Transgender people. They assert that healthcare professionals are key in disseminating accurate information to prevent family rejection of Transgender individuals. This recommendation is also classified under the importance of relationship and trust building. Meanwhile, Ng et al. (2014) recommend clinicians to be critically reflective in writing recommendations to school-based professionals. The authors assert the importance to phrase reports that facilitate collaborative dialogue versus directive language. Finally, Smith

(2020) asserts the importance of clinicians building trust with Transgender clients in tandem with cultural competence and empathy.

Changes to assessment and intervention protocols

Ten recommendations focus on making shifts in assessment and intervention approaches, including broad shifts from individual focused approaches to those that are contextualized within the given political, social, linguistic, cultural, relational, and historical realities (Pillay & Kathard, 2018). Pillard and Kathard (2015) assert that the most vulnerable and poorest populations will not be served within a healthcare model that only focuses on the individual. They argue that population-based interventions need to be implemented to address service inequities. Others recommend that clinicians use non-standardized assessment tools (e.g., dynamic assessment), protocols with the aim of effectively differentiating between language disorders and language/dialect differences, and questioning the validity of colonial languages being used as standards to evaluate speech-language proficiency for Indigenous people (Gillispie, 2016, Gould, 2008; Peltier, 2008). Others argue for cultural responsiveness (Pesco, 2014), and strategies such as considering population diversity related to immigrant generation status, age of exposure to English, specific types of bilingualism (Khamis-Dakwar & DiLollo, 2018), and strategies informed by an understanding of racial microaggressions and the impact of colonial trauma during assessment and intervention (Allison-Burbank, 2016). Gould (2008) asserts that the educational system must ensure that assessments for Indigenous children occur with full support and in collaboration with children's families. Pound (2011) uses the concept of active citizenship to argue for peer support to focus on personal development, social exchange, and community building for service users' "being, belonging, and becoming" (p. 201). Finally, Shefcik and Tsai (2021) make a specific recommendation with respect to assessing voice related experiences among non-binary individuals by using the Voice-related Experiences of Nonbinary Individuals (VENI) while recognizing that further psychometric evaluation is needed.

Changes to the curriculum

15 articles recommend changes to curriculum. A couple of articles recommend primary school curriculum changes (e.g., cultural concepts and native languages) so that they are relevant for Indigenous children and permissible by the child's family and community (Gillispie, 2016; Allison-Burbank, 2016). One article addresses demands for reviews of South African language policies within higher education and the need for these policies to be "Africanised" (Pascoe et al., 2020, p. 109). One article recommends adopting a neurodiversity lens and strengths-based approach to intervention with students with dyslexia by applying a Universal Design for Learning (Rappolt-Schlichtmann, et al., 2018). One article focuses on clinicians learning from service users. More specifically, Pound (2011) recommends the importance of creating opportunities and conditions for people to develop as active citizens and to see them as colleagues, providers, and role models. The author specifically discusses an example whereby people with aphasia were trained to have conversations to provide feedback to health care staff on ways the latter can improve their communication with the aim of making services more accessible. The other articles refer to changes in professional training for audiology and SLP students with a specific focus on coursework/modules on: a) case studies from research literature for SLP students or SLPs engaged in professional development as a way to reflect on how SLPs and Indigenous parents / educators can discuss what is deemed important in children's development and education (Pesco, 2014), b) critical thinking in cultural competency training of graduate students when working with Arab Americans (Khamis-Dakwar & DiLollo, 2018) and Transgender people (Jacob & Cox, 2017), c) ongoing critical self-reflection and learning culturally responsive intervention when working with Indigenous peoples in addition to understanding Indigenous demographics, region, and history (Allison-Burbank, 2016), d) going beyond English when teaching SLP students phonetic transcription in multilingual settings (Pascoe et al., 2020), e) and implementing Africa-centered courses and a postcolonial stance in a broader context of a decolonized South African curriculum (Khoza-Shangase & Mophosho, 2018; Moonsamy et al., 2017; Pillay & Kathard, 2015). More specifically, CSD professions are recommended to specifically introduce political consciousness and address imperialism, colonialism, and apartheid (Khoza-Shangase & Mophosho, 2018; Pillay & Kathard, 2015). In the author's argument for the application of curriculum of practice to the entire CSD field, Pillay (1998) states the importance of understanding *why* a given curriculum is taught, *to whom* the curriculum is being taught and *who* is teaching the profession. This way, CSD students can better understand underlying beliefs and values informing the dominant curriculum, including the ways in which time is not spent on building long-term relationships with a given population and that this needs to change (Pillay & Kathard, 2015). Pillay and Kathard (2015) also recommend the democratization of classrooms whereby future professionals are trained in dialogical models, whereby collective participation is valued. Lastly, Tönsing and Soto (2020) advocate for attracting students from diverse language and cultural

backgrounds to programs (including for AAC training) while encouraging them to be meaningfully collaborative, reflective and responsiveness practitioners.

Changes in clinicians’ attitudes, values, and/or behavior as this informs service delivery

18 articles recommend awareness of/changes to attitudes, values, and/or behavior. Several articles specifically focus on work with LGBTQ+ people, recommending affirming practice (Taylor et al., 2018), cultural competence, empathy, trust building (Smith, 2020), and the use of Voice-related Experiences of Nonbinary Individuals (VENI) as a questionnaire specifically designed to assess diverse voice-related experiences among non-binary people (Shefcik & Tsai, 2021). Khoza-Shangase and Mophosho (2018) recommend that institutions and service delivery in South Africa be Africanized. By advocating for curriculum of practice, Pillay (1998) questions clinicians’ fundamental beliefs about communication and its constructed disorders as informed by an English imperialist rooted framework of practice. Some authors recommend the importance of CSD students better understanding underlying beliefs, values, power, and the nature of the relationship between client and therapist while reflecting on principles of equity, accountability, and mutual engagement (Pillay & Kathard, 2015; Pound, 2011). Similarly, Purdy (2020) argues that [settler] clinicians shifting from a traditional western view of health to an Indigenous worldview may facilitate cultural responsiveness and safety in clinical and research practice. Pillay and Kathard (2018) assert that valued beliefs about communication, hearing, and swallowing disabilities will shift when applying a South African/postcolonial or Southern discourse to disrupt the global north’s colonial imposition of its values on communication. In order for service providers to interrogate inequity in intervention services in South Africa and the United States (U.S.), the use of political consciousness, population-based (vs individual only) concerns, professionals challenging their cultural assumptions, and responsive clinical approaches (Kathard & Pillay, 2013; Hyter, 2014; Tönsing & Soto, 2020) are recommended. This dovetails with similar recommendations embedded within a critical thinking cultural competency training whereby graduate students explicitly discuss anti-Arab and anti-immigrant attitudes in the United States and respective impacts on service delivery (Khamis-Dakwar & DiLollo, 2018). Similarly, Pascoe et al. (2020) discuss potential attitudinal changes in SLP students through phonetic transcription training in the languages of South Africa as a way to change SLP students’ attitudes so that they are better prepared to work in multilingual environments. Service delivery recommendations also include centering participants’ (e.g., people who stutter) knowledge through narrative therapy (Leahy et al., 2012). Self-awareness and the decolonization of attitudes, belief systems, and practices as part of colonial institutions is recommended (Allison-Burbank, 2016; Penn et al., 2017). Finally, a shift in attitudes that adopt a neurodiversity and strengths-focused approach for people with disabilities, including students with dyslexia, is recommended (Rappolt-Schlichtmann, et al., 2018).

Systemic and policy changes

12 articles make recommendations related to policy and systemic changes. Moonsamy et al. (2017) argue that SLPs and audiologists must advocate for systemic change with respect to accessibility to relevant resources and services for marginalized populations in both urban and rural areas in South Africa. Kathard and Pillay (2013) use the lens of political consciousness to discuss South African policy-driven opportunities, such as the National Health Insurance, for SLPs to promote public health equity. Penn et al. (2017) recommend advocating for Indigenous peoples with communication disorders across clinical, community, and policy contexts in tandem with trust building. Navsaria et al. (2011) argue that there is a need for SLPs in South Africa to expand their services in ordinary schools given that there is a large student population at risk of learning difficulties, including literacy. Pascoe et al. (2020) discuss the potential of phonetic transcription as a way for SLP students to engage with language diversity and multilingualism as a concrete way to facilitate institutional inclusivity and social cohesion as per the Revised Language Policy for Higher Education in South Africa. Simon-Cereijido (2017) argues that SLPs need to continue advocating for multilingualism and protecting clients from language policies that violate their communication rights. Similarly, Khoza-Shangase & Mophosho (2018) assert a transformation in language and clinical training policy in South Africa that respects people who speak several languages, not solely English or Afrikaans. There is also a recommendation that people within CSD adopt public health roles particularly when working with Indigenous people with aphasia to discuss issues of racism, power, and equity, and to work towards revised service delivery models that are sensitive to societal factors such as displacement, mobility, struggle, and socio-political history (Brewer et al., 2020; Penn & Armstrong, 2017). This includes the educational context whereby educational policy should not be based on assimilation and paternalistic practices towards Indigenous students, and instead culturally responsive models need to be adopted (Gillispie, 2016), including language testing (Gould, 2008). Pillay (1998) argues that the curriculum of practice promotes policy as practice in terms of understanding the relationship between policy and practice with respect to who is developing a given policy and the process of policy development itself in the given political context. More specifically, context-facilitated

learning, which demands a critical, political, social, and historical reading of the situation to inform policy changes towards equity and decolonization.

Conclusion

The current paper discussed recommendations provided by CSD literature based on a recent scoping review of literature applying a critical analysis. Nine recommendation domains were discussed: identifying and countering colonialism; using Indigenous epistemologies for the benefit of Indigenous Peoples; advocating for the implementation of critical theories and critical conceptual frameworks; critically examining the construction of disability; trust and relationship building; changes to assessment/intervention protocols; changes to curriculum and learning; awareness/changes in clinicians' attitudes, values, and behavior as this informs service delivery; systemic and policy changes. This paper aims to contribute to a flourishing landscape of criticality, learning, and moving towards deeper actions in confronting and dismantling unjust CSD practices as a way to work towards collaborative learning, human connection, equity, communication, and social justice for all.

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Complex Dynamics of Epistemic Agency in a College Physics Lab Course

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Abstract: We study students in a college physics lab course encountering a designed-for discrepancy between their data and the relevant physical model. We examine the moment-by-moment dynamics of the groups' efforts at problematizing and sensemaking, with a specific focus on *epistemic agency*. Drawing from prior studies of agency – as it relates to learning (Damşa et al., 2010), inquiry (Keifert et al., 2018), and scientific practice (Pickering 1995) – we study the complex ways in which epistemic agency manifests (and doesn't) in the students' work. Our analysis suggests several influences on the students' agency, including features of the social and material context as well as how the students frame what it is they are doing (Hammer et al., 2005), in the lab as a whole and in moments within it. The findings suggest implications and questions with respect to designing labs to support disciplinary practices.

Introduction

There are several efforts at reform in introductory physics labs to position students with greater epistemic agency, in line with many years of calls for reform in physics instruction (Otero & Meltzer 2017; Miller et. al. 2018). Rather than guide students toward "discovering" canonical results, curriculum developers have been designing activities to generate uncertainty (e.g., Phillips et al. 2021), often guiding students to experience particular empirical discrepancies. These labs aim to promote students' problematizing (Phillips et al., 2017) and sensemaking (Odden & Russ, 2019). Evidence to date shows that sometimes students take up these opportunities (Sundstrom et al., 2020), and sometimes they do not (Phillips et al. 2021) – more study is clearly needed.

We build on this previous work and draw as well on research in other contexts, including elementary school science (Manz, 2015; Louca et al. 2004) and college biology (Hayes & Gouvea, 2020), to study why, how, and when students in reformed undergraduate physics labs take up opportunities to act as epistemic agents. We adopt Miller et al. (2018)'s definition of epistemic agency as "students being positioned with, perceiving, and acting on opportunities to shape knowledge building" (p. 1058). In our case, lab is designed to provide students with opportunities to shape knowledge building. We attend to students' perception of these opportunities, which we see as part of their framing what is taking place.

Framing in the sense we adopt here refers to how an individual or a group understand what is taking place (Tannen, 1993). To frame a situation is to tacitly answer the question "what is it that's going on here" (Goffman, 1974) and how an individual or group frames a situation shapes their understanding of what could happen, what features of the event require attention, and what qualifies as appropriate action (Hammer et al., 2005). For example, Phillips et al. (2021) found that students who framed the learning activity as confirming a known result or as a series of hoops to jump through to complete the assignment did not problematize upon encountering a discrepancy between their data and the models they were testing. Hayes and Gouvea (2020) similarly found that students framing lab as "about demonstrating a target idea" and that destabilizing this framing helped students better see opportunities to construct knowledge.

Like Hayes & Gouvea (2020), we examine how students perceive and take up opportunities to engage in knowledge building. Through an analysis of the moment-to-moment evolution of these students' framing as they work in the lab we explore questions of why, how, and when they take up opportunities to act as epistemic agents.

Theoretical framework

We draw from Damşa et al. (2010) and Keifert et al. (2018) to identify evidence of epistemic agency. Damşa et al. (2010) outline *shared epistemic agency* as a descriptive construct to understand collaborative efforts to create knowledge objects. Damşa et al. (2010) focus on actions and outline two main dimensions of shared epistemic agency: actions that lead to the creation of a knowledge object (epistemic); actions that organize the process of knowledge creation (regulative). While Damşa et al. (2010) provide a way to identify when collaboration in learning environment involves epistemic agency, Keifert et al. (2018) develop a conceptualization of epistemic agency centered on the experience of participants engaged in inquiry; their lens "focuses our attention on what participants do that signals productive work *to them*" (p. 2). Specifically, Keifert et al (2018) examine the interactions in which participants negotiate the context of inquiry.

Additionally, we use Pickering's (1995) account of experimental science as a dance of agencies to connect the students' enactment of epistemic agency to disciplinary practices. In this view, scientists set up an experimental apparatus and then position it with a kind of agency: they see what it has to say, what it contributes to knowledge, in the data it produces. The dance is between scientists' agency and the materials' – "a dialectic of resistance and accommodation" (p. 22) – a complex and cyclic interaction that, hopefully, progresses toward alignment. This formulation provides a detailed account of meaningful activity in experimental science.

Course context and data collection

The data analyzed here comes from an introductory physics lab in a large, four-year research university in the northeastern United States. The data were produced as part of a project to study students' thinking in labs designed to promote student autonomy in devising experimental methods and drawing their own conclusions (Descamps et al., 2022; Philips et al., 2021). Graduate or undergraduate teaching assistants taught sections of up to 14 students. Instruction occurred in the Spring of 2021 when the course was operating in a hybrid format due to the COVID-19 pandemic. Students worked in groups of two or three, with some students in-person and others virtual. Students recorded their video calls, and we had a camera and audio recorder in the room.

The first author watched the videos, taking notes and logging activity in 5-minute intervals (Derry et al., 2010). He then selected candidate episodes for workshopping (Hammer et al., 2018), focusing on episodes of (potential) sensemaking and scientific inquiry (Odden & Russ, 2019; Watkins et al., 2018). He prepared analytic memos (Bailey, 2007) to present to the research team, constructing and revising based on discussion and feedback. Like in Hammer et al., (2018), the team considered a range of theoretical scales, from individuals' thinking (diSessa, 1993; Tannen, 1993) to social interactions and activities (e.g., Jordan & Henderson, 1995)

In this episode, two of the students, Peter and Holly, are in-person at the same lab table; their other lab partner, Judy, is virtual (all pseudonyms). The students are in the second week of the first lab activity of the semester: investigating Galileo's claims that the period of a pendulum does not depend on either the mass of the bob or on amplitude. In fact, the period does depend on amplitude, which careful measurement can show; the lab is designed for student to encounter and grapple with that discrepancy. The instructions for the lab ask students to provide an "unambiguous statement" of whether their data do or do not deviate from Galileo's claims. We turn now to our data and analysis of the students at work, as they work to analyze their data.

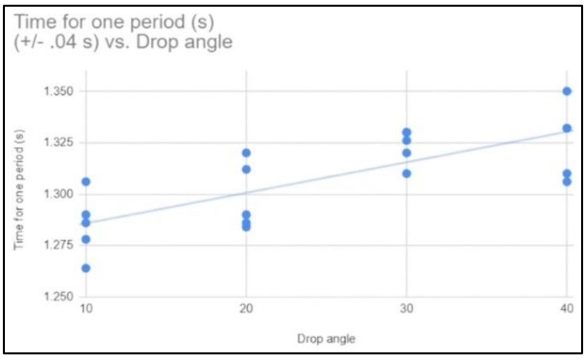
Data and analysis

We present the data and analysis in four sections, beginning with the students first noticing the discrepancy, continuing with their taking two different approaches to addressing it, and finally their arriving at their conclusion. Line numbers refer to the full transcript, which we excerpt here.

The students encounter a discrepancy

Holly, Judy, and Peter produced data for amplitudes of 10, 20, 30, and 40 by timing five swings of their pendulum and dividing by five to find the average period; they did five trials at each amplitude. They estimate their uncertainty in timing to be ±0.2 seconds, which makes the uncertainty in their period measurements ±0.04 seconds. To show their data, we provide as Fig. 1 a graph the students produce toward the end of the lab period.

Figure 1
Students' data



This episode begins immediately after they finish collecting data, a little over an hour into their lab period.

01 Peter:	I mean so we are clearly seeing like very slight changes. I know, I think we had the same thing last time that the amplitude seemed to change it just a tiny bit. I wonder what about like how we're doing it is making it change it consistently?
02 Holly:	Is it not supposed to change?
03 Peter:	Uh, it should be the same regardless of amplitude. But I guess there must be something else that we're doing that's making it change just a little bit. Although it's very insignificant.
04 Holly:	I wonder if it's, um, friction. Like, is it— does this move back and forth [reaches up to examine pendulum string]— No

Peter immediately sees the data as "clearly" showing "slight changes" in the period with amplitude, which he remembers their seeing in the first lab session as well. He locates the problem in their doing of the experiment: something they did made the data change in this way. With Holly's question about what is supposed to happen and her suggestions in line 4, we infer that both Peter and Holly are framing their lab activity as confirming a known, correct result. Judy, on the other hand, suggests a different interpretation of the data:

08 Judy:	But I feel like the correlation is too strong to ignore, like it— like it makes sense, like it's decreasing very slightly as you decrease the amplitude
09 Peter:	Yeah, I mean, I think looking at our data, it would seem that it is related, but just at a really small like ratio I guess, so like the amplitude has a really small effect. But like, I know, theoretically we shouldn't be seeing any effect. So I'm wondering what about what we're doing is making it look like that.
10 Holly:	I don't know. Like, yeah, like where is our error coming from?
11 Peter:	Uh… also, what parts could have error? The drop, the starting and ending of the timer

In line 8, Judy begins to argue that the amplitude does have an effect on the period. Her saying "but" suggests she distinguishes her interpretation from Peter's and Holly's; that the effect they see in their data could be a feature of the phenomenon. She does not seem to frame the goal of their work as confirming Galileo.

In line 9, Peter acknowledges the logic of this reasoning, that "it would seem" the period changes, based on their data. Still, he continues in line 9 to defend his articulation of the problem. He clearly vests epistemic authority in Galileo (or perhaps the instructor). At the same time, he readily admits that their data is saying something different; he and Holly frame the problem they need to solve as finding the source of their "error."

The problematizing evident in these first 11 lines is a clear demonstration of epistemic agency: the students identify a discrepancy between their data and the theoretical model and then, in dialogue with each other, they refine their understanding of what is the problem to solve. For both Damşa et al. (2010) and Keifert et al. (2018), students developing ideas that help regulate the direction of their intellectual work is fundamentally epistemically agentive (inter)actions. In addition to the social negotiation occurring here, the apparatus and phenomenon are central to the emergence of epistemic agency.

Peter and Holly troubleshoot their apparatus

Following Holly's comment in line 10, she and Peter begin to brainstorm ideas for where their error could come from. Judy does not participate. Instead, after Peter remarks "Although it's very consistent for some reason" (line 13) Judy suggests they graph their data and starts working on that. In other words, she decides to produce a new knowledge object. Meanwhile, Peter and Holly try to figure out their problem.

19 Holly:	I wonder if error could also be in the drop itself. Like if you don't just like [random noises] take your hand directly away, like if it's like cushioning it at all. But like, I don't know how that would
20 Peter:	Yeah and, I mean, would that have a larger effect at higher drop height? That's the question.

21 Holly: I don’t know. I mean actually it might
22 Peter: It might. Cause I think, like I’m doing my best to release the ball at once and obviously I’m not
23 Holly: Right. I see and there’s nothing you can do to make that better, unless you have like a literal like hard thing holding it up and you take that away immediately, like there’s no way to remedy that.
24 Peter: Yeah, so I mean, that could be it. Do we think, can we think of a reason why it would be a larger effect at a higher drop. I mean, say it’s staying exactly where it is for a little bit before it starts to fall.
25 Holly: Um, well I don’t know. Cause like if you only bring it out to here it has more velocity in the x direction than the y direction whereas up here [pendulum stand almost falls over] […] If you bring it up here, like it has like, past— well it’s not like we’re going passed 45 degrees, but like there’s more velocity in the y direction up, up at a higher point… maybe

Holly suggests a possible physical effect that might affect the pendulum’s motion, perhaps in releasing the bob; Peter asks if that effect would vary with amplitude. In this way both students are focused on possible physical mechanisms that might explain the trend in their data. It is possible Judy’s critique had an influence – Judy told them not to ignore the correlation. Their first ideas, that the error might come from timing or from the drop, are not sufficient explanations to them. Rather, they are the beginning of a search for a mechanism that would consistently increase the period length as they increase amplitude. We see this troubleshooting work as an aspect of disciplinary practice as they are holding possible explanations accountable to the data.

Indeed, the troubleshooting seen above embodies Pickering (1995)’s description of scientific practice as a dance of agencies: the students have constructed a combination of instruments and machinelike human practices (e.g., stopping the timer) to capture the phenomenon of pendulum motion. Their experiment produced data contrary to their intentions and now the students are actively and intentionally working to accommodate this "resistance” (Pickering 1995) on the part of the materials. Holly’s and Peter’s work here involves grappling with and deconstructing the production of their data, a sophisticated epistemological framing (e.g., Hardy et al., 2020) that is nested within, and we suggest supported by, their confirmation framing of the lab as a whole. That is, they expect to confirm the authoritative claim, but the apparatus resists with discrepant data, and this prompts them to troubleshoot. The clear material resistance drives Peter and Holly to enact epistemic agency.

New ideas for data interpretation

A few turns of talk after line 25, Judy returns to the conversation to share with them the spreadsheet she has made, and Peter works to plot this data.

40 Judy: Cause, yeah um, it looks like it’s really linear.
41 Holly: Yeah.
42 Judy: Do you see this? [laughs]
43 Peter: Yeah. Wha— uh…
44 Holly: Guys we just disproved Galileo’s theory
45 Judy: It’s a literal straight line!
46 Peter: No no no, it’s it, this is not a straight line for the reason you think this is a straight line, look at the axes flipped [laugh]
47 Judy: But like it’s so straight, like the line is like
48 Peter: I mean the reason it’s straight is because we’re, this isn’t an actual x-axis on the bottom, like look at what the units are on the bottom
49 Judy: Oh, I’m so silly [laughs]

Judy’s sharing her spreadsheet prompts Peter and Holly to shift their attention back to the data. Looking at the clear, “straight line” of the graph, Holly and Judy conclude that they have disproved Galileo, that amplitude affects period. Holly, who was previously invested in figuring out how their experimental procedure caused error, now exclaims “we just disproved Galileo” (line 45). From her tone, it is not clear how much she believes this statement; perhaps she was less than fully serious. Judy, on the other hand, is clearly happy about this development.

Peter, however, notices a mistake in the graph that is the reason for the straight line. We do not have direct evidence of the mistake, but we reproduced what we suspect it was: they included the word "seconds" in the cells with their raw data, and the period values are to the left of the amplitudes. This would have Excel ignore the period values and plot (1, 10), (2, 20), (3, 30), and (4, 40) – a straight line that does not reflect their data.

Judy recognizes the mistake Peter identifies – "I'm so silly" – and in the work that follows she steps aside, asking, "Can somebody else attempt this, I'm, maybe I'm just terrible at Excel but it's literally just not letting me" (line 59). For the rest of the lab session, Judy's participation is notably diminished.

We return to the students' work as they examine a new graph of their data. Holly leans towards her computer and says,

64 Holly: It almost looks like it dips down at 30
65 Judy: Yeah, it could just be from like error. But they're all like 1.3 something, {like they're very close—}
66 Peter: {Oh. That's, that's that's} the issue, it's cause this was, uh, was 1.28 here and 1.33 and [Unclear] uh cause we had it 30 20 10 40

Peter and Judy briefly discuss some spreadsheet logistics and Peter narrates some data reformatting for about a minute before Holly makes another observation about their data.

69 Holly: It's interesting how much closer the 40-degree and 30-degree values are compared to the 10-degree and 20-degree ones
70 Peter: Yeah
71 Holly: So I wonder if using a bigger amplitude would have us— or, a larger amplitude would allow us to have more accurate results in accordance with the theory
72 Peter: It's possible. Yeah I think it would probably be easier to measure for larger amplitude because we are, you know, it's a more extreme peak.
73 Holly: So then maybe it is a timing error for the smaller ones.
74 Peter It might be.

In addition to her comments in lines 64 and 68, Holly's body language – leaning in towards her computer – is evidence she is focused on interpreting the data. Her observation and conjecture in lines 69 and 71 reflect and support a return to sensemaking, as she considers another possibility for explaining the discrepancy. Peter joins this work, articulating this explanation in his own words and elaborating on the mechanism.

Judy, too, seems to shift in her approach to the data and to the activity. Even though her comment in line 65 is an evidence-backed explanation, she now seems to view the data as relatively consistent. That said, Peter's comment in line 66 suggests that, perhaps, the current plot has the amplitude data incorrectly ordered. As figure 1 makes clear, reordering the amplitude data would undercut the evidence for a linear relationship, perhaps informing Judy's new explanation. Recall the dispiriting exchange in line 40-50, which could also have contributed to her shift. Additionally, that she says "just" seems to indicate that the abstract notion of "error" is a now sufficient explanation for the data, which is certainly a shift in her thinking.

In between lines 66 and 69 Peter generates a new and (likely) accurate graphical representation of their data. In contrast with their first sensemaking conversation in which Holly and Peter deconstructed their experimental set up to think through the possibilities for error, here, their sensemaking is grounded in their plot and data interpretation. In lines 69-74 Holly and Peter position their data as a legitimate source of information that needs to be explained and/or reconciled with the theoretical model.

Furthermore, the central idea of their discussion – perhaps there are larger timing errors for the smaller amplitudes because those are harder to measure – exemplifies the complex, entangled relationship between human and material agency that Pickering (1995) envisioned: "disciplined human agency and captured material agency are, as I say, constitutively intertwined; they are *interactively stabilized*" (p. 17). Holly and Peter claim here that certain configurations of their apparatus – which involves both instruments and machinelike human actions – enables them to capture the phenomenon and produce data more accurately.

Starting in line 74, Peter returns to tweaking the formatting of their plots. First, he seeks to plot "exact" averages of their trials, then tries to include the extrema of trend lines. That is, he wants to plot the trend line from the shortest period of the smallest amplitude to the longest period of the largest amplitude and vice versa in order to compare them (this is a technique the TA mentioned at the beginning of the lab when talking about how uncertainty measurements influence the conclusions you can draw from data). Before she joins Peter in figuring out how to plot such trendlines, Holly continues to make observations about the data.

Although we do not include the transcript (mostly discussion of Excel), it is important to point that this discussion, too, treats their data as a legitimate source of information. To use the language of knowledge-creation, Peter and Holly are invested in generating knowledge-objects to concretize their ideas; this Excel reformatting is a demonstration of shared epistemic agency. Notably, they engage in this behavior while still framing the activity as confirming a known result. Their (epistemic) agency is disciplined by their (epistemic) framing of the activity.

The students reach a conclusion

The students have excel put in a generic trendline for their data, which spurs the following exchange

92 Holly:	Unfortunately, it's not super horizontal
93 Peter:	Yeah, I mean it, I think actually it is close enough to horizontal because of how small our axis is. Like if I zoom this out, uh, if I go from like 0 to 2, like it's extremely horizontal
94 Holly:	Do we want to like make another copy of this graph, show a zoomed in version versus a zoomed out version?
95 Peter:	We could do something like that.
96 Holly:	And be like, despite what it looks like this line is actually fairly horizontal.

Line 92 is a representative description of how Holly and Peter have been interpreting their data: "Unfortunately, it's not super horizontal." Holly is honest about what their graphical analysis demonstrates and understands it to be a problem. While Peter had previously shared in this interpretation of their data (see line 1), his response in line 93 seems to be a departure: it's close enough to horizontal, it's *actually* not a problem. On its face, Peter's explanation is not based in physical or mechanistic reasoning – that the graph looks horizontal is the evidence.

Still, rescaling plots to gauge the relative size of an effect is a reasonable, if novice, analytic technique. It does not seem to us that Peter means to manipulate their data to hide this problem. In fact, following the exchange above (line 97), he asks Judy directly about her thoughts on this new zoomed out graph, clearly a bid for her participation, and perhaps a bid for consensus. In line 94, Holly signals her agreement by suggesting that they show both graphs. Holly has her own conditions for being satisfied with this explanation and conclusion to their inquiry: intellectual honesty and epistemic accountability.

Part of what makes Peter's invitation for Judy to participate notable is that Judy is largely absent from the later discussions. Judy responds to Peter's question by letting him know that she can't even see the graph that they are referring to. They work it out for her to see the graph, but it is clear (and unsurprising) that Judy not being in the room with Holly and Peter generates different experiences. For example, in line 75, Holly makes another observation about the data Judy starts to respond, but Peter talks at the same time and neither he nor Holly seem to recognize that Judy was cut off. Furthermore, the general tone and pace of conversation between Holly and Peter is notably different than when Judy participates. By the end, despite Peter's invitation to participate, she mostly remains quiet. In essence, we both see how intersubjectivity drives their enactment of (shared) epistemic agency and we see how constraints on that sharedness distort or inhibit epistemic agency.

After Peter shows Judy the zoomed-out graph it appears that Judy agrees with Peter's explanation. Less than a minute later, the TA enters their video call, which changes the activity and ends the episode.

Discussion

Trends in education research and contemporary national curricular standards have shifted toward objectives of students' *doing science*, seeking to "engage students in knowledge construction—to position them as doers of science, rather than receivers of facts" (Miller et. al. 2018, p. 1056). Yet, designing for doing science and effectively supporting students enacting epistemic agency is not simple (e.g., Manz, 2015, Sundstrom et al., 2020 Phillips et al., 2021). As more undergraduate science labs seek to promote disciplinary practices and epistemic agency, it is crucial to examine the dynamics underpinning the emergence of productive behavior.

Holly, Judy, and Peter's encounter with anomalous data – more specifically, the inconsistency between their results and their expectations – leads them to problematize, troubleshoot their apparatus, and produce various plots to analyze their data. They primarily work to build an explanation for their discrepant data and ultimately conclude that the effect they are seeing is insignificant. In this episode, Holly, Judy, and Peter are epistemically agentive: they take their data seriously as a meaningful reflection of the phenomenon they have constructed and, upon encountering unexpected results, enact various (epistemic) actions.

That they position themselves as epistemic agents while simultaneously framing the activity as confirming a known result is surprising. In previous studies examining student framing in instructional labs designed to support student agency (Smith et al., 2018; Smith et al., 2020; Phillips et al., 2021), researchers observed that students framing the activity as confirming known result did not take up epistemic agency. These students focused on producing or aligning their data with what they presumed to be the "correct" answer. As Philips et al. (2021) point out: "if a group of student expects to reproduce known results in the lab, they regard knowledge as something that will be given to them by the instructor or written resources rather than constructed by them" (p. 2). Indeed, as we see in line 9, Peter admits that just looking at their data would indicate amplitude has an effect, but the authoritative claim they have been given by the instructor paints a different picture; much of their intellectual work is driven by their commitment to an external epistemic authority.

Consider also the perspective of Reiser, Novak, and McGill (2017) who state that if students do not have a hand in articulating the overarching question driving their experimental work, then they cannot be "truly engaging in scientific and engineering practices" (p. 4). Once again, Holly, Judy, and Peter's commitment to an external epistemic authority drives their work – they frame the activity as confirming Galileo. Still, their framing shifts in subtle and complex ways throughout this episode. Nested within an overarching confirmation framing, the students engage in troubleshooting and data interpretation. They are not simply going through the motions of science, but agentively engaging in disciplinary practices.

Holly, Judy, and Peter view their data as a genuine problem and work to resolve it. In the beginning, all three participants signal, negotiate, and experience their efforts as productive inquiry. The material resistances they encounter motivate their intentional, disciplinary accommodations (Pickering, 1995). That they frame the activity as confirming a known result is a key reason that they seek out such accommodations. They attend to the production of their data and create, refine, and make sense of concretized conceptual artifacts; throughout, they wrestle with the entanglement of human and material agencies that facilitated the capture of this phenomenon. Through both conceptual and procedural actions, the students show epistemic agency.

We have identified several aspects of this learning environment that affected this agency: supportive social interactions and access to them, values of intellectual honesty and epistemic accountability, material resistances that are clear to the students, the freedom to create knowledge-objects, as well as their framing the activity as confirming a known result. The last may be surprising, as confirmation framing is generally associated with limited epistemic agency (Philips et al., 2021; Smith et al., 2020). Here, as in other cases (e.g., Jeon et al., 2023; Sundstrom et al., in prep), much seems to depend on the particular dynamics of the group. Idiosyncrasy is a general feature of complex dynamics, and it suggests limits on what curriculum and course designs can accomplish in themselves to support students' epistemic agency.

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Exploring Network Visualization of Data in Elementary Classrooms

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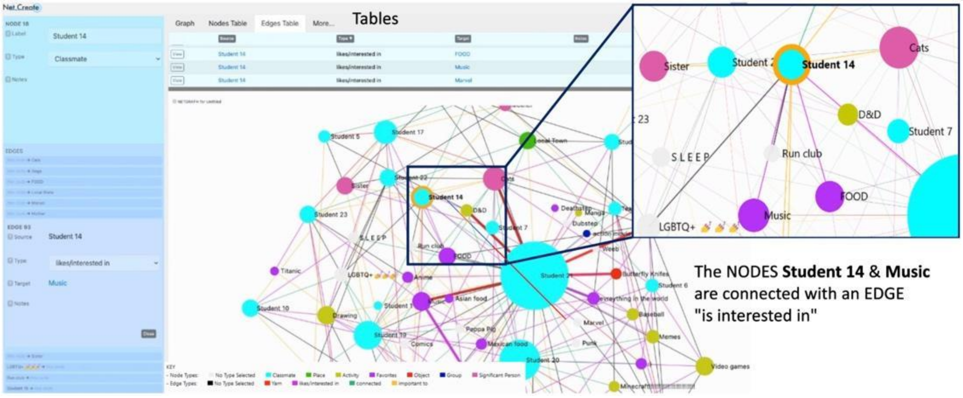
Abstract: This study aims to understand how elementary students can reason about data and data visualization through participation in thematic network visualization activities that integrate locally relevant, personally meaningful data. Young students constantly struggle to focus beyond individual data points to comprehend the overall trend for a complete dataset (Rubin, 2020). This study describes the design of a curriculum unit that incorporates a series of network visualization activities as building blocks to develop students' reasoning skills on aggregate patterns of the entire dataset. Our analysis draws on Cultural Historical Activity Theory (Engeström, 1999) to identify mediators within four network visualization activities and explicate how they transformed students' progressive understanding of the aggregate dataset they were exploring to make inferences.

Introduction

In an era of data deluge, the general public has more access to a massive amount of data and more opportunities to engage in data reasoning activities than ever before. Therefore, learning scientists have intensified efforts to prepare students for working with this kind of data in personally meaningful contexts (Rubin, 2020) and advocated for further strengthening young students' data reasoning abilities to support future learning (Jiang et al., 2022).

Fundamental data literacy activities include data collection, management, analysis, and interpretation using data visualization tools (Rubin, 2020). The expert's viewpoint on data exhibits a fluid and flexible switching between local and global observations (Ben-Zvi & Arcavi, 2001). Local data observation refers to a focus on individual data points, whereas global observations include summarizing the overall pattern of the entire dataset and making inferences from the patterns. This global observation serves as the foundation for the identification of broad patterns within the data. For example, to recognize specific data points as outliers, it is necessary to consider how they relate to other data values from a distributed perspective. However, young students frequently struggle to move beyond individual data points and find it difficult to reason about the overall dataset patterns, leading this to be a perennial barrier in data literacy education efforts (Rubin, 2020).

Figure 1
Students' identity network in Net.Create (left) with an expanded view of sample nodes (right)



The NODES **Student 14** & **Music** are connected with an EDGE "is interested in"

Visualization tools can be vital to support students' reasoning with data; for example, CODAP (Hardy et al., 2020) and TinkerPlots (Rubin & Morkros, 2018) support learners in viewing different data graphs and answering relevant data questions. The present study utilizes Net.Create (Craig et al., 2021), an open-source network visualization tool that enables multiple users to intuitively co-construct and co-revise network datasets. It has previously been successfully implemented in undergraduate-level humanities classrooms to engage students in sensemaking about historical figures, events, and their relationships with each other (Craig et al., 2021). Net.Create allows students to work on a collective network simultaneously by creating nodes of various types and linking each node via different kinds of edges. A node is a circle typically representing a person, place, thing, or event. Figure 1 depicts one Net.Create network used in the present study, illustrating students’ collective identity in the form of interests, experiences, and connections to each other. The nodes represent individual students, hobbies, or locations, and the edges (lines between them) represent relationships such as “likes/interested in.” Net.Create, like other network visualizations, can automatically adjust the size and positions of each node and edge based on how many connections a node has to other nodes. Node size is determined by the number of connections to other nodes, a value often labeled as degree centrality. By visualizing this as the size of the node, network visualizations show the relative importance of the influence of the individual nodes in the network. Users can further explore the influence of a node by manipulating the network physically, as larger nodes have more “gravity” and thus pull smaller nodes along. An edge’s thickness also communicates the number of connections between two specific nodes and may therefore indicate the impact of these relationships. In addition to the network representation, Net.Create includes other interconnected data displays (e.g., tables) to support students’ data reasoning across those displays (see Figure 1, top middle). Although the affordances of visualization tools support data exploration and interpretation, students need an entry point to engage productively with visualizations (Roberts & Lyons, 2020). Therefore, we designed a series of network visualization activities to mediate students’ data reasoning and interpretation as part of the present study. The present paper includes an analysis of this sequence to better understand how learners engage with the range of tasks and networks. We specifically aim to answer: how do different ways of mediating students’ exploration of network visualizations affect their reasoning about network datasets?

Theoretical framework

Our work is grounded in Cultural Historical Activity Theory, or CHAT (Engeström, 1999), and particularly takes up the notion of mediation to examine how different network activities transform students’ emergent understanding. Mediation (Vygotsky, 1978) is the idea that activities, including learning, are transformed by other elements of the social and cultural environment (Danish, 2014). These elements or mediators include tools, community, rules, and the division of labor that shape learners’ activity as they pursue a shared goal, often referred to as the object of activity (Engeström, 1999). The present study examines four network activities (Table 1) with objects ranging from creating/modifying networks to making inferences from pre-built networks. In each activity, our analysis focuses on how individual students (subjects) participate in the creation, modification, or analysis of network visualizations (tools) in different group settings (a division of labor). Their participation is also regulated by the classroom *norms and rules* of each activity.

Design

This study is housed within a larger project called Visualizing Funds of Identity (VFOI), which intends to leverage network visualization tools to help students understand more about themselves and their community as well as to hone their fundamental data literacy skills (Stiso et al., 2023). The entire curriculum spanned six forty-minute class sessions designed to engage students in a cycle of creating, modifying, and exploring network visualizations of different topics. Those topics were co-designed with one classroom teacher and utilized class-based projects and a board game format in order to display network values in locally and personally meaningful ways. The present study focuses on the ways that two physical networks and three digital networks mediated elementary students’ progressive data literacy skills. See Table 1 for a summary of the four network activities.

Table 1
A Summary of the four network activities

Topic	Format	Summary
Collective identity	Yarn network	Icebreaker to explore how a network represents people and relationships
Collective identity	Net.Create	Use Net.Create to learn basic network terms, how to create a network, and the value of network visualization compared to the yarn network
Chicken industry	Net.Create	Explore the meaning of sizes (node & edge) in a network visualization for a real-world context
Social media marketing	Net.Create and board game	Apply meanings of sizes and types of nodes and edges to a real-world context

Data sources and analysis

Twenty-three fifth and sixth-grade students from the Midwestern United States participated in this study, and seventeen of them completed both the pre-and post-tests. This analysis examined what students learned from their performance on the pre/post-test and their in-situ understanding that emerged through classroom activity mediation. The pre/post-test contains seventeen open-ended questions aimed at evaluating students' grasp of a range of practices of network visualization and data literacy. The authors iteratively developed and refined qualitative characterizations of students' understanding of the key concepts explored in their answers during the pre/posttests with a focus on data literacy concepts that were used to identify patterns in students' understanding. The classroom video data analysis began with reviewing and content logging students' recaps and debriefs of each activity across the six days of implementation. The present analysis focuses on four network activities, selected to provide a rich contrast regarding how the different modalities support a wide range of network utilization and, thus, aim to represent the potential of these kinds of activities rather than every single moment from the present study. Finally, all authors performed Interaction Analysis (Jordan & Henderson, 1995) to determine how students' understanding arises across those network activities and mediators that supported their emergent understanding through iterations of collaborative data sessions.

Findings

Pre/post tests

Analysis of these tests shows that students improved their understanding of what a network is, particularly how networks are made up of nodes and edges and their ability to interpret network visualization as a means of making sense of the underlying data represented within it. Findings also indicate that students began to recognize the practical uses of networks in real-world contexts. Students' explanations about networks shifted from vague references to a network as "a thing on the internet" to more robust technical definitions such as "a network is usually something online that shows how people might be connected to certain things." Students' interpretations of the network moved from initially describing details depicted in individual nodes (e.g., video games, Minecraft) to indicating a rich appreciation of the relationships between multiple nodes within the network. For example, ten students indicated their awareness of connections within the network in the post-test, while one student did in the pre-test. In addition, nine students appreciated the utility of networks as a way "to get to know each other better/ people's like and dislike." While not all students completed the post-test worksheet due to the number of questions, we view these results as quite promising, especially given how the network activities also helped students to explore key ideas of interest to the classroom and teachers, such as how the chicken farming industry works (see below).

Three cases

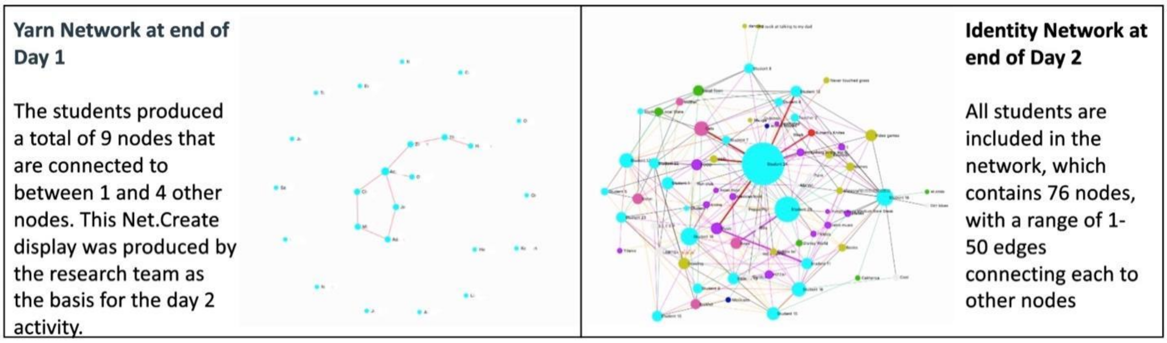
The three cases below were chosen from the four network visualization activities in which students participated in the exploration, comprehension, and utilization of network datasets. Select deidentified example networks can be seen at: http://theraptlab.org/projects/netcreate_examples. For each activity, we iteratively reviewed the classroom video data, discussing as a team what we felt was the most salient mediator within each episode. We then conducted Interaction Analysis (Jordan & Henderson, 1995) to explore how the salient mediators appeared to influence the students' activity. Case one depicts two network activities from the first two days of the intervention in which students first built a physical yarn network of their interests and then expanded that network within the Net.Create software. Here, we examined how the community and network tools in the activity functioned to enhance students' awareness of their connections. In case two, students' prior knowledge and the teacher's facilitation mediated their exploration of a pre-made network visualization of how the chicken farming industry works, a topic chosen to complement a semester-long cross-curriculum project the teachers had previously planned, which will involve the students in researching various locally relevant farming industries. Case three depicts an activity from day 5 where students' explorations of how marketing may work in social media websites were mediated by their emergent understanding of networks, the activity rules, and the facilitators.

Case1: Starting to explore the classroom as a network

Students constructed a physical yarn network as the opening activity of the implementation. In this activity, each student acted as a node (representing themselves) and was connected to peers who had overlapping interests or experiences using yarn (tool) that was strung between them on the floor. To create the network, we developed eight questions (tools) based on the Funds of Identity literature (Esteban-Guitart & Moll, 2014) to prompt students to share their own experiences and stories (rule). Sample questions included "name a place that is important to you?" and "what is an activity or hobby you enjoy?" Initially, none of the students were connected. The first student then selected a question from the list and shared an answer as well as an elaboration (rule). Next, any peers who felt they had a similar experience would raise their hand (a division of labor), and the first student would pick one to "connect" to, passing them the ball of yarn. This next student often explained their connection to the student who passed them the yarn, they would then select a new question, and the process continued.

Figure 2

Students' yarn activity on day 1 (Left). A complete identity network (Right)



Yarn Network at end of Day 1

The students produced a total of 9 nodes that are connected to between 1 and 4 other nodes. This Net.Create display was produced by the research team as the basis for the day 2 activity.

Identity Network at end of Day 2

All students are included in the network, which contains 76 nodes, with a range of 1-50 edges connecting each to other nodes

This yarn activity led students to tell elaborated stories about themselves and their families, many of which were previously unknown to the teachers and the class. We see this in class debriefs in which many of them indicated that they had learned something new about one another. For example, one student shared that her mother was from Ireland, which surprised the teacher, who exclaimed, "I cannot wait to hear the story." The teacher (community) asked follow-up questions which served to mediate the students' description, leading them to share an anecdote about how the mother's Irish accent perplexed family members. In addition to prompting students' story sharing, we observed that teachers (community) rephrased key details in the stories in a more general way or identified other stories to help mediate the process of students identifying connections. For example, in this instance, the teacher shifted the initial focus from the mother's Irish family roots, which did not lead to anyone claiming a connection, to the student's father, who is from San Francisco, and asked if anyone connected to California, which inspired many students to speak aloud about their connections in various ways. While creating a physical yarn network allowed students to get to know one another better, they also complained that many of them were unable to connect due to the time constraints and the activity rules that only one new student receives the yarn after each prompt.

To help students see further connections amongst themselves and appreciate the value of computerized network visualizations over physical constructions, one researcher created a digital replica of the yarn network using Net.Create to model students as individual nodes that were connected to other nodes of classmates, significant people, and objects through edges of three categories (like/interested in, connected, important to) (Figure 2 Left). This digital yarn network was used as a starting point for the day 2 activity, in which students worked in pairs (the division of labor) to add more content to the network. Each dyad created new nodes and edges that they felt described their individual interests. While they were asked to enter their individual interests, they worked in pairs so that they could discuss the process, and our intention was that the completed network (Figure 2 Right) represents the class as a whole (rule & division of labor).

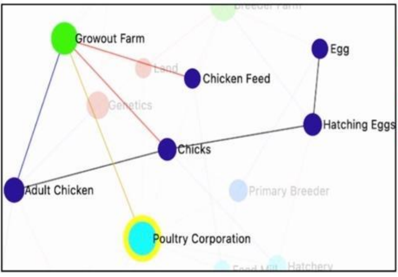
Students' comments during the post-activity debrief indicated they had begun to pay attention to the content of the nodes rather than just stating that they knew more about each other. Upon being asked, "What did you learn about your classmates?", many students looked back at the network before responding. They then responded with content that was in the nodes, such as cats (Figure 1 Right), the name of the town, and the state where they lived. The fact that students oriented towards the network visualization and then focused on the specific nodes and edges indicates that they were relying upon the visualization to mediate their response in ways that the yarn network could not, potentially supporting early appreciation for the power of network visualization tools.

Case 2: Understanding the importance of degrees (edge counts)

The activity for day 4 features a pre-built network modeling vertical integration in the poultry industry that was integrated as a part of a teacher-designed project that involved students designing and managing a fictional farm. The teachers had developed this cross-curricular activity because the school is located in a small suburban community adjacent to many rural farm areas, with an active locally sourced food community. Students worked in pairs (the division of labor) and were asked to vote for the top three nodes in the pre-built network that they felt were most crucial for operating a successful chicken farm (rules). There is no "correct" answer to this question, but it was intended to motivate learners to make sense of the network in order to vote. Information contained in the network visualization, including the characterized categorization (indicated by different colors), different numbers of edges, and nodes' sizes, was intended to mediate students' noticing and interpretation.

Figure 3
Left: A subset of the nodes that students attended to. Right: A re-creation of the information in the table view, which showed students' votes juxtaposed with the degrees of centrality (connections).

Left is a subset of the nodes, highlighting the ones students discussed.



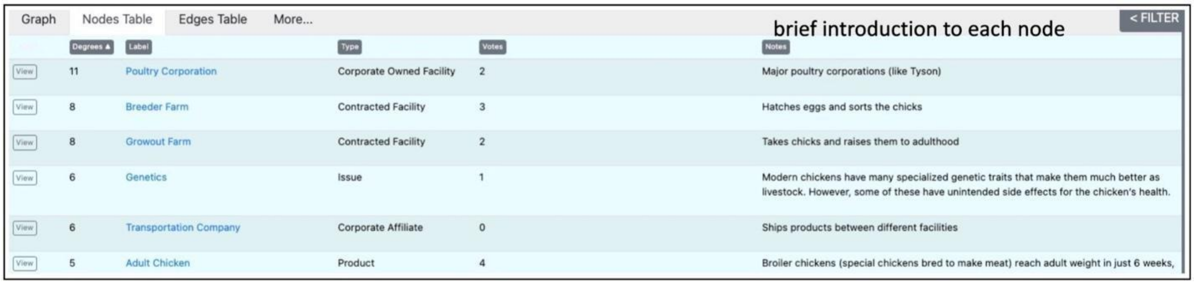
Node	Degrees	Votes
Poultry Corp.	11	2
Breeder Farm	8	3
Growout Farm	8	2
Genetics	6	1
Chicks	4	4
Adult Chicken	5	4
Chicken Feed	3	4

Right is a table indicating connections and votes that students had (re-sorted by votes).

Students initially voted for chicken feed (degree=3; vote=4) and chicks (degree=4, vote=4) as the top two important elements in the network. Students' explanations indicated that their awareness of individual node's content and out-of-school knowledge/experiences mediated their interpretations rather than network features, "I voted for chicks because they are cute, and they are chickens. You need to have chickens to have chicken farms" and "you can feed chicken pretty much anything, … like you can feed chicken chickens." However, when asked whether connections of the network influenced their voting, one student mentioned the importance of connections, "I feel like if the circle node has more connections, then you can tell it is very important." They explained the importance of these connections by stating that "all of (the) things connected to [the node], probably make it happen." This suggests that they recognized the value of degrees of centrality but were not yet aware of how to articulate these ideas. Researchers also asked the two students who voted for the most connected node, poultry corporation (degree=11), why they had selected it. Unfortunately, the students were not able to articulate a reason for this choice.

The next round of exploration prompted students explicitly to consider if the number and types of connections revealed something crucial to a successful farm operation, "let's take two mins to go back to the network and explore this. Tinker with what has a lot of connections and not a lot, and see if you think it matters. … So, you look at and see, do the number of connections or types of connections help you understand." During the discussion, H claimed that the network did not visualize the statement "everything comes from the egg." However, when asked how to redesign the network to emphasize the connection, her response indicated the connection string of egg-hatching egg-chicks (tool, Figure 3 left) may be valuable to her recognizing the developmental process starts from eggs, "eggs went to hatching eggs which went to chicks, so I thought, which went to, so, which was very important, so I was thinking about now, egg is where the chicken is born from." We read H's responses as showing that network connections made some relationships more salient to them, although they may still struggle to articulate the significance of connections in the network fully.

Figure 4
Each node's brief introduction



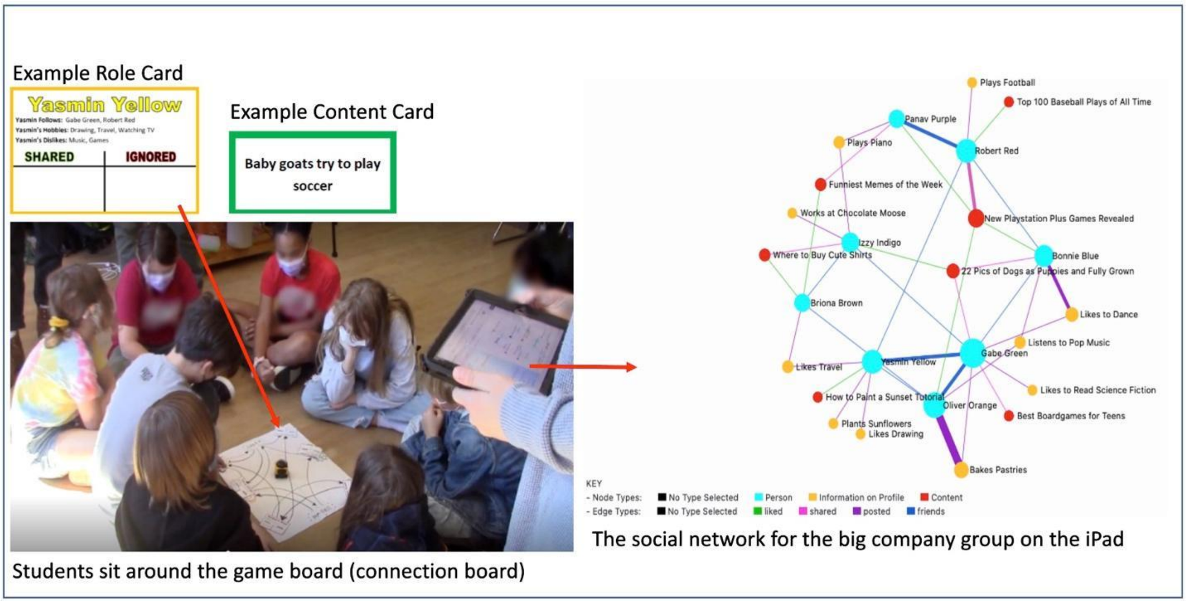
	Degrees ▲	Label	Type	Votes	Notes
View	11	Poultry Corporation	Corporate Owned Facility	2	Major poultry corporations (like Tyson)
View	8	Breeder Farm	Contracted Facility	3	Hatches eggs and sorts the chicks
View	8	Growout Farm	Contracted Facility	2	Takes chicks and raises them to adulthood
View	6	Genetics	Issue	1	Modern chickens have many specialized genetic traits that make them much better as livestock. However, some of these have unintended side effects for the chicken's health.
View	6	Transportation Company	Corporate Affiliate	0	Ships products between different facilities
View	5	Adult Chicken	Product	4	Broiler chickens (special chickens bred to make meat) reach adult weight in just 6 weeks,

Students' tendency to focus on familiar individual data points is also evident in their small group conversations. In one group, despite the teacher's efforts to re-mediate students' attention toward nodes' connection numbers by navigating students in that group to identify nodes with the most and the second most connections, they remained focused on a node, adult chicken, "yes, but me and M voted adult chicken three times because you need adult chicken to get chicks.” In the whole-class discussion, we observed the teacher’s continued mediation of orienting students’ attention to the nodes’ connection numbers by rationalizing their votes, “when we see what the second most important thing, we found this growout farm. and this connected directly to you H because this growout farm takes chicks and raises them to adulthood.” The teacher’s explanation of the growout farm was based on a brief introduction (Figure 4) of that node that we incorporated into the Net.Create design (tool). Thus, the interface further mediated the teachers’ and students’ exploration of the chicken industry. The teacher also aimed (a division of labor) to help re-orient the students’ attention toward the number of connections and node details as the students explored the network. While not all of the students shifted their activity, they did all have the opportunity to participate in the resulting whole-class discussions that built on these interactions, giving them a chance to notice the same connections their peers did, which may have helped in later activities.

Case 3: Make inferences based on a combination of connections numbers and edges types

Case 3 involves students playing a board game designed by the research team in which they were divided into two groups (a division of labor), with one representing big companies (e.g., TikTok) and another representing fictional social media users. A Net.Create social network (tool) was made available to the big company group allowing them to gain information about the social media users’ profiles, the content they shared/liked, and people whom they are friends with (Figure 5). Students in this group were given a series of content cards that represented social media memes (e.g., sports videos, or cute puppy videos) and were tasked with leveraging network information to identify the best user who would see a content card first and then disseminate the content through the network to more users (a division of labor). For example, students might give the “cat video” card to a user whose media personality indicates loving cats. The media users group has a connection board (a tool) (Figure 5) with information about who follows whom on social media so as to determine how to distribute the content card once they receive it (a division of labor). In addition, each user receives a role card (a tool, Figure 5) summarizing their likes and dislikes as a reference to choose whether or not to share the content card chosen by the big company group (rule). As part of this activity *rule*, the social network visualizes users’ partial interests. Therefore, to develop an effective marketing tactic of distributing a content card to a bigger audience (object), it becomes essential for the big company group to use the social network to infer influencers and their interests.

Figure 5
Social media marketing context



Example Role Card

Yasmin Yellow
Yasmin Follows: Gabe Green, Robert Red
Yasmin's Hobbies: Drawing, Travel, Watching TV
Yasmin's Dislikes: Music, Games

SHARED	IGNORED

Example Content Card

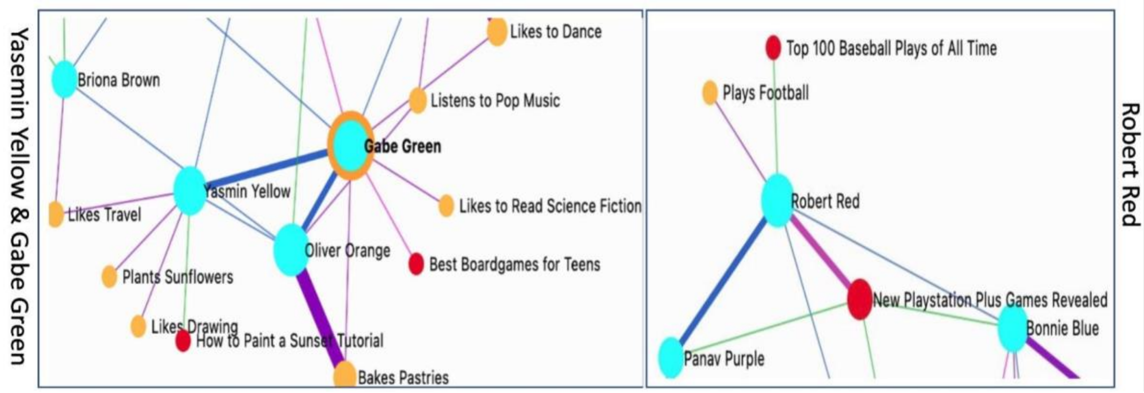
Baby goats try to play soccer

Students sit around the game board (connection board)

The social network for the big company group on the iPad

The initial conversation on marketing strategy demonstrated that students’ network visualization reasoning is mediated by their emergent understanding of how networks work. O shared her marketing strategy of passing a content card to those with the most connections, and her game-playing aligns with the strategy. Her first marketing attempt was to choose Gabe Green (Figure 6 Left), who has the greatest connections (degree=11), to receive the content card “Best Sports Bloopers of the Week." However, this content card was ignored because of Green’s distaste for sports. O’s second trial chose Yasmin Yellow (Figure 6 Left), who has the third-highest number of connections (degree = 8); however, the chosen content card concerning music (Playlist: Music to paint to!) is what Yasmin Yellow finds objectionable. Thus, neither content card spread to the second player since the card content did not match the person's interests and was disregarded. Here, we interpret O's strategy as mediated by the idea of using the connection number of a node to assess its significance, which may be learned from the chicken industry network; however, this strategy failed to completely utilize the social network as a mediational means to make inferences, as O only attends to connection numbers of nodes and ignores edge types and connected nodes. This was a great opportunity to help students re-orient toward the specific node and edge content.

Figure 6
Yasemin Yellow & Gabe Green (Left) Robert Red (Right) connections



The next player was H, whose marketing strategy was more successful as the content card she chose spread to many of the other peers. In the final discussion, O summed up H's marketing strategy as choosing the first person "based on what was being liked, instead of giving it (content card) to somebody randomly." Here, how H played the game (a division of labor) functions as a mediational means for O to identify the best marketing strategy. We reviewed H's gameplay to see if this was indeed her strategy. H role-played the big company and picked a content card of "Highlights of local sports games." She talked out loud about the card content to the teacher (community) who participated in this group as a social media user. Then, the teacher (community) began to look at the role cards of the users sitting next to him to determine who likes/dislikes sports. However, this violates the game *rule*, in which the company group is supposed to rely only on the social network. A researcher halted this infraction by reminding them of the rule, which prompted H to turn to the social network on the iPad. While zooming in on the social network, H murmured, "Who likes, ok, Robert really likes Sports." She continued to zoom in and out of the social network silently before finally handing Robert Red the content card. It was unclear what other factors H was considering before choosing Robert Red; however, H's marketing strategy turned out very effective. This is because Robert Red is the third most connected node (degree = 8) and enjoys sports, as indicated by his sharing of sports content (Figure 6 Right). Although we do not have a full picture of H's reasoning, her pick of Robert Red and the accompanying murmuring indicate her attention to what was being connected to the Red's node (e.g., interests). H's successful marketing plan of identifying the right person to promote a content card matching the person's interest is mediated by the teacher's guidance in getting her to find whose interests match the content card within the network visualization (tool). Thus, it appears that H's successful marketing strategy mediated O to notice the importance of what and how nodes are connected in addition to the connection numbers (a division of labor).

Discussion

This study demonstrated that elementary students are able to use network visualizations productively to make sense of a wide range of topics related to both their classroom pursuits and data literacy. We reported how different mediators present across the three activities supported students' data reasoning in the network visualization. Case one explicates different mediations of the physical network and the virtual network in supporting students' exploration and comprehension of connections. Case two showed explicit conversations about connections and Net.Create's built-in features mediated a discussion of a more interconnected view. Case three illustrates that students' understanding built on their emerging understanding of networks and different roles-taking attuned them to connection numbers and information flows in the network. Attending to students' participation in four network visualization activities provides insights for activity designers and classroom teachers into how mediation in activities and discussion was necessary to support students in exploring network visualizations as aggregate representations as opposed to focusing solely on specific nodes they are familiar with. While not all students appeared to display a nuanced articulation of network visualizations, many developed an appreciation for the affordances of network visualizations for exploring patterns in data. Like with other data representations and previous research (e.g., Ben-Zvi & Arcavi, 2001), familiarity with individual ideas continued to distract some students from aggregate patterns, but we view the results as promising given that many students did begin to exhibit emergent attention to those aggregate patterns. In addition to developing students' data literacy skills, this project highlighted the potential of network visualizations as a vehicle for leveraging locally relevant content (e.g., students' interests and the classroom focus on the poultry industry) and incorporating physical activities (e.g., yarn activity and board game) to help students make some of the relationship relevant to them. In the future, we will further explore how we can re-mediate learners' activities to help even more students attend to these network features and explore how network visualizations might support other dimensions of data literacy.

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Supporting the Appropriation of Historical Practices in a Game-Based Undergraduate History Classroom

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Abstract: This study took a cultural-historical activity theoretical lens to a game-based history learning environment. Situated in an undergraduate history course titled *Greek History through Games*, students participated in a semester-long bespoke strategy-board game known as *Cities on the Edge of War*. This study examined how designed elements of the game and course mediated students in appropriating five historical practices, which are difficult to teach in lecture-style courses and noted as important learning goals by the professor of the course and Author 4 of this paper. Alongside designed elements, we considered historical practices to be key mediators of students' interactions. We analyze where in interaction these historical practices emerged and unpack the most common mediators within the learning environment that co-occurred alongside these historical practices.

Introduction

A persistent challenge in teaching history is imparting the practices that historians use to overcome and account for these biases of the present (Wineberg, 2001). Historians understand that the people of the past had their own culture, histories, and values that influenced their actions and decisions. One way to address this challenge is to design active learning environments to support students in engaging in these historical practices, such as *game-based learning* (GBL) environments. The present study looked at an undergraduate history GBL course designed by authors 3 and 4 titled *Greek History through Games*. Through a combination of strategy-board game elements and role playing, students in an upper-level history course took on the social and political realities of historical actors in a game called *Cities on the Edge of War* to foster historical practices that are a necessary component in the study of history (van Hover & Yeager, 2004; Craig, 2017).

This work is grounded in *cultural historical activity theory* (CHAT; Engestrom, 1999) which centers the importance of context (i.e., the places, languages, tools, cultures, and histories) in learning. Within this epistemology, learning is defined as *an appropriation of mediators which supports a shift in one's participation to be in line with the community they are interacting with*. Specifically, how appropriating designed mediators of the GBL environment alongside historical practices transforms students' participation aligned with how historians interact and interpret the past. Toward this end, we ask the question: *Within a history based GBL environment, what mediators support students' appropriation of historical practices?*

Literature review

Learning through a game-based history classroom

At the undergraduate level, lectures are typically how students are presented with historical content. While lectures are useful at conveying a large swath of information to many students, they tend to fall short at fostering the types of skills which are valued in a given field (Bransford et al., 2000). To foster these kinds of historical practices in students, more active learning designs for classrooms, such as the GBL context of this study, provide ways to deeply engage students in taking up these kinds of practices through creative activities (Birdwell & Uttamchandani, 2019). In this study, we focus on analyzing where students take up the historical practices of *perspective-taking*, *evidence use*, *reflection*, *argument construction*, and *articulations of context* in interaction. These were practices that the professor of the course noted they had trouble fostering in their students in their typical lecture-style classes, and the GBL environment was a way for students to better engage in them.

We define a game and gameplay as a form of playful activity focused on winning as an end condition for activity with a set of well-structured rules (DeLiema et al., 2019). GBL environments typically take the form of a set of activities within a curriculum unit, designed with the intention of engaging students in cycles of inquiry around a gamified problem, where a particular problem is framed as an activity that needs to be solved, with a set of rules and conditions to win guiding participation (Fields & Kafai, 2018). For example, the Reacting to the Past game setting allows for students to play alongside others and engage with the social and political conditions of a certain period (Hagood et al., 2018). In Cities on the Edge of War, this type of roleplay was a core mechanic which allowed for students to think at various levels of the factions they were a part of, as they might be simultaneously working with and against each other depending on their unique characteristics.

The design of a semester-long game-based course was intended for students to continuously engage with various historical perspectives over a long stretch of time, creating opportunities for reflection and articulations of the actions and decisions they made as a historical actor (Stiso et al., 2020; Ryan et al., 2021). This was grounded in the idea that extended engagement with the complexities of the historical context might create opportunities for students to reflect on and better appreciate the situated tensions felt by historical actors of the period. At its core, our design was intended to structure a system of activity which mediated students' engagement with historical practices which are necessary for historians to develop.

Mediating learning through the appropriation of historical practices

Activity as a unit of analysis through a CHAT lens allows for an in depth look at students' interactions within the course with attention paid to what in the environment is mediating students' fostering of historical practices. *Practices* in this context refer to the patterned forms of participation within activity that evoke shared assumptions, rules, and values that mediate interactions of a group participating in the game (Danish & Phelps, 2011). This goes beyond simply "doing" in a context, but doing in specific historical and cultural ways that are relevant to a specific context.

For example, historians assert that to effectively learn about the past, certain practices are needed such as articulating context, reflection, argument construction, and perspective-taking (Craig, 2017; Monte-Sano, 2011; Shopkow et al. 2012). These practices are more than simply recollecting names and dates, but rather allow for students of history to "go beyond the written word and examine the intention, motive, plan, and purpose" of historical actors (van Hover & Yeager, 2004, p.9). For instance, historical *perspective-taking* is the action of taking on the situated perspective of historical actors during a given socio-political period in history (Wineberg, 2001), and is considered to be a key historical practice as a way to combat what Wineberg (2001) calls presentist thinking by preventing historians from slipping into misconceptions of the past by viewing it through a contemporary lens, inserting values and beliefs which are situated in our world into a completely novel context where they do not readily transfer into. Through a CHAT lens, these practices are key mediators which help to orient students' participation towards their activity goals in ways that align with how historians interpret the past.

Students' appropriation of historical practices involved taking them up within in-game interactions, which created opportunities for transforming students' participation in activity in specific ways which align with how historians' appropriate discourse, tools, and actions which mediate their studying history. Grounding both the design of the course as well as the present study in CHAT allowed us to think explicitly about how our GBL activities shaped learners' abilities to interpret the past in line with how historians do. Here, a practice such as perspective-taking can be thought of as a tool which is shaped by the goals of the game as well as mediators such as course readings that helped students to take on a historically situated perspective (Stiso et al., 2020). The present study unpacks the most common co-occurring designed mediators which supported the appropriation of these practices, which in turn became key mediators within interaction to transform how students oriented themselves in interpreting history.

Design

Within the course *Greek History through Games,* students played the bespoke board game *Cities on the Edge of War*, originally designed by the 3rd and 4th authors of this paper, and later revised by the entire team (Ryan et al., 2021). Set prior to the Peloponnesian War in ancient Greece, students took on the roles of leaders of various Greek City- States (e.g., Sparta, Athens, and Argos), and navigated the material, social, and political conditions of the war-time period in their City-State teams. At the start of each game, students were given a character to roleplay, either a named character in history (e.g., Lysander of Sparta) or an unnamed archetype leader (e.g., oligarchic leader of Corinth). Students were given a character sheet with information regarding their characters and explicit goals that they should prioritize as they played the game. Roleplaying as these characters provided students to think about their game decisions on multiple levels, as they had competing goals and tensions to consider. For example, students certainly needed to work as a team for their City-State to prosper, but students also had individual goals that might make them work to defeat a political rival within their own City-State to usurp power for themselves (e.g., Lysander of Sparta seeks an elevated position in Sparta, and should aim to overthrow the kings if they are able).

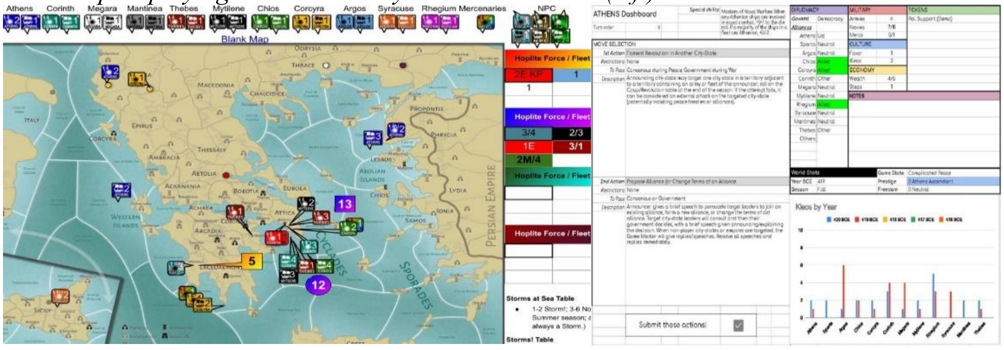
The design of Cities on the Edge of War centered most of the synchronous class time on students playing the game as a whole class, with 2 hours of the 2.5-hour block dedicated to playing the game. There were 12 City-State teams, with Athens and Sparta both having 5 student players, and the other City-States having 2 players. The game was broken into three phases consisting of planning, diplomacy, and action phases. Planning phases consisted of private breakout sessions in Zoom where teams planned their actions and moves. Diplomacy sessions were designated planning sessions where teams could talk and plan actions with their allies, or negotiate with enemies without conflict (i.e. in-game war and battling army units via strategy board-game). Action phases were the main turn-taking portion of the game where various actions were taken by teams in a single season of the game (e.g., late summer or spring). The available actions were pre-specified by game cards and included things such as moving a military force, seeking the favor of the Gods, or dispatching a secret envoy.

While students had the freedom to carry out special actions that were not listed on the available action cards, the game cards were meant to structure accurate historical choices and conditions of the time, such as realistic distance a large army would be able to move in a single season, or leaders of the Greek world seeking favor from their patron God of their pantheon for in-game bonuses. The bespoke nature of *Cities on the Edge of War* meant that we could link explicit game elements to the core learning objectives set out in an undergraduate history course.

Along with the action cards students could select from, we also incorporated several other strategy board game features to help structure students' choices. This included a virtual game map tracking all City-State teams military units and colonies and dashboards tracking their in-game stats (see Figure 1), including Kleos, which is Greek for "glory" or "renown" and served to keep track of various cultural achievements made by City-States (e.g., Megara makes a grand philosophical discovery). Kleos and favor from the Gods gained City-State teams in-game bonuses which could help them to compete with the other teams along military, cultural, and economic dimensions.

Figure 1

Game map displaying various military units and colonies(left) and Athen's Virtual Dashboard (right)



Cities on the Edge of War was designed explicitly as a sustained GBL environment to allow for students to continuously engage with various historical practices and decision-making over the course of a semester-long course. The game elements described above all had distinct design purposes that were meant to support different aspects of students' engagement in the historical period. Like the current study, the design of *Cities on the Edge of War* was also theoretically grounded at the crossroads of GBL (Fields & Kafai, 2018) and activity theory (Engestrom, 1999). We were particularly interested in how these game elements could support learners' pursuit of in-game goals, and we had certain design conjectures for game elements that we thought would help to support students' learning and ensure that their in-game decisions were grounded in relative historical accuracy of diplomacy and warfare of the ancient period.

Methods

Data sources

This study took place during the spring 2021 semester in an undergraduate history course at a large university in the midwestern United States. As a result of the covid-19 pandemic, the course was held virtually over Zoom. There were 27 students enrolled in the course. Data consisted of Zoom video recordings of two City-State teams', Sparta and Argos, planning and diplomacy sessions to analyze interactions. Note that the team membership changed between the first and second game session, so this represents 4 different total groups of students. Each session consisted of between 25-40 minutes of interaction data, with approximately 750 minutes of total analyzed video data. These teams were identified as potential cases because they were filmed across both game sessions, whereas other teams were only filmed for one of the two games. These two teams were selected for the focal analysis because they represent both the small (Argos) and large (Sparta) team dynamics present within the game, leading to unique forms of interaction within each team. Even though the team membership changed between games, following the same City-State allowed us to see how different students pursued similar goals across the two games, and analyze 14 of the 27 students.

Data analysis

Analysis began with students' final exams, confirming that historical practices were present at the end of the course. A brief interview with the professor verified how similar style final exam scoes differed from past lecture-based courses they taught on the same topic. Knowing that these historical practices were present within students' final summative assessments, the goal of the analysis was to identify where these practices emerged in interaction and how the mediators present within the game-based activity system supported the appropriation of these practices. After selecting the focal City-State teams, reviewed the video data in two passes where we content logged and coded for historical practices, followed by a pass of interaction analysis (IA; Jordan & Henderson, 1995).

The first pass we content logged events and noted when player talk shifted from one topic to another. These consisted of either planning, conflict, or negotiation, with conflict and negotiation being either internal within the City-State or *external* between multiple City-State teams. Within each logged interaction, we then open coded for any of the five historical practices noted as learning goals by the professor of the course: a) *argument construction,* b) *articulations of context,* c) *reflection,* d) *perspective-taking,* and e) *evidence use* that emerged within interaction was marked as well. *Evidence use* was split into three distinct forms of referencing prior knowledge, prior gameplay, or primary sources read in the course.

The second pass of the video data we used IA on specific episodes of video of the teams' planning and diplomacy sessions. To select episodes, we looked for co-occurrences of historical practices and mediators that were present in the interactions. These mediators consisted of aspects of a system of activity and included the *subjects*, *objects* (i.e., goal pursuit), *tools, rules, community,* and *divisions of labor* (Engestrom, 1999). Here, goal pursuit was broken down into three forms that were structured into player's character sheets within the game which included *City- State, Greek world,* or *individual-based* goals being pursued. Episodes were selected to serve as exemplars of trends where multiple historical practices and interactional mediators tended to co-occur alongside each other.

Results

The professor stated at the end of the course that the final exams were "collectively impressive". Over half of students writing in the exams were "remarkably good", with overall student performance being "notably better than my students generally manage on finals". Students' performances on their final exams demonstrated not only an understanding of the course content, but that a grasp on the historical practices laid out as learning goals by the professor and designers of the course supported the learning outcomes present within the final exams (see Table 1). We chose to omit the practice of *argument construction* from analysis of these final exams, as the prompts for the exam explicitly asked for students to produce a historical argument. This meant that it would be present in all the exams that received a passing grade, as opposed to the practice naturally emerging in students' interactions.

Table 1
Historical practices and frequencies in students' final exams.

Historical Practice	Example	Distributions Across Finals
Articulating Context: Unpacking the social, political, and/or details surrounding a historical context or event.	*"While most city states depended on the yields of their own lands to support them, by maintaining access to the sea Athens could now utilize the massive fortune they had accrued via tribute from their Delian league members to keep the inflated population of Athens fed for the foreseeable future."*	**188**
Evidence Use – Gameplay Events*: Direct reference to events that occurred in gameplay.	*"For example, in the second game round, a round wherein fairly little warring occurred for the majority of the time, Sparta had the goal of dismantling the Argive alliance."*	**68**
Evidence Use – Primary Source: Direct reference to a primary source using a formatted citation.	*"In Sparta, this issue also arose, despite the Spartan virtue of caution, as King Archidamnus struggled to contain Spartan calls for war against Athens, calling for caution and vigilance even as troops departed (Thuc. 2.11)"*	**182**
Perspective-taking*: The action of taking on the situated perspective of historical actors during a given socio-political period.	*"In Athens, the pretenses with which they propelled their empire were recognized by even themselves, admitting that the only true justification for their conquests was the desire for power over Greece."*	**51**

Reflection*: Deliberately thinking about a specific action or event outside of when it occurs.	*"In our historically based game, justifications for war and conquest were rarely so eloquent, or based on honor or spirituality; more often, they were contingent on who threw the first stone."*	**76**

(*= Only emerged on certain questions on the final exam)

One important note is that the final exam was structured so that students had a choice of 2 questions from a 6-question bank. Not all these questions were directly asked about their gameplay, which might explain the lower counts of Evidence use - Gameplay Events, Perspective-taking, and reflection if students were not directly referencing their gameplay in their writing. Students who did answer questions asking about their gameplay tended to use each of these practices an average of 4-5 times in their exams, whereas students who did not answer questions related to gameplay used these between 1-2 times in their exams. The results below highlight the most common interactional trends of what mediators co-occurred and supported the historical practices that emerged within students' gameplay (see Table 2).

Table 2

Summary of common co-occurrences between mediators and historical practices

		<u>**Historical Practices**</u>				
		Argument Construction (16)	Articulating Context (61)	Evidence Use (110)	Perspective-taking (68)	Reflection (41)
Mediators	Negotiation (67)	12	20	43	**39**	1
	Planning (107)	4	**38**	55	22	**32**
	City-State Goals (115)	**14**	**40**	**74**	**42**	**32**
	Greek-World Goals (30)	6	14	24	20	1
	Individual Goals (21)	4	10	15	14	4
	Roleplay (73)	**12**	22	48	**63**	5

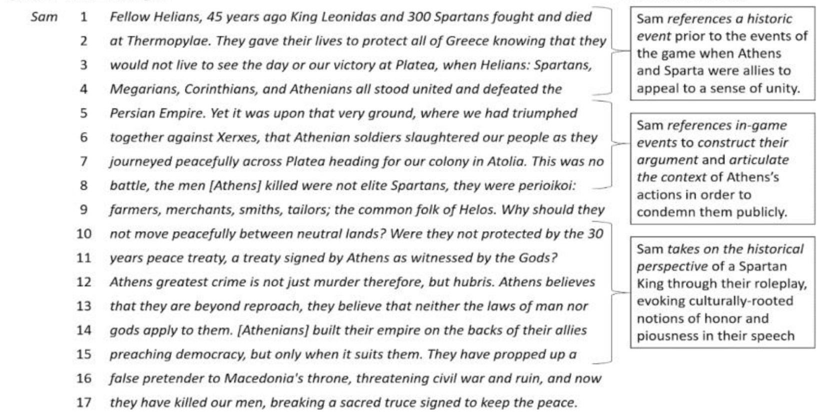
Bold #s = Co -occurrences where mediators were present more than 50% of a given historical practice

Perspective-taking and roleplaying

Within this analysis, perspective-taking in interaction nearly always co-occurred alongside students' engaging in roleplay as their game characters within their planning or diplomacy sessions (63 of 68 instances). For example, during one diplomacy session midway through the first game, a Spartan player, Sam, gave a rousing speech condemning Athens in the game, who had just attacked Sparta (see Figure 2). As they give their speech, Sam role-plays in the perspective of their character, a Spartan King whose people were just attacked in neutral territory. This isn't Sam simply referring to themselves in character, but rather through their speech they evoke culturally and historically rooted notions of piety and honor. For example, Sam condemns Athens claiming, "Athens believes that they are beyond reproach, they believe that neither the laws of man *nor Gods* apply to them" (Lines 12-13). Sam also denounces Athens not simply for violating a sacred treaty, but for the dishonorable act of "[propping] up a false pretender to Macedonia's throne…and now they have killed our men, breaking a sacred truce signed to keep the peace" (Lines 15- 16). This perspective that Sam took on was made salient through multiple mediators. Sam's unique character goals explicitly laid out in their goal sheet for the game helped to mediate what goals they might pursue for themselves, their City-State, and the Greek world. The course readings described actions their character made in history to mediate how they might respond to certain events. Their sustained gameplay allowed Sam to continually engage with and develop their character across multiple game sessions, allowing for opportunities to experience the consequences of their decisions as in-game events.

Figure 2

Transcript of Sam's speech as a Spartan King.



Speaker	Line	Dialogue	Historical Practices
Sam	1	*Fellow Helians, 45 years ago King Leonidas and 300 Spartans fought and died*	Sam *references a historic event* prior to the events of the game when Athens and Sparta were allies to appeal to a sense of unity.
	2	*at Thermopylae. They gave their lives to protect all of Greece knowing that they*	
	3	*would not live to see the day or our victory at Platea, when Helians: Spartans,*	
	4	*Megarians, Corinthians, and Athenians all stood united and defeated the*	
	5	*Persian Empire. Yet it was upon that very ground, where we had triumphed*	Sam *references in-game events to construct their argument* and *articulate the context* of Athens's actions in order to condemn them publicly.
	6	*together against Xerxes, that Athenian soldiers slaughtered our people as they*	
	7	*journeyed peacefully across Platea heading for our colony in Atolia. This was no*	
	8	*battle, the men [Athens] killed were not elite Spartans, they were perioikoi:*	
	9	*farmers, merchants, smiths, tailors; the common folk of Helos. Why should they*	
	10	*not move peacefully between neutral lands? Were they not protected by the 30*	Sam *takes on the historical perspective* of a Spartan King through their roleplay, evoking culturally-rooted notions of honor and piousness in their speech
	11	*years peace treaty, a treaty signed by Athens as witnessed by the Gods?*	
	12	*Athens greatest crime is not just murder therefore, but hubris. Athens believes*	
	13	*that they are beyond reproach, they believe that neither the laws of man nor*	
	14	*gods apply to them. [Athenians] built their empire on the backs of their allies*	
	15	*preaching democracy, but only when it suits them. They have propped up a*	
	16	*false pretender to Macedonia's throne, threatening civil war and ruin, and now*	
	17	*they have killed our men, breaking a sacred truce signed to keep the peace.*	

As students roleplayed, they utilized the perspectives of the historical characters they embodied in pursuit of their in-game goals. In the example above, Sam utilizes the perspectives of a Spartan king, a leader of a City-State, and member of the Greek world to better appeal to their peers during negotiations and planning. This directly mediated not only the student taking on the perspectives, but the students role playing alongside them as they situated themselves in the social and political realities of the period in their negotiations. Additional mediators that supported this co- occurrence pattern were the structure of the game which supported multiple players to participate in interactions, such as in the five-person team of Sparta or in external negotiation types of gameplays. In fact, perspective-taking and roleplaying emerged in most moments of negotiation across the game (39 of 67 instances), lending merit to students' arguments or articulations to their peers when discussing events of the game.

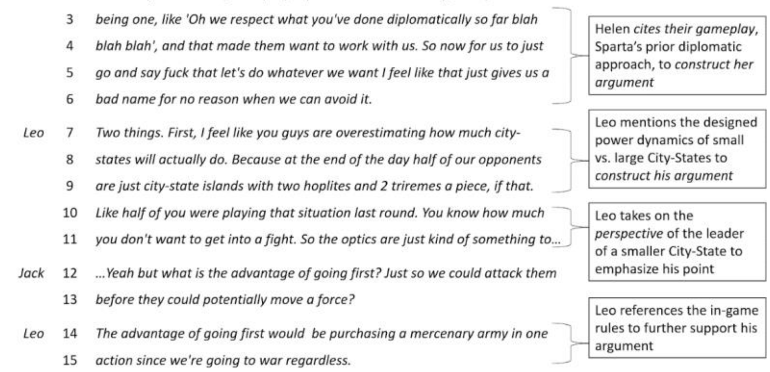
Argument construction and negotiation

Primarily, students engaged in *argument construction* in interactions of in-game negotiation, both internal and external (12 of 16 instances). These negotiations were directly mediated by the game design of larger teams leading to more internal negotiation, and diplomacy periods as one of the phases of the game allowing for interactions across teams. For instance, in an internal negotiation of whether Sparta should declare war (a structured game action which worked to mediate students' discussion of options to include debates) three students, Helen, Leo, and Jack developed competing arguments in pursuit of their common team goals of building up their City-State (see Figure 3). While there was agreement on the need to declare war, the game structure of needing to choose the temporal sequence of actions mediated the discussion of how and when to engage, leading students to construct arguments for their perspective.

Students' arguments were often bolstered by additional mediators and even other historical practices, such as the game rules and *articulations of context* (i.e., the unpacking of the social and political details surrounding historical context), to support students' argumentation. For example, in the above exchange Leo articulates that "at the end of the day half of our opponents are just City-State islands with 2 hoplites and triremes a piece, if that" (lines 8-9), so it really does not matter what their reaction would be to Sparta declaring war. Additionally, Leo frames his argument by referencing explicit game rules, noting that "the advantage of going first would be purchasing a mercenary army in one action since we're going to war regardless" (Lines 14-15), noting the game rule that a team cannot purchase an additional mercenary army *unless* they were already at war. In these interactions, mediators such as the structure of the 5-person Spartan team, the explicit game rules, and other practices such as *articulations of context* or *perspective-taking* mediated students' formulating their arguments in pursuit of their in-game goals.

Figure 3

Transcript of two Spartan players negotiating their next actions.



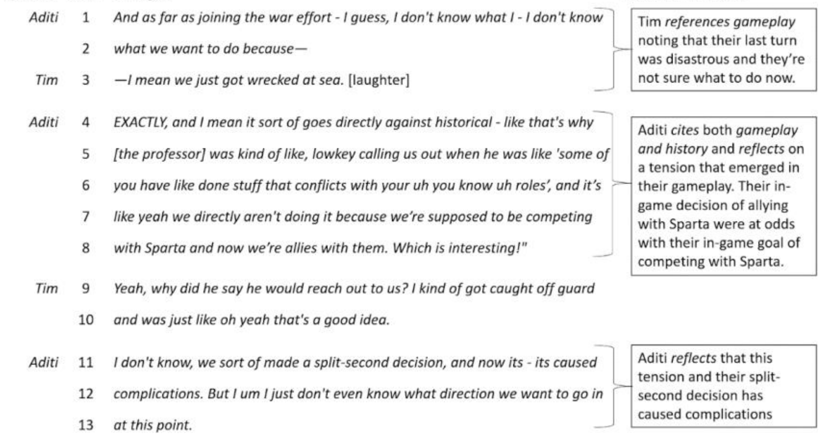
Speaker	Line	Dialogue	Historical Practices
Helen	1	*I think you severely underestimate the impact that [declaring war] has on*	
	2	*other City-States. Like, multiple people have told us already, like Syracuse*	
	3	*being one, like 'Oh we respect what you've done diplomatically so far blah*	Helen *cites their gameplay*, Sparta's prior diplomatic approach, to *construct her argument*
	4	*blah blah', and that made them want to work with us. So now for us to just*	
	5	*go and say fuck that let's do whatever we want I feel like that just gives us a*	
	6	*bad name for no reason when we can avoid it.*	
Leo	7	*Two things. First, I feel like you guys are overestimating how much city-*	Leo mentions the designed power dynamics of small vs. large City-States to *construct his argument*
	8	*states will actually do. Because at the end of the day half of our opponents*	
	9	*are just city-state islands with two hoplites and 2 triremes a piece, if that.*	
	10	*Like half of you were playing that situation last round. You know how much*	Leo takes on the *perspective* of the leader of a smaller City-State to emphasize his point
	11	*you don't want to get into a fight. So the optics are just kind of something to...*	
Jack	12	*...Yeah but what is the advantage of going first? Just so we could attack them*	
	13	*before they could potentially move a force?*	
Leo	14	*The advantage of going first would be purchasing a mercenary army in one*	Leo references the in-game rules to further support his argument
	15	*action since we're going to war regardless.*	

Reflection and planning

When thinking about students' reflections as a historical practice, we take up the definition of Schon's (1983) idea of *reflection on action*, or deliberately thinking about a specific action or event outside of when it occurs, to define how we searched for students participating in reflection on both the game events and their course readings. For example, in one interaction between the players in Argos, Aditi and Tim, reflect on the turn that just took place prior to the planning session they are currently in (see Figure 4). The episode emerged from a co-occurrence trend wherein *reflection* within students' interactions primarily occurred within the 2-person City-State team Argos (30 of 41 instances). Additionally, students' reflections primarily occurred in the planning sessions explicitly designed within the game (32 of 41 instances), where interactions were limited to only a player's City-State team.

Figure 4

Transcript of Argos players reflecting on the game.



Speaker	Line	Dialogue	Historical Practices
Aditi	1	*And as far as joining the war effort - I guess, I don't know what I - I don't know*	Tim *references gameplay* noting that their last turn was disastrous and they're not sure what to do now.
	2	*what we want to do because—*	
Tim	3	*—I mean we just got wrecked at sea.* [laughter]	
Aditi	4	*EXACTLY, and I mean it sort of goes directly against historical - like that's why*	Aditi *cites* both *gameplay and history* and *reflects* on a tension that emerged in their gameplay. Their in-game decision of allying with Sparta were at odds with their in-game goal of competing with Sparta.
	5	*[the professor] was kind of like, lowkey calling us out when he was like 'some of*	
	6	*you have like done stuff that conflicts with your uh you know uh roles', and it's*	
	7	*like yeah we directly aren't doing it because we're supposed to be competing*	
	8	*with Sparta and now we're allies with them. Which is interesting!"*	
Tim	9	*Yeah, why did he say he would reach out to us? I kind of got caught off guard*	
	10	*and was just like oh yeah that's a good idea.*	
Aditi	11	*I don't know, we sort of made a split-second decision, and now its - its caused*	Aditi *reflects* that this tension and their split-second decision has caused complications
	12	*complications. But I um I just don't even know what direction we want to go in*	
	13	*at this point.*	

These two co-occurrence trends indicate that reflection in the context of the game was best supported in small group interactions. For example, in the exchange above Aditi reflects that "that's why [the professor] was lowkey calling us out…it's like yeah, we directly aren't doing it, we're supposed to be competing with Sparta, but right now we're allies. Which is interesting!" (Lines 4-8). Here, they reflect on an event that occurred where the professor mentioned that they were currently going *against* their designed City-State goals, which are rooted in the historical context, by not directly competing against Sparta. However, in the context of the game Argos and Sparta politically aligned as allies with each other, which Aditi noted came from "a split-second decision, and now it's - it's caused complications" (Lines 11-12) for their historically rooted goals. The game design allowed students to collectively create their own narrative of the history, which inevitably created incongruences between the in-game and historical reality. These tensions that emerged mediated students' reflection on their in-game actions and the historical reality, such as deciding which of their in-game goals were most important to them as City-State leaders.

Discussion

The primary goal of this study was to closely examine the context of *Cities on the Edge of War* and understand how mediators in the learning environment supported students in taking up historical practices. In the results section above, episodes detailed some of the most common co-occurring mediators alongside a historical practice in interaction, such as the designed game elements helped to structure students' interactions in these moments. Notably, when historical practices co-occurred with each other, they became additional mediators which supported each other within interaction. It would be worthwhile to carry out further work to study the relationship between historical practices, and how they mediated each other within interaction to support students' appropriation of these practices.

The field of the learning sciences has long valued studying the full complexity of learning and the complex environments which support it. Yet, when it comes to researching the types of interactions and mediators which foster disciplinary practices the field has primarily pursued contexts within STEM fields. We hope that this study has demonstrated that it is worth expanding our analytical lenses towards new disciplinary horizons. We believe the field has a lot to offer how we might structure history learning environments to be more playful and aim to foster intricate practices that enculturate students into being doers of historical research rather than passive observers of historical events. In designing game-based activity towards humanities-based learning objectives, the field can come to better understand what kinds of norms, roles, and tools better support students engaging in this type of sustained playful activity.

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Contextual Dynamics in a College Student's Reasoning about Natural Selection

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Abstract: Empirical studies of students' reasoning about natural selection show evidence of context-sensitivity, yet prior work has not been able to explain why certain contexts evoke different reasoning patterns. Applying a knowledge-in-pieces perspective, we present a moment-by-moment analysis of a student's shifting understanding of context in an interview about natural selection. We describe how different contexts activated different locally coherent sets of conceptual resources. This work builds theory that can account for previously unexplained empirical patterns in the domain of natural selection. More generally, by demonstrating how coherence changes with the scale of context, this work contributes to general understandings of the role of context in students' reasoning.

Introduction

An enduring concern of research in science learning is how conceptual understandings develop. A knowledge-in-pieces (KiP) perspective posits that novices construct understandings out of fine-grained knowledge elements or "resources" and that a central mechanism of conceptual development involves gradual refinement in patterns of resource activation within and across contexts (diSessa, 1988, 2014; Hammer *et al*., 2005). An important area of research within the KiP program is to build theoretical knowledge of how and why different contexts function to activate, stabilize, or destabilize resource activation and coordination (Chao *et al*., 2018; Sherin *et al*., 2012). We contribute to this aim by investigating the moment-by-moment contextual dynamics of a student's reasoning in the domain of natural selection.

Natural selection is an especially promising domain in which to investigate how context influences patterns of resource activation because students' reasoning in this domain varies with many features of task context (e.g., Nehm & Ha, 2011). Interview studies have also described within-subject shifts in reasoning (e.g., Southerland *et al*., 2001). Despite the empirical evidence of context-dependence and within-subject variability, little research has been done to attempt to model the underlying contextual dynamics from a KiP perspective. Much of the prior work on students' reasoning in natural selection has been focused on explaining the prevalence of misconceptions in terms of deeply held cognitive biases or naive theories (Ferrari & Chi, 1998; Kelemen, 2011) or mixed models in which normative and non-normative ideas co-exist (Opfer *et al.,* 2012). Neither of these types of models can explain why students would sometimes construct correct explanations and construct incorrect explanations at other times.

In this paper, we examine the role of context in activating different conceptual resources for reasoning about natural selection. We present a moment-by-moment analysis of an interview with one college student, describing her changing interpretations of context across the interview and how these shifts help explain different patterns of resource activation and the tentativeness of her responses. We claim that while her reasoning could be described as inconsistent or mixed when viewed at a global level, in local contexts her reasoning is much more consistent and sensible. This consistency holds for explanations that she has prepared ahead of time as well as those that she appears to construct in moments in the interview.

Theoretical framework

A "knowledge-in-pieces" (KiP) perspective models learners' knowledge in terms of fine-grained knowledge elements that are dynamically activated and coordinated in moments of reasoning (diSessa, 1988). Working in the domain of physics, diSessa (1993) described phenomenological primitives (p-prims) as one type of knowledge element. Subsequent work has used the more expansive term "resources" to describe a range of conceptual, contextual, and epistemological elements that can be coordinated together to form *dynamic mental constructs* (DMCs)—temporary, local assemblies of resources (Sherin *et al*., 2012).

A core tenet of the KiP perspective is that resources cannot be described as correct or incorrect independent of their use in contexts (Hammer, 1996; Smith *et al*., 1994). Rather it is the activation and coordination of resources into DMCs in particular contexts that may be considered more or less aligned with correct conceptions. For example, the application of the p-prim *closer means stronger* can be correctly applied to explain the change in temperature with distance to a heat source like a flame, but incorrectly applied to explain the seasons in terms of closeness to the sun (Sherin *et al*., 2012). Given the potential application of resources to generate both correct and incorrect explanations, an important mechanism of conceptual development involves changes in how resources are activated and coordinated in different contexts rather than the eradication or replacement of those resources. Understanding the role of contexts in activating, stabilizing, and triggering shifts in reasoning is therefore central to understandings the mechanisms of conceptual development (Chao *et al*., 2018; diSessa, 2014; Hammer *et al*., 2005; Sherin *et al*., 2012).

Both perceptual and conceptual features of tasks function as contexts that can lead to differential patterns of resource activation (diSessa, 2014; Hammer, 1996; Sherin *et al*., 2012). Task features can prime the activation of contextual resources that make the activation of different sets of linked resources more or less likely (Chao *et al*., 2018). In addition, shifting framings during an interview can create different contexts for resource activation. For example, when students perceive themselves in the situation of an *oral examination*, they tend to offer school-sanctioned ideas, whereas when students perceive an interview as an opportunity to engage in *inquiry*, they are more likely to show evidence of tentativeness and offer informal or everyday ideas (Russ *et al*., 2012). Thus, from a KiP perspective context is constructed dynamically as interpretations of tasks and situations are coordinated to prime different sets of resources. In this work, we model a student's shifting interpretations of context and associated shifts in resource activation in an interview about natural selection.

Candidate resources and contexts in the domain of natural selection

In this section we briefly review prior work in the domain of natural selection that suggests candidates for relevant conceptual resources and aspects of contexts that could influence resource activation.

Conceptual resources for reasoning about natural selection

To our knowledge there is only one example of a knowledge element being described explicitly from a KiP perspective in the natural selection literature. Southerland *et al*. (2001) described *need as a rationale for change* as a "biological p-prim" that captures the idea that organisms will evolve when they experience some challenge that cannot be met in their current form. For example, organisms that are visible to their predators experience a "need" to adapt to camouflage themselves. Notice that this idea is neither intrinsically correct nor incorrect. Need can be applied correctly to describe the gap between a current state and a better adapted state, or incorrectly if used to describe intentional change by the organism to meet this need.

While not described in terms of resources, other conceptions described in the literature on students' reasoning about natural selection can be "reconceived" as resources (c.f. Smith *et al*., 1994). These include conceptions about *variation*, *inheritance*, and *differential success* that are considered to be the core components of scientifically normative Darwinian explanations of natural selection. Also included are ideas such as *need as a rationale for change*, *change due to use*, or *environmental pressure*, each of which has been described as incorrect or "naïve" (Nehm & Ha, 2011; Opfer *et al*., 2012). Each of these ideas can theoretically function appropriately in evolutionary explanations or as part of incorrect explanations. However, because these resources can be used ambiguously or metaphorically, it can be challenging to interpret their intended meaning in data, particularly in written responses in which students have no ability to clarify or elaborate (Rector *et al*., 2012). For example, the statement "environmental pressures cause species to evolve" could be considered incorrect if the student is thinking that the pressure itself is the direct cause of the change. However, a metaphorical use of "pressures" to explain that environmental factors that have an impact on differential survival could be considered correct. From a KiP perspective, these ambiguities call for caution in interpreting the correctness or incorrectness of students' explanations. For this reason, we refrain from evaluating individual resources as correct or incorrect and use caution in making inferences about their correctness or incorrectness.

Contexts that influence reasoning about natural selection

Analyses of students' written explanation have revealed significant differences in how students respond with varying features of natural selection tasks, including taxonomic group (e.g., plants or animals), trait type (e.g., morphological or behavioral), direction of trait change (gain or loss of function), unit of analysis (population or species), and students' familiarity with the organisms. For example, students tend to include more statements that are considered canonically incorrect when reasoning about the evolution of a loss of trait function as opposed to a gain of function (Nehm & Ha, 2011).

While analyses of written responses have demonstrated that features of tasks can influence response patterns, such methods are not able to explain how or why these features activate different resources for students. Such explanations must attend to the moment-to-moment dynamics of how students are interpreting contexts. In an interview study of middle school students, Southerland *et al*. (2001) found that students' explanations included different knowledge resources when they interpreted interview questions as asking them to explain *why* a trait evolved as opposed to *how* it evolved. Building on this work, we examined how a student constructed different understandings of context and the resources she activated in these different contexts.

Methods

Study context and participant selection

This case study interview was selected from a study of 8 community college students enrolled in a tropical biology course taught in Costa Rica. As part of a course activity, each student participated in a brief interview during which they were asked to define natural selection as well as provide an explanation for how a trait that they had observed in their field excursions could have evolved from an ancestor that did not have that trait. Students were allowed to choose the trait that they wanted to explain.

We chose one interview with a student named Anna for the focus of this analysis. While we saw shifting patterns of resource activation in all 8 interviews to some degree, the clarity of shifts among clusters of resources in Anna's interview make it a useful illustrative case. At the time of the interview, Anna was in her first year as a biology major at a community college. For her interview, Anna chose to explain the gain of "jumping ability" in a tropical mudskipper (*Periophthalmus spp*.) or "skipping fish" that can use its front fins to guide the fish to jump from one tidepool to the next. The interview lasted 7 minutes and was captured on video. Anna is bilingual, and the interview was conducted in English, which was not her first language. In our transcription of the interview, we left Anna's expressions unedited. As part of our analysis, we divided the interview into 8 segments, each of which corresponded to shifts in the context (see Figure 2).

Characterizing contexts

We characterized contexts by analyzing the question posed by the interviewer and evidence of how Anna interpreted the question in the moment. For example, when the interviewer asked Anna, "What, in your mind, is natural selection?" Anna responded with "Natural selections [sic]. It is…." Together the request (*What is*) and her response (*It is*) suggest a mutual understanding of the context as *defining of natural selection*. Overall, we identified 5 contexts: *defining of natural selection*, *explaining why an organism evolved*, *explaining how a trait evolved, attending to variation*, and *making analogies to humans*.

Identifying conceptual resources and characterizing DMCs

Descriptions of conceptual resources were constructed through iterative rounds of coding and discussion of the interview video as a research team. We began by describing candidate resources in each of the 8 interview segments using the following three heuristics: Candidate resources were components of explanations that were (1) propositional (2) general enough to apply beyond the specific mudskipper question, and (3) neither correct nor incorrect. We then cross-referenced our descriptions with descriptions of conceptions from the natural selection literature.

In some cases, we agreed that our descriptions straightforwardly captured Anna's intended meaning. For example, when Anna described offspring as "not all identical" we agreed that her meaning was well captured by the resource *variation*. In other cases, Anna's meaning was more difficult to interpret. In these cases, we made tentative resource assignments and articulated alternative possibilities. For example, at one point we encountered uncertainty in assigning the resource *differential success*. When Anna was describing how jumping could have evolved, she described a transition from fins balancing to fins that can jump. In her description Anna said, "eventually the fins become stronger so like over time they survive." In this example, it is unclear what Anna means by "they." Anna could be using "they" to refer to only those fish that have stronger fins, a reference to *differential success*. Alternatively, "they" could mean all the fish, in which case the success is not differential. While later in the interview, Anna does say that she doesn't think all the fish will evolve the new abilities, we cannot tell what she intends in this moment.

Another ambiguity concerned whether Anna intends the idea *use enhances a trait.* As she was describing how mudskippers' fins could have evolved from fish, she began to talk about how a fish out of water wobbles around and "maybe like, like over time they have like, they create more muscle or more energies like to do the wobbly thingy." One interpretation of what Anna is saying here is that muscles get stronger through use. However, her use of the term "over time" makes this interpretation ambiguous. It could be that Anna is talking about muscle changing at the scale of evolutionary time. In examples like these, we maintained uncertainty in our assignment of resources, which we denote with parentheses in our results (see Table 1).

Analysis of interview framing dynamics

Russ *et al*., (2012) used verbal (e.g., hedging language), paraverbal (e.g., pauses) and nonverbal (e.g., gaze) behaviors to make inferences about how interviewees were framing interview interactions. They noted that shifts in clusters of behaviors could be evidence of shifts in framing.

To conduct gaze analysis, we first viewed the video in its entirety and identified four distinct observable gaze patterns: looking forward at the interviewer, looking down at her paper, looking to the right, or looking to the left (Figure 1). Using NVivo, we coded the entire 7-minute clip using these four categories. We also identified moments of pause and calculated their duration and coded all instances of hedging language. Finally, we coordinated these patterns across the different interview segments to make inferences about how Anna might be interpreting or experiencing the interview in those moments.

Figure 1
Categories of gaze: forward, down, right, left

Findings

Contextual activation of resources

We found two patterns in how Anna activated resources across the interview. As summarized in Table 1, we found distinct patterns of resource activation across contexts. We also found that in each context the resources were linked in coherent and sensible DMCs.

Table 1
Presence/absence of resources in different contexts (parentheses indicate tentativeness in resource assignment)

	Define natural selection	Why organism evolved	How trait evolved	Attend to variation	Analogy to humans
variation	x			x	
inheritance	x		x		
differential success	x		(x)		
change takes time	x		x		
genetic basis				x	
need as rationale		x			
environ. pressure		x			
trait function		x	x		
use changes trait		(x)	(x)		
transitional forms		x			
change via learning					x

Defining natural selection activates darwinian DMC

When Anna understands the context to be asking her to *define natural selection* she activates a DMC that includes conceptual resources considered to be in line with canonical Darwinian explanations.

> Anna: Natural selections it's like when, um, one or- organisms, like over generations, like parents, they have babies, but they have like similar babies, but they're not identical, like colors and everything, and whichever's strongest and fit with the natures, they can survive but the weak one dies.

While this would not be considered a completely correct Darwinian explanation, we characterize this DMC as Darwinian because it includes the core concepts of *variation*, *inheritance*, and *differential success* to describe *change over time* occurring within a population. Anna activates this same set of ideas a second time later in the interview when asked to connect her response to "what she said earlier about natural selection" (see Figure 2).

Explaining why organisms evolve activates evolutionary rationale DMC

The interviewer asks Anna to explain how the skipping fish could have evolved the ability to jump from "ancestors who could not do that." Anna begins by describing possible ancestral forms (fish- or salamander-like) and then describes challenges posed by the environment that provide a rationale for why those ancestors would evolve.

> Anna: At first I thought that maybe because they always like, got wash away to the beach, like nearby the beach and then like, if they couldn't jump, they eventually die.… Or just like another reasons, like, it's possible, like when they wash in the tide pool and then they start living there, there's like a lot of predators like crabs chasing them and they get cornered so if they can't jump, then they'll die.

In this context, Anna links *environmental challenges* (waves and predators) to *differential success* by noting that those individuals who could not jump, would die. In doing so she is providing a rationale for why functional fish-like ancestors would evolve into the "skipping-fish" form. Given these environmental challenges, adapting a jumping ability could be seen as a clear advantage.

Explaining how trait evolved activates pathway of transitional forms DMC

In the next section the interviewer attempts to clarify that he is looking for an explanation of how the trait evolved via natural selection. However, it appears that Anna understands him to be asking for a proximate physiological explanation of how a fish-like form could be transformed into a jumping form. Anna describes how jumping could have evolved from a "wobbling" behavior of an ancestral fish.

> Anna: Maybe (0.5s) at first, you know how fish, usually they do that when there's no waters, like wobbling around, maybe like (0.5s) like over time they have (0.5s) like they create more muscle or more energies like to do the wobbly thingy. And then like eventually they can jump and then like maybe the fins- because they're like supporting the ground, like they're trying to support the ground when they jump. So eventually the fins become stronger so like over time they survive and then their offsprings have a really good jumping skills and stronger fins so it feels like they can walk.

In explaining how a complex trait like jumping could evolve, Anna provides a series of *transitional forms.* Each transitional form has its own *function*, that could plausibly define a pathway from the evolution of an ancestral fish to a jumping mudskipper. She begins with the wobble in an ancestral fish and then posits that this form evolved into a form that used its fins to support the ground. Eventually, the fins got stronger allowing the fish to jump. Note that in describing how the fish could "create more muscle" and fins becoming stronger as the fish tries to "support the ground", it appears that Anna is activating the resource *use enhances a trait*. In addition, she connects this trait development to *inheritance* by offspring. Thus, her description of transitional forms includes elements of "Lamarckian" explanations (Ferrari & Chi, 1998).

Attending to variation activates ideas about the genetic basis for traits

Anna's reasoning shifts when she is asked to attend to variation in the population. This shift happens twice when the interviewer asks Anna to explain if all the fish are "born with" the ability to jump (see Fig 2). In each instance, Anna begins by establishing that she understands that individuals are not all identical—a *variation* resource. In the second instance, Anna also activates ideas about the *genetic basis* for this variation for the first time in the interview.

> Interviewer: Okay. So do they all—let's say you have a population of them can, they're born, can they all develop that ability?
>
> Anna: (1s) Not all of them, like only some of them. And then like (1s) so this fittest one survives and then they reproduce with another fittest one and their generations become—they have a good gene for that.

Anna later clarifies that the “good gene” she is describing is for “jumping abilities and strong fins.” It is difficult to interpret from this utterance exactly what role the gene plays in her explanation. One interpretation is that Anna is saying that phenotypic variation in the population for jumping ability corresponds to a gene and that over time those who have this ability, and this gene, will be more successful and increase in frequency (*differential success*). Another possibility is that Anna is somehow imagining that the gene changes along with or because of the phenotypic change.

Analogies to humans activates learning as a mechanism of change

Towards the end of the interview, the interviewer shifts from asking Anna to provide an explanation to asking her to reflect on her “thought processes” and any “past experiences” that she is using in answering this question. The reference to her own prior experiences appears to be understood by Anna as asking for *analogies to humans.*

> Interviewer: Are there things from your past that you've learned or know, or, or have heard that you're using like tools? You know what I mean?

Anna: I think so like (0.5s) humans experiences maybe <rising intonation> Like (0.5s) just like a kids, for example, like, um, if a human, like, for example like maybe at first they don't know that snikes [sic] are snakes are poisonous and like one person get bitten and then like they (0.5s) and then the next person they tell another person not to touch it so it's like nowadays humans don't touch snakes anymore, but maybe like in the old times-something like that I don't know

In this segment Anna is describing a process whereby humans change their behavior by learning to avoid snakes. Learning has not previously come up in this interview in Anna’s explanations for the skipping fish.

A blend of learning and genetics contexts reveals a contradiction

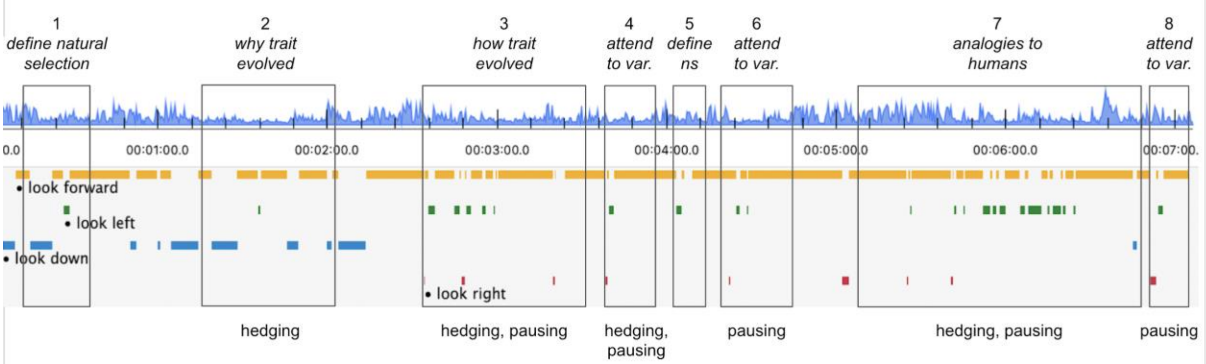
When following up on what Anna is saying about learning, the interviewer asks if Anna thinks the skipping fish learns. Anna agrees, despite having said earlier that the jumping trait has a genetic basis. This contradiction prompts the interviewer to clarify.

> Interviewer: Okay so the skipping fish learns
>
> Anna: Yea
>
> Interviewer: to put its muscles like that
>
> Anna: Mm hmm
>
> Interviewer: But it’s genetic
>
> Anna: (.5s) Well, when they'll learn, sometimes (1s) I believe in mutations, like, although like you're learning some things yeah so it's passed down the traits.

It appears that when these two contexts come together Anna is unsure how to reconcile her ideas. She does not seem to want to reject learning as a mechanism, yet at the same time she affirms her belief that traits have a genetic basis. The interview ends here with these two sets of ideas left in play.

Figure 2

Gaze, hedging, and pausing across the interview segments



Shifts in framing behaviors across contexts

Anna's gaze, use of hedging language, and speech cadence vary over the course of the interview (Figure 2) suggesting she is engaging in different types of explanation in different segments. In segment 1, when Anna is defining natural selection, she alternates between looking down at her paper and looking up at the interviewer. While Anna does not appear to be reading, her gaze suggests that she is referencing a prepared response. She uses no hedging language, and her speech is steady without pause. This cluster of behaviors suggests Anna is reciting her prepared response. In the next segment, Anna continues to look down as if referencing her writing, and while her speech is still clear, she now includes hedges such as, "I think" and "maybe." These inclusions make sense because Anna is explicit about offering her "hypotheses" here. Thus, while she is signaling that these ideas are tentative, she again appears to be reporting of a prepared response.

In segment 3, Anna's behaviors shift. She looks to the right and then repeatedly to the left as she begins to answer. Looking left overlaps with hedging language ("maybe") and pauses. A similar cluster of behaviors is evident in segment 7 as Anna is offering an example of how humans learn to avoid snakes. These behaviors suggest Anna is actively constructing her responses in these moments.

Finally, each time Anna is asked explicitly to attend to variation (4, 6, 8), she briefly flickers her gaze. During these shorter responses it appears Anna is pausing to think, indicating that she is perhaps initially unsure how to respond, but then settles on a response without extensive construction—each time affirming that she would expect variation in the population.

Discussion: Global incoherence and local coherences in context

Anna does not draw from a singular, globally coherent mental model of natural selection in her explanations. Over the course of the interview Anna's responses vary in terms of their alignment with each other and with scientifically accepted explanations. When asked simply to define natural selection, Anna's explanation included the appropriate use of the core concepts of variation, inheritance, and differential success. In contrast, Anna's explanations of *why* and *how* the jumping trait could have evolved included resources that have been described as "naïve" (Nehm & Ha, 2011; Opfer *et al*., 2012). Yet, when viewed in relation to the contexts of their activation, these resources appear both locally coherent and sensible.

Anna applies ideas about *need as a rationale for change* when she identifies features of the environment that would favor jumping ability. These sorts of explanations, because of their focus on trait function, have been explained in terms of underlying teleological biases (Kelemen, 2011). Anna uses the environmental problems to provide a reason why a fish would need to evolve into a mudskipper. Her explanation does not appear to suggest that Anna thinks that the need itself caused the change. In the segment prior, Anna has already explained change in terms of the differential success of variants and the inheritance of traits over time. In line with Southerland *et al.* (2001), we argue that Anna's use of the "need" resource is sensible in the context of the "why" question she understands herself to be answering.

Similarly, Anna's description of a *series of transitional forms* that get "stronger" and are inherited by offspring could be described as evidence of an underlying "Lamarckian" theory of evolution. While it does seem like Anna is suggesting that changes within an individual can be inherited by offspring, mechanisms of inheritance are not the focus of her explanation. Anna is focused on describing a plausible series of transitional forms connecting an ancestral fish to a jumping fish and explaining the physiological mechanisms, such as changes in muscle and energy, that could underlie the transformation of one into the other. Given that this is her focus, it is not clear whether she intended to communicate that the change happens through *inherited use*. Moreover, throughout this response Anna makes several references to the idea that *change takes time* (e.g., "eventually they get stronger"), possibly intending to communicate change over a longer evolutionary time.

Finally, when Anna interprets the interviewer as asking her for analogies to humans, Anna activates ideas about *learning as a mechanism for change*. This idea makes sense applied to how humans might have learned to avoid snakes. When the interviewer switches the context back to the skipping fish, Anna continues to affirm the use of this resource. This moment is evidence of the strength of context effects. Anna has not previously mentioned learning, but once the idea has been activated it seems to stay active. When challenged to consider the genetic basis of the trait, an idea that Anna had offered previously, Anna appears to attempt to combine the two ideas together seemingly indicating that both mechanisms have a role to play.

Our interpretations are limited by the fact that Anna is a bilingual English language learner and the fact that the interview was time limited. Open questions remain about Anna's meaning in various moments. Nevertheless, Anna's interview suggests that different constructions of context played a strong role in explaining the patterns of resource activation in Anna's reasoning. Anna's thinking was sensibly related to context whether she was recalling a prepared response or constructing an explanation in the moment. Overall, these patterns in Anna's thinking align with a KiP model comprised of interconnected sets of resources that are temporarily assembled in interaction with contexts.

Significance and implications

Researchers continue to advocate for the need to directly address students' misconceptions about natural selection during instruction (e.g., Nehm *et al.*, 2022). Without consideration of the role of context in influencing reasoning patterns, these interventions are unlikely to result in lasting conceptual change. Our work suggests that ideas that are considered misconceptions play a functional role in context-specific explanations, making eradication an untenable and undesirable goal. Additional work is needed to understand the mechanisms by which students develop the fluidity to activate resources in appropriate contexts as well as to reconcile seeming contradictions across contexts. In addition, work may also be required to help instructors understand how students are constructing contexts so that they can more appropriately interpret and respond to students' thinking.

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Mathematics Curricula that Center Black Brilliance and Joy: Design Principles and a Task Analysis

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Abstract: Building on *Black Feminist Mathematics Pedagogies* (BlackFMP; Joseph, 2021), we examine how discipline-specific features of curricula can support antiracist teaching. BlackFMP builds on scholarship that attends to (a) individual Black girls' mathematics experiences, (b) the historical context that situates those individual experiences, and (c) the brilliance of Black girls and women. Based on the contents of the BlackFMP framework, we synthesized four guiding questions and developed a codebook to further articulate how each of the questions might manifest in a mathematics curriculum. Our findings indicate that the process of coding mathematics curricula using the BlackFMP framework can create learning opportunities for curriculum writers as they explore ways to create textbooks that have increasingly equitable opportunities for Black girls and for all students.

Overview

Mathematics curricula are saturated in whiteness (Battey, 2013; Martin, 2010; Stinson, 2011). Mathematical spaces, including curricula, align with white ideals and culture and thus constrain the ways learners are allowed to exercise their agency (Battey & Leyva, 2016; Gutiérrez, 2017). Even more, schools function as a vehicle for social reproduction, preparing students of color to exercise less agency in society than their white peers (Anyon, 2013). In fact, racism has profound effects on the educational opportunities of marginalized students. For example, when Berliner (2006) disaggregated the results of the PISA of 2000 by race, they found that:

> If the educational opportunities available to White students in our public schools were made available to all our students, the United States would have been the 7th highest scoring nation in mathematics, 2nd highest scoring nation in reading, and the 4th highest scoring nation in science. Schooling for millions of US White children is clearly working quite well. On the other hand, were our minority students 'nations,' they would score almost last among the industrialized countries of the world. (pp. 963-964)

Though these results are from over two decades ago, the inequitable distribution of opportunities to learn has not changed much (Carnoy & Rothstein, 2013). Although it is important to tell this story of oppression, many Black scholars today are arguing that if white teachers and scholars understood what Black Joy looks like, schools would be a more humanizing place for students of color (Math Learning Center, 2022).

As scholars who create mathematics curricula that affect over 700,000 students each year, we have a responsibility to hear this call to action. Because evidence suggests that mathematics curriculum substantially impacts instruction and students' experiences in the classroom (Kloosterman & Walcott, 2010), we wonder how frameworks centering Black brilliance and joy from an intersectional perspective can be leveraged to influence the work of curriculum designers. We also recognize the limitations of reimagining mathematics curricula in alignment with reform-oriented mathematics education given the enduring differential learning outcomes for Black students even after over three decades of current reform efforts (Berry et al., 2014; Bullock, 2019; Martin, 2010). Yet, for now, teachers and students do continue to work and learn within the existing system. Our work aims to disrupt the status quo to make a difference for those with immediate needs.

To do so, we take up Dr. Nicole Joseph's (2021) *Black Feminist Mathematics Pedagogies* (BlackFMP) framework and use it to analyze a reform-based secondary mathematics curriculum designed to support ambitious mathematics instruction (Lampert et al., 2010) and culturally responsive teaching (Gay, 2018; Hammond, 2014) to find ways curricula can support an antiracist stance. This pedagogical framework supports us in identifying elements in the written curriculum that can foster instruction that features pedagogical actions that benefit Black girls (see Stein et al., 2007 for connections between the intended and enacted curriculum). Taking up BlackFMP to guide us, we ask: How can frameworks centering Black girls' mathematical experiences help us understand how mathematics curricula do and do not support humanizing and just teaching in ways that are actionable for curriculum designers?

Conceptual framework: Why center black girls?

Black girls experience intersectional forms of oppression (Crenshaw, 1989), including sexism and the US's ongoing history of antiblack racism and violence against Black people. We take up BlackFMP for our analyses because it builds on scholarship that attends to (a) individual Black girls' mathematics experiences, opinions and perspectives, and ways of relating to the broader collective of Black woman/girlhood (Black Feminist Thought; Collins, 2000; Dillard, 2000; Smith, 1989), (b) the historical context that situates those individual experiences (Critical Race Feminism; Evans-Winters & Love, 2015; hooks, 2000), and (c) the brilliance of Black people in general and Black girls and women in particular (both theories, Joseph et al., 2016). The critical theories that BlackFMP is built upon argue that a commitment to human solidarity and justice more broadly is required for justice for Black women and girls in particular, making scholarship from this intellectual tradition ideal for considering educational justice for a diverse student body (West, 2019).

Another essential reason for centering Black girls in our analyses is the violent ways that antiblack racism manifests for Black girls in schools. Black girls experience antiblack racism in schools through (a) the adultification of Black girls (i.e., the belief that Black girls need less nurturing, protection, and support than white girls); (b) the characterization of Black girls as too social, loud, and disruptive; and (c) disproportionate discipline, resistance to naming Black girls' intellect even when they excel, to name a few (Epstein et al., 2017; Joseph, 2021). Centering Black girls' experiences in the pursuit of justice can motivate, for example, making mathematics learning environments increasingly nurturing places where students are invited to bring their full selves and demonstrate their brilliance (i.e., humanizing mathematics; decentering whiteness; Collins, 2002).

This focus on Black girls' experiences does not negate the experiences of other groups who experience oppression and violence by white people and largely white governments (e.g., Native/Indigenous peoples, Asian Americans, Jews). Because antiblackness is the most predominant and visceral form of racism in America, attending to the experiences of Black girls should benefit all students and teachers, and perhaps extend internationally as racism in the US may be an exceptionally informative "extreme case" (Flyvbjerg, 2006). Centering the design of curricular materials in ways that benefit and build on the brilliance of Black girls will benefit all due to the considerable impact of curriculum on what students learn (Kloosterman & Walcot, 2010) and providing supports necessary for healing for the nuanced and varied ways students experience and internalize antiblack racism (Case, 2019) (1).

We center the BlackFMP framework because it builds on scholarship that attends to the experiences of individual Black girls in US schools (Joseph et al., 2016) while also situating those experiences within a historical context with an eye toward the brilliance of Black people in general, and of Black girls and women in particular. BlackFMP builds on ambitious reform efforts but argues that they are not enough, and in some sense have had a colorblind impact as they still create inequitable opportunities for Black girls. Thus, BlackFMP says that ambitious mathematics instruction is not enough.

Research design

Based on the contents of the BlackFMP framework (Joseph, 2021), we synthesized the following four guiding questions: (1) Ambitious Mathematics Instruction: How does the curriculum engage students in argumentation, reasoning, modeling, and problem-solving? (2) Academic and Social Integration: How does the curriculum allow humor and socializing to promote healing from intellectual trauma and violence in math spaces? (3) Critical Consciousness and Reclamation: How does the curriculum create opportunities for alternative, transgressive, hybrid spaces generated and occupied by students' conscious spirits? (4) Robust Mathematics Identities: How does the curriculum support students to view themselves positively as math learners and doers, as well as having strength, agency, and resistance to oppressive mathematical experiences?

We then developed a codebook (see Table 1) to further articulate how these questions might manifest in a mathematics curriculum. This codebook was based on the BlackFMP framework and revised to reduce overlap across and within the four categories and to ensure the codes and our conversations centered Black girls. We also expanded what was in the codebook based on how the curriculum we coded "answered" the questions.

In addition, BlackFMP distinguished between procedural fluency and conceptual understanding, but to resolve coding disagreements, we found we needed a more nuanced approach to cognitive demand and so took up Stein et al.'s (2000) framework of high cognitive demand (i.e., *doing mathematics* and *procedures with connections*) and low cognitive demand (i.e., *procedures without connections* and *memorization*). The cognitive demand framework supports our analysis because we aim to discover how rich curricular tasks are rather than assuming their richness ("groupworthy tasks," Lotan, 2003) or looking at whether they spur rich interactions (e.g., sociocultural studies of learning; Engle & Conant, 2002; Sengupta-Irving & Enyedy, 2015).

After coding several lessons, discussing the results, resolving dilemmas, and modifying the codebook further, we developed sub-codes for each of the four guiding questions. We share the sub-codes in Table 1 to support a fuller understanding of how we understand each guiding question based on the BlackFMP framework and our attempts to use it to code curricula. Because we conjecture that this framework centering Black girls will benefit all students, we use "students" in our codes rather than "Black girls."

Table 1
Working codebook

Guiding Principle	Codes
Ambitious Mathematics Instruction	High cognitive demand, Low cognitive demand, Status and equitable participation, Access and productive struggle, Make sense of student thinking and build on student ideas
Academic and Social Integration	Humanizing, Responsiveness
Robust Mathematics Identities	Mathematical dispositions, Representation of mathematics[a], Expansive definition of achievement[a], Disrupting dominant narratives[a]
Critical Consciousness and Reclamation	Read the world with mathematics, Write the world with mathematics, Power and solidarity[a], Author positionality[a], Teacher positionality[a]

[a] Codes not yet used in our analysis.

To further refine our working codebook, we honed our agreements of coding practices and identified areas of tension to outline our ongoing analysis through coding an additional two lessons that immediately preceded our focal lessons. The focal lessons on wage inequities foreground the curriculum developers' (i.e., CPM Educational Program, 2022) explicit efforts toward centering culturally responsive materials and intersectional discrimination based on race and gender.

Secondary mathematics curriculum

The CPM Educational Program (CPM) has demonstrated commitments to equity-oriented instructional practices since its inception in 1989, specifically through its three pillars of collaborative learning, problem-based learning, and mixed-spaced practice (CPM, 2022). Over the years, CPM, specifically, and the mathematics education field broadly, has continued to develop nuanced understandings of how mathematics curriculum can better support students from more diverse backgrounds. As such, CPM began developing the Inspiring Connections curriculum for 6th- through 8th-grade mathematics (Inspiring Connections 1, Inspiring Connections 2, Inspiring Connections 3). Currently, the Inspiring Connections series is under various stages of development and field testing, with Inspiring Connections 1 undergoing the second round of year-long field testing in 20 classrooms across 14 US cities.

We selected CPM's Inspiring Connections series for our proximity to the development of the curriculum. Jasien began supporting CPM's development through the organization's research arm in 2019, synthesizing research to inform the curriculum writing process and engaging in critical evaluations of CPM deliverables to foster more equitable mathematical experiences for students in CPM classrooms across the country. Informed by his experiences partnering with Black and Latinx high school students in Newark, NJ, Lolkus joined the CPM writing team in 2022 to develop culturally relevant and social justice-focused mathematics curricula. Our commitment to supporting CPM's mission of bringing more mathematics to more students encourages us to question who is and can be served by our most recent efforts to develop mathematics curricula centered around tenets of culturally relevant teaching. We detail findings from two lessons in Inspiring Connections 1, *The Job Offer* and *Weekly Earnings*, which have students write, interpret, and simplify expressions in contexts related to wage discrimination in the United States.

Findings

Though BlackFMP centers Black girls, we found that this framework helped us consider dimensions of the curriculum that are important for all students. In our findings, we share the actionable ideas we developed through the coding process. Notably, we found more value in the process of coding and in the rich conversations the coding sparked than in producing reliability amongst the research team. This outcome aligns with our aim to find ways that the BlackFMP pedagogical framework can support meaningful learning for curriculum designers: as we iteratively coded and refined the codebook, our conversations led us to redefine each code in ways that made the pedagogical framework of BlackFMP increasingly more particular to curriculum design.

In addition, our coding differences led us to conversations in which we imagined new curricular possibilities. For example, when we expanded BlackFMP's attention to procedural fluency versus conceptual understanding to account for levels of cognitive demand (Stein et al., 2000), we had disagreements over whether many problems should be coded as high cognitive demand ("procedures with connections") or low cognitive demand ("procedures without connections"). Through our conversations about the most meaningful ways to code, we recognized that most tasks had lower-level procedural scaffolding (e.g., part (a) and part (b)) that led to a more conceptual ending (e.g., part (c); see Figure 1).

Figure 1

Example mathematical prompts that utilize scaffolding in the focal lessons

STATS AND
HEALTH INC

Camila Rodriguez
Stats and Health Inc.
31415 Pie Court
Cherry Hill, MT 59721
406.926.5358

July 10, 2021

Emily Miller
2718 E Street
Golden, CA 90452
916.281.8284

Dear Emily Miller,

I am pleased to offer you full-time employment at Stats and Health Inc. A detailed job description is attached to this letter for your reference. This position will begin on Monday, July 23, 2021. The hours of work are 7:00 a.m. to 4:00 p.m. Monday through Friday, with a one-hour lunch break each day, for a total of 40 hours per week. Pay will be at a rate of $10.75 per hour.

If you accept this offer of employment, please sign and return the attached contract.

I look forward to working with you.

Sincerely,
Camila Rodriguez
President, Stats and Health Inc.

6-21. Emily gets a job offer at Stats & Health Inc. Her job offer is shown in the letter.

a. What would Emily's annual salary be if she accepts this position? Assume that she works 50 weeks a year.

b. How does the salary you calculated in part (a) compare with the salaries listed in the table in problem 6-20?

c. Do you think this offer is fair? Why or why not? If not, what do you think is a fair offer?

Our disagreement lay in whether the scaffolds in the problem reduced the cognitive demand of the richer, more conceptual parts of the problem. Without resolving this completely, we concluded that we could increase the cognitive demand of each lesson and have students do mathematics (the highest level of cognitive demand) by flipping the parts of each task, putting what was at the end first, and providing students with the resources that are currently scattered throughout the current lesson at the beginning of the lesson. This was true in both the scale of the lesson and of the task: the task in Figure 1 would be richer if it started with part (c). The scaffolding questions could be included in the teacher edition of the textbook for just-in-time support as students solve the non-routine tasks. In this way, there are multiple options for curriculum designers to iterate on their designs, either at the scale of the lesson or at the scale of tasks.

There is an endemic challenge to designing mathematics lessons that foster students' engagement with social issues: too often, lessons foreground mathematics or social content instead of meaningfully interweaving each due to constraints, such as time (Gregson, 2013), the instructor's sociopolitical or mathematical knowledge (Kokka, 2015), or even challenges to aligning the mathematics and sociopolitical goals (Brantlinger, 2011). In the case of the CPM curriculum, we found that the scaffolds that we interpret as the curriculum designers' attempts to avoid de-elevating the mathematics actually reduced the cognitive demand across the questions. Thus, the intent and the impact of the design are mismatched. Figure 2 and Figure 3 showcase one example of this tension.

Figure 2
Mathematical prompts for investigating the fairness of Emily's job offer

6-22. Emily wants to make sure the job offer is fair, so she decides to keep investigating.

First, she talks with some of her older friends who already work at Stats & Health Inc. None of her friends have worked for the company for more than two years. She asks them what their salaries are and writes them in a list.

$25,600, $26,500, $28,750, $29,100, $29,950, $30,075, $35,250, $36,300, $37,050, $38,275

Next, Emily does an Internet search for information about salaries at Stats & Health Inc. and she finds the following infographic.

a. Calculate the mean and median of Emily's friends' salaries.
b. What does "salary range" mean?
c. What is the maximum salary at Stats & Health Inc.?
d. What information does the bar graph provide?

Figure 3
Mathematical Prompts for Investigating the Fairness of Emily's Job Offer

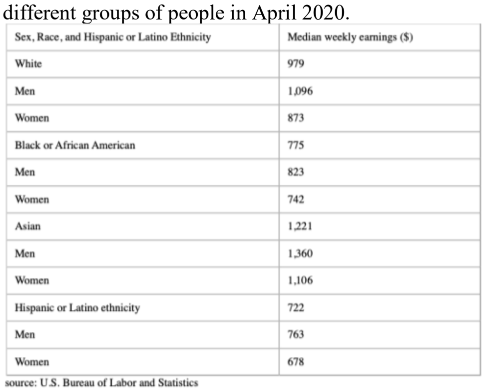
6-23. Emily needs your advice about the job offer.
   a. Should she accept the job offer? Why or why not? Use the information in problem 6-14 to support your answer.
   b. Suppose Emily decides to negotiate for a higher salary. What salary do you think she should ask for? Provide at least two data points to justify this salary.

Students begin investigating scaffolded mathematical questions (i.e., Figure 2) that build to more cognitive demand (i.e., Figure 3) throughout the lesson. If the questions were flipped, with the current initial task instead provided as just-in-time scaffolds, then the curriculum would better support both high cognitive demand mathematics learning as well as more meaningfully support students to develop their critical consciousness with connections to their lived experiences.

We also note that many of the social issues and higher cognitive demand features of the Inspiring Connections 1 lessons were located in the teacher edition of the curriculum (see Figure 4 and Figure 5). In relation to the student edition's push for social analysis, we see a table that includes gender and race/ethnicity. This may support students in grappling with gender discrimination and wage inequality. Yet, the questions in the student text do not prompt students to notice or explore these issues, making it possible that such issues remain unexamined in the public space of classroom discussion. Instead, the social issues are explicitly mentioned in the teacher edition of the text as a caution to ensure that, if students use the data to affirm racist and sexist ideas, teachers know to facilitate a discussion about that use of the data as unacceptable.

Figure 4
Student Version of Problem 6-33

6-33. Bailey finds data from the U.S. Bureau of Labor Statistics. The table shows the median weekly earnings for different groups of people in April 2020.



Sex, Race, and Hispanic or Latino Ethnicity	Median weekly earnings ($)
White	979
Men	1,096
Women	873
Black or African American	775
Men	823
Women	742
Asian	1,221
Men	1,360
Women	1,106
Hispanic or Latino ethnicity	722
Men	763
Women	678

source: U.S. Bureau of Labor and Statistics

Bailey writes the three expressions shown in parts (a) through (c). For each expression, complete the following:

i. What question might Bailey be answering by writing this expression?
ii. Justify your answer by explaining what each term in the expression means.
iii. Perform the calculation to answer the question you wrote in the first bullet.

a. 52(678 + 678)
b. 5 x 52 x (1,096 + 823)
c. (1,360 + 1,106) - (763 + 678)

Figure 5
Teacher Version of Problem 6-33

Move teams to problem 6-33. the expressions in this problem require using the Order of Operations to evaluate. Students need to complete the addition within the parenthesis before completing the other operations. Students have been evaluating expressions like this since 3rd grade (3.OA.B.5), so this problem should serve as a reminder. However, continue to monitor their work as you circulate and provide support as needed.

The context of problem 6-33 (median weekly earnings for men and women of different races and ethnicities) lends itself to a conversation about income inequality. After teams complete this problem, lead a class discussion. Start by reminding students of the class's agreed-upon expectations for respect and collaboration. Then ask the class questions, such as:

- *What do you notice? What do you wonder? Was anything surprising to you? What questions do you have?*
- *Why were these data collected? Where did they come from?*
- *Who is affected by these data? Who could be hurt by them? Who could be misled by them?*
- *What are the benefits and challenges of living in a diverse society?*

These data highlight issues of income inequality in the U.S. based on sex, race, and ethnicity. The data highlighted in this problem could cause some people to create confirmations of racism or sexism. For example, they might argue that Black people should make less money because they do not work as hard. This racist argument is unacceptable. Instead, the data and the subsequent discussion should be used to challenge the system that has created the inequities. Consider collaborating with your colleagues in the Social Studies or History departments to continue the discussion beyond this lesson.

If you do not feel a class discussion would be appropriate or productive for your class, conduct another Dyad instead so that students can express their thoughts about the data. Students will likely start asking about up-to-date information about income. Move them to problem 6-34, which gives them an opportunity to research this information.

Relating to cognitive demand, the student-facing version of Problem 6-33 (i.e., Figure 4) has students engage in procedures without connections because there is little ambiguity about what they need to do and how to do it. The teacher-facing instructions (i.e., Figure 5) provide opportunities to further increase the cognitive demand of the problem by prompting students to ask follow-on questions that support students to make connections between the sociopolitical contexts and the procedures they investigated. This makes it more likely that overworked and underpaid teachers are less likely to encounter these elements and more likely that students experience less ambitious instruction and teacher responses that are less sensitive to the social issues within the curriculum. We know that teachers often plan lessons using the student versions of their textbooks (e.g., Superfine, 2008), so this finding has prompted discussions about how to strengthen the content in student materials.

Discussion

Joseph's (2021) BlackFMP framework supported our sensemaking about both the rigor of the curriculum from a perspective of ambitious mathematics instruction and opportunities for curriculum writers to engage with essential dimensions of mathematics learning: bringing students' full selves to the mathematics classroom (i.e., Academic and Social Integration), generating in transgressive spaces (i.e., Critical Consciousness and Reclamation), and developing mathematical identities that center their own strength, agency, and resistance to oppressive experiences (i.e., Robust Math Identities). Through this interrogation of Inspiring Connections 1, we are working toward a reimagined mathematics education that can provide equitable opportunities to Black girls to correct for the historic and ongoing harm of low expectations and limited opportunities provided through our nation's education system. Though beyond the scope of this analysis, we note that a professional learning session we hosted for Inspiring Connections curriculum designers resulted in changes to the lessons presented here and, suggesting the session will shape future lessons.

While this critical analysis of a secondary mathematics curriculum demonstrates promise for supporting curriculum designers to attend to students who have historically been marginalized in mathematics classrooms, more is needed. We note that many of the codes we did not use in our analysis (because they were not present in the lessons analyzed) are essential to taking an antiracist stance in curriculum design. For example, under Robust Mathematics Identities, we did not use the codes Representation of mathematics, Expansive definition of achievement, or Disrupting dominant narratives. We argue that these codes may not be a good fit for a lesson on gender discrimination and wage inequity, but nevertheless are essential to designs for curricula that seek to dismantle the status quo. Likewise, curricula must explicitly support teachers to understand that mathematics lessons are appropriate places for students to be playful and goofy (i.e., humanizing) and that support students to see and embody their full brilliance (i.e., Robust Mathematics Identities).

Noting that we were not able to code for author positionality within these social inequality lessons (or the textbook as a whole), we call on curriculum designers and researchers (including ourselves), both within and beyond CPM, to (a) engage in critical reflections on their own positionality and (b) complicity in developing classroom materials that harm, rather than celebrate, Black girls; and (c) identify individual areas of growth, such as commitments to engage students in problems that foreground BIPOC characters and mathematicians that break multiple, intersecting, social stereotypes and use mathematics as a tool for developing students' and teachers' critical consciousness.

Endnotes

(1) Students from dominant, oppressive social groups are also harmed by antiblack racism, for instance, by internalizing negative stereotypes and distorted representations of Blackness that they perpetuate into adulthood (Baines et al., 2018; Wynter-Hoyte & Smith, 2020).

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Design and Implementation of a Week-long, High School Curriculum Unit Integrating Physics and Computational Modeling

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Abstract: Engaging students in computational modeling (CM) to explain natural scientific processes can help prepare pre-college students for STEM careers and lower boundaries to teaching computer science in pre-college schools. This study addresses the need for concise CM experiences that typical teachers can feasibly integrate into science instruction and are accessible to students from historically excluded STEM groups who have no programming experience. We describe the design and enactment of a one-week CM unit and report on its classroom feasibility, students' learning outcomes, and students' CM activities. We observed significant pretest/posttest gains indicating that the unit benefited students even after completing a typical course of study on kinematics. Two student vignettes illustrate how students' CM activities provided learning opportunities in physics and computational thinking.

Introduction

This study responds to recent efforts to integrate the teaching and learning of science and computational thinking (CT) in pre-college classrooms. The emergence of computation as the third pillar (alongside theory and experiment) of science and engineering compels schools to incorporate CT into the existing pre-college science courses and address disciplinary intersections highlighted in contemporary education standards in science (e.g., Next Generation Science Standards) (NGSS Lead States, 2013) and computer science (K-12 Computer Science Framework, 2016). To prepare for STEM careers, pre-college students must engage in authentic STEM practices that increasingly rely on CT. Computation-based STEM practices are needed for students to explore natural scientific processes and apply scientific knowledge to design solutions for real-world STEM problems. Incorporating CT into science also lowers boundaries to teaching of computer science (CS) in pre-college schools, as not all schools have the necessary programs or expertise to teach CS. Including it in core subjects (such as science) has the potential to broaden global participation in CS.

Engaging students in developing computational models (CMs) offers promise for supporting coherent integration of science and CT experiences for pre-college students (Sengupta et al., 2013; Basu et al., 2016; Weintrop et al., 2016). CMs provide representations that support modeling of dynamic phenomena that can be simulated by a computer (Weintrop, 2016). Teachers face numerous challenges with implementing CMs as part of science instruction. Developing CMs requires some programming expertise, which students must acquire and teachers must support in the classroom. However, many science teachers do not have experience with programming and are unable or unwilling to set aside the instructional time needed first to teach requisite CT concepts, then engage students in applying these concepts to modeling science phenomena. Many teachers and students would benefit from the availability of short, integrated experiences that can be implemented feasibly into their science instruction. In response to this need, we describe the design and implementation of a one-week kinematics computational modeling (KCM) unit, report on its classroom feasibility and students' learning outcomes in physics and CT, and examine relationships between students' learning and the nature of students' CM activities as logged by the environment. In this design-based study, we investigate the following research questions: (1) What are students' learning outcomes in physics and CT from using the KCM unit? and (2) How is students' physics and CT learning associated with their CM activities?

Perspectives and rationale

We build on affordances of CM building for pre-college students. Developing a CM of a scientific phenomenon leverages constructionist learning perspectives (Papert, 1980) and involves key aspects of CT, such as identifying mathematical rules that govern system behavior, comparing generated representations with observations of target phenomena, and refining models to achieve increasingly sophisticated explanations of the phenomenon. Integrating CT and scientific modeling can benefit learners in numerous ways (Sengupta et al., 2013), such as emphasizing CMs as a core scientific practice (Soloway, 1993) and providing a contextualized representation to support the teaching of programming (Hambrusch et al., 2009). Prominent examples of environments that support integration of science and CMs include Boxer (e.g., diSessa, 1991), NetLogo (e.g., Wilensky & Rand, 2015), DeltaTick (Wilkerson-Jerde et al., 2015), and CTSiM (Basu et al., 2016).

While studies on these environments provide evidence for design principles and learning mechanisms for integrated science-CT learning in pre-college students, many use only descriptive case studies, engage students only in advanced science classes or at schools with selective admissions criteria, or engage researchers as teachers instead of students' classroom teachers. As such, these studies often do not demonstrate the classroom feasibility of these environments or examine learning in typical instructional conditions. Relatively few studies provide evidence of promise of integrated science and CT that (1) include a large proportion of students from historically excluded STEM groups, (2) are short enough to be practical for typical teachers, (3) engage students' own teachers in teaching the units, and (4) demonstrate pre/posttest learning gains in science and CT for hundreds of students.

In this study, we address salient challenges to the practical implementation of integrated science and CT instruction that use CMs. For students, challenges include the time required to learn programming constructs and model building practices. For teachers, challenges include the length of the instructional interventions and the need for programming expertise to support students with CM building. One way we address these challenges is by scaffolding students' CM building and problem-solving through the creation of a domain specific modeling language (DSML) (Jackson & Sztipanovitz, 2009) implemented using visual, block-structured constructs. Our DSML uses computational blocks that are directly linked to concepts in the kinematics domain, facilitating students' conceptualization and development of CMs (Hutchins et al., 2020). The use of a block-structured format provides not only relief from the burden of learning the syntax of general-purpose programming languages, but also a level of abstraction that exploits the synergies between CT constructs and CM building practices in the domain. This study examines how combining a DSML with a visual programming language can help make short CM experiences in science feasible and beneficial for both teachers and students.

Design

Domain specific modeling language and computational modeling environment

The C2STEM (Hutchins et al., 2020) CM representation (Figure 1) uses custom kinematics DSML blocks developed on top of NetsBlox (Broll et al., 2018), a block-based extension of Snap! (http://snap.berkeley.edu/). We have developed a physics DSML for our high school physics curriculum targeting the key domain concepts and practices in kinematics. In the context of integrating physics modeling and CT practices, our DSML is designed to support a temporal step-by-step approach to modeling the motion of an object. This approach, in contrast to equation-based modeling, aims to help students apply kinematics principles to decompose the motion of the object into components by updating the velocity and then updating position of an object at each time point, improving students' understanding of how the motion occurs over time. Similarly, other constructs, such as the use of domain-relevant variables (e.g., acceleration, velocity, and time), and explicit constructs (blocks) for initializing and updating the variable values helps students discern how chosen initial values and functions for updating variable values together affect the system behavior. In addition, students also learn to use traditional computational constructs (variables, expressions, conditionals, and loops) in a physics context, thus facilitating their understanding of these constructs and their use in programming.

Figure 1 illustrates the C2STEM system modeling interface and includes example code for modeling the motion of a truck moving with constant acceleration. The left panel depicts the DSML, which includes physics-specific blocks, computational control flow blocks, and custom blocks that define the initialization and the simulation steps of the students' CMs. In order to program, students drag appropriate blocks from the left panel to the center model building space. When students run the simulation, they can observe the motion of the object on the stage located on the right side of the interface.

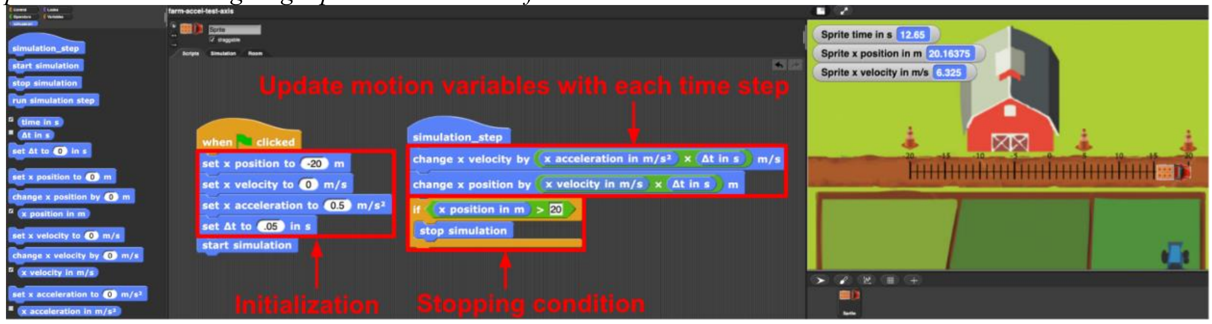
In C2STEM, a computational kinematics model consists of three parts (labeled in red in Figure 1). (1) When the green flag is clicked, the model sets the initial conditions of the motion (e.g., position, velocity, and acceleration of the object and the duration of the time step), then executes the simulation step. The simulation step then specifies (2) how the motion variables are updated with each time step iteration and (3) a stopping condition that determines when the simulation ends (e.g., when the position crosses a particular threshold).

Instructional design

The week-long unit used for this study was based on a longer unit designed to integrate physics and computational thinking practices and concepts across a semester of physics instruction on force and motion (Hutchins et al., 2020). The unit's design approach involved (1) unpacking the science and computational thinking disciplines to identify the key physics and CS constructs to be addressed in the instruction (2) developing integrated learning goals and corresponding evidence statements (describing students' proficiency with the learning goals) to establish coherent connections between physics and CT disciplines, and (3) developed curricular activities aligned with these evidence statements.

Figure 1

The C2STEM CM environment showing a horizontal motion model. Left panel: Physics-DSML blocks. Center panel: Model building. Right panel: Animation of the motion simulation.



```
when [flag] clicked
set x position to -20 m
set x velocity to 0 m/s
set x acceleration to 0.5 m/s²
set Δt to .05 in s
start simulation

simulation_step
change x velocity by (x acceleration in m/s²) × (Δt in s) m/s
change x position by (x velocity in m/s) × (Δt in s) m
if (x position in m) > 20
    stop simulation
```

Sprite time in s 12.65
Sprite x position in m 20.16375
Sprite x velocity in m/s 6.325

Because the length of the original unit precludes practical implementation for many high school physics teachers, we developed the single-week version (based on the original) used for the current study. We examine the KCM unit's feasibility and affordances for typical physics teachers who could devote a single week of instruction to integrating CT and participate in a modest amount of professional development prior to enactment. The unit sequence consisted of the following six activities:

- **Create a flipbook (Day 1).** Students create a paper flipbook animation and reflect on the experience to support their understanding of how the computational simulation represents motion.
- **Code comprehension (Day 1).** Students explore and manipulate the code of a simple CM of an object moving at constant velocity, with the goal of explaining the function of each coding block. Motion values are hard-coded rather than being expressed in terms of kinematics variables.
- **Model horizontal constant velocity (Day 2)**. Students develop a generalized CM of a truck moving at constant velocity, test the model, and use it to solve a series of simple kinematics problems.
- **Model horizontal constant acceleration (Day 3)**. Students augment the constant velocity model to model constant (non-zero) acceleration and use it to solve a series of horizontal constant acceleration problems.
- **Model vertical constant acceleration (freefall) (Day 4)**. Based on the previous model, students develop a model of a medical drone delivering a package to a target (vertical motion using acceleration due to gravity), then use the model to solve a series of freefall problems.
- **Model projectile (2-dimensional) motion (Day 5)**. Based on the previous models, students develop a model of 2-dimensional projectile motion and use it to solve a series of projectile problems.

Each modeling scenario was designed to build on code students developed previously. Each student worked in a paper and pencil packet that guided the modeling tasks using C2STEM. Each student worked at their own computer but was encouraged to collaborate with an elbow partner. Students worked through the activities at their own pace. We did not expect all students to complete all activities. We expected most students to complete the horizontal motion activities and many students to complete the freefall activity. In the Results section, we report on students' variation in their completion of the activities.

Methods

Participants and context

We conducted the study at a large public high school (approximately 3500 students) in the western United States. Most students were 16-18 years of age. More than 80% of the student population belongs to STEM underrepresented racial groups (Black, Latine) and 71% are reduced-price lunch eligible. All four of the school's physics teachers used the unit with all 16 of their mixed-ability physics classes, so each teacher taught 3-5 classes. One teacher had previous professional experience in programming and more than 5 years of science teaching experience. Another teacher (having more than 10 years of science teaching experience) advised the school's robotics club and had enacted a prior version of the KCM unit at their previous school. The other two teachers each had less than five years of teaching experience and no prior programming experience.

Teachers described the science and math achievement level of the students in these classes as wide ranging, remarking that some students struggled with mathematics required for physics problem solving, while other students chose not to enroll in the advanced physics class only because of scheduling conflicts. Teachers had high interest in using the unit because they wanted students to experience an innovative method for learning physics and to raise awareness of the role of computing in STEM careers. Prior to engaging in the unit, the teachers and students had already completed a standards-aligned course of study in kinematics addressing problem solving about motion with constant velocity and constant acceleration in one dimension (but not two dimensions). As such, this study examines the value added of the unit relative to typical kinematics instruction.

Teacher supports for implementation

We used four approaches to support teachers' classroom enactment of the KCM unit. (1) We developed daily lesson plans that guided teachers with a timeline for the activity, suggested discussion and reflection prompts, and ways to address anticipated student challenges. (2) We developed an annotated version of the student packet, including answers and descriptions of specific anticipated challenges or incorrect answers, to help teachers rapidly gauge their students' progress on the activities and inform subsequent classroom discussions. (3) Prior to implementation, we conducted a two-hour training session where we introduced the student materials and demonstrated the C2STEM environment, then supported teachers as they developed the kinematics CMs for each of the modeling activities. The teacher who had prior programming experience was not able to attend the training session, but worked independently on the CM tasks before classroom enactment. (4) During classroom enactment, a member of the research team modeled the teaching of each activity for the first one or two classes of the day, while the teacher observed and assumed a supportive role. For the remaining classes in each day, the teacher and researcher switched roles, with the teacher leading the activity with support from the researcher. Between classes, teachers and researchers had opportunities to debrief the activities, and in some cases teachers made adjustments to increase their comfort with pedagogy, leverage students' prior knowledge, or attend to classroom norms. Classroom enactment lasted five days for about one hour per day. Two of the teachers used the unit during the first week and the other two used it the following week.

Data sources

Pre/post assessment. We developed a pre/posttest with a physics subtest (max score = 16) and a CT subtest (max score = 13). Both subtests were based on the test used in a prior study (Hutchins et al., 2020). The physics subtest consisted of 5 task scenarios and 12 total items and addressed kinematics concepts involving constant velocity and constant acceleration in one and two dimensions. To measure learning resulting from CMs (which involves a discrete, rather than continuous, representation of motion corresponding to the time step), the tasks were designed to be able to be solved by using discrete motion representations (they did not require the use of kinematics equations typically taught in high school physics). The CT subtest consisted of 3 task scenarios and 9 total items and addressed the key programming concepts of variables, expressions, conditionals, and loops that needed to be used for students' CM development. Seven of the items were based in everyday contexts not related to motion. The remaining two items asked students to comprehend a simple block-based computational motion model. All CT tasks used either pseudocode or block-based programs using everyday language (and not Snap! Code) so that pre/post gains would not merely measure students' improved facility with Snap!. We administered the pretest and posttest to students the week prior and the week following the unit enactment, respectively. Pretest and posttests were identical except for changes in item order and superficial differences such as numeric values or names.

Student background questionnaire. Immediately following the pretest, students responded to a short questionnaire about their programming experience and mathematics coursework.

C2STEM process data. The C2STEM environment logged students' actions during the CM activities. We retrieved logs from 271 participating students. Our analysis focused on (1) the total number of actions students performed; (2) the number of play actions, which indicates the number of times students ran their models; and (3) the number of non-play actions performed, which includes model building actions such as assigning values to variables, adding coding blocks, and moving coding blocks.

Student artifacts. We collected the paper and pencil packets that students completed individually.

Classroom observations. We developed a classroom observation protocol documenting shifts in classroom activities, the quality of student participation and engagement, and episodes of teacher questioning. At least one researcher who was not leading or supporting classroom instruction documented observations in each class for each teacher. We documented whether each class was led by a researcher or the classroom teacher.

Teacher interviews. After teachers finished enacting the KCM unit, we conducted semi-structured interviews with three of the four participating teachers. The interview focused on teachers' perceptions of student engagement, successes and challenges, and what the teachers learned from the experience.

Scoring and analyses

Three researchers collectively scored 280 students' pretests and posttests. The researchers were trained using responses from 20 students' pre-and posttests. Then, more than 20% of responses were scored by two researchers each and interrater agreement computed. Once 80% agreement was achieved on 20% of the responses, the remaining responses were each scored by one of the three researchers. Scoring discrepancies were resolved by discussion. To examine learning gains, we conducted paired t-tests on the physics and CT tests separately. We conducted multiple regression analyses predicting posttest scores and pre/post gains to identify predictive factors for learning. We analyzed students' actions for each CM activity they completed, computing total actions, play actions, non-play actions, and the ratio of non-play to play actions for each student for each activity. Finally, we illustrate our conjectures about students' learning processes and their posttest performance using descriptive vignettes based on two students' pre/posttest responses and logs of their CM activities.

Results

Unit feasibility and student engagement

The unit was enacted as intended, without any technology issues. Students exhibited variation in their completion of the activities. Based on the C2STEM logs, 264 students engaged in the horizontal constant acceleration modeling activity, 149 students engaged in the freefall modeling activity, and just 33 students engaged in the projectiles modeling activity. The variation in activity completion was consistent with expectations, based on teachers' descriptions of student variation in ability level. During the unit, we generally observed students to be highly engaged with the activities, and their engagement increased as they progressed and gained familiarity with the nature of CMs and features of C2STEM. Teachers noted that students' engagement was high, relative to their typical instructional activities. One teacher described a student who "never did anything" during typical classes but was highly engaged throughout the unit enactment. Another student told us that they were highly motivated to complete the tasks because they believed the experience would support their future university studies in STEM.

Pretest-posttest performance

Overall, students exhibited small but significant pretest to posttest gains on both the physics [M(pre)=7.0, SD=2.2; M(post)=7.3, SD=2.3; t=2.7, df=279, $p<0.01$; d=0.13] and the CT tests [M(pre)=4.8, SD=2.1; M(post)=5.5, SD=2.4; t=5.7, df=279, $p<0.001$; d=0.31]. Further, performing a median split and comparing gains of low pretest students with high pretest students shows that the gains were considerably higher for low-pretest students (effect sizes of 0.6 and 0.8 for physics and CT respectively). These gains indicate that the unit had added value for students, especially for those with low prior knowledge in physics and CT, even after completing a typical course of study on kinematics based on algebraic problem-solving methods and hands-on lab activities. This finding is consistent with the idea that low prior knowledge students had more room for improvement, especially on CT concepts, which would have been more familiar to students with prior programming experience.

We conducted t-tests comparing outcomes of students in researcher-led classes to teacher-led classes. These analyses did not reveal significant differences in pre/post gains between these groups, indicating that the participating teachers were able to feasibly enact the unit after participating in the training session and observing researchers teaching earlier in the day. We also conducted a multiple regression analysis to relate students' posttest scores to the extent of their unit completion (based on students' completion of the paper packets). We found significant, positive relationships between students' unit completion and their physics ($p<.01$) and CT ($p<.05$) posttest scores, controlling for students' pretest scores. This finding indicates that students' posttest performance and unit completion were not mediated only by students' prior knowledge level, providing evidence that students' engagement in the CM tasks had impacts on their learning in both physics and CT.

To further illustrate learning approaches that might have resulted in these gains, we describe two illustrative student vignettes: "Chris", who scored above median on both the physics and CT pre-tests but made modest pre/post gains on each subtest, and "Sam", who scored below median on both the physics and CT pre-tests and made relatively large gains on each subtest.

Illustrative vignette 1: Chris (high pretest scores, high posttest scores)

Over the course of the KCM unit, Chris developed CMs for all four modeling activities in the unit. On the background questionnaire, Chris reported "a little" prior experience with programming and a relatively strong background in mathematics, having enrolled in pre-calculus and statistics. Chris made a modest improvement on the physics subtest, from 9.5 to 11. Most of the gain was a result of improved performance on the item asking students to compare the motion of two projectiles moving in two dimensions. This improvement is consistent with

Chris being one of just 33 students who engaged in the projectile modeling activity. The students in this study did not learn about 2-dimensional motion in their previous instruction because the topic is not included in the state standards, so Chris' improvement is likely a result of their engagement with the modeling task.

Chris also improved from 8 to 11 on the CT subtest. All of their CT pre/post improvement was from improvement on items assessing the CT concept of conditionals (students had to write expressions representing conditions for ending and for winning a computer game). Chris earned zero points on these pretest items and three points on these posttest items. The improvement on these items is consistent with Chris' CM activity (as illustrated in more detail below).

Our analysis of Chris' modeling activities based on the log files reveal that their non-play to play ratio for the final modeling activity was 5.89, much higher than their non-play to play ratios for the constant acceleration activity (3.96) and the freefall activity (2.85). This trend illustrates how Chris made a smaller number of changes to the code between tests for most of the activities, but made more changes to the code between tests in the final activity, reflecting increased comfort with C2STEM and CMs.

Figure 2 shows Chris' CMs for the constant velocity and constant acceleration activities. Both models correctly simulate the motion specified for the respective tasks, including appropriate initial values, kinematics relations, and stopping conditions. The constant acceleration model (Figure 2b) includes unused programming blocks (outlined in red) that illustrate how Chris attended specifically to the stopping condition reflecting the change in direction relative to the previous motion scenario. Specifically, the value of "5" in the unused block illustrates how Chris previously tested the model using the incorrect conditional expression, then replaced the incorrect condition (position > 5) with the correct one (position < 5). This episode of debugging the model is consistent with Chris' pretest to posttest improvement on the CT items related to conditionals.

Figure 2

Chris' (a) constant velocity model and (b) constant acceleration model. Note: A non-numerical value of Δt (which appears in the model on the right) is assigned by the environment to a default numerical value.

```
when 🏴 clicked
set x position to (-13) m
set x velocity to (8.6) m/s
set Δt to (0.4) in s
start simulation

simulation_step
change x position by ((x velocity in m/s) × (Δt in s)) m
if <(x position in m) > [25]>
  stop simulation
```

(a)

```
when 🏴 clicked
set x position to (20) m
set Δt to (.0.1) in s
set x acceleration to (-0.6) m/s²
set x velocity to (0) m/s
start simulation

simulation_step
change x velocity by ((x acceleration in m/s²) × (Δt in s)) m/s
change x position by ((x velocity in m/s) × (Δt in s)) m
if <(x position in m) < [5]>
  stop simulation

<[ ] > [5]>
if < >
```

(b)

Illustrative vignette 2: Sam (low pretest scores, high posttest scores)

Over the course of the KCM unit, Sam developed CMs for only two of the four modeling activities, both addressing horizontal one-dimensional motion. On the background questionnaire, Sam reported no prior experience with programming and a modest background in mathematics, having enrolled in coursework up to only advanced algebra. Sam made a large pre/post improvement on the physics subtest, from 5.5 to 9.5. Two of Sam's four point pre/post gain was a result of their improvement on an item asking students to solve a kinematics problem involving velocity, acceleration, and time; Sam was unable to solve it on the pretest, then solved it correctly on the posttest. The assessment task reflected the same type of motion (one-dimensional, constant acceleration) that Sam engaged with for most of their time studying the KCM unit. Sam also made a large improvement on the CT subtest, from 4 to 7.5. The entire 3.5 point gain was a result of improvement on assessment items addressing the concept of iteration. (Students were asked to predict the output of block-based programs containing a "repeat" block.) Sam's large improvements on both the physics and CT subtests is promising, illustrating that engaging with the KCM unit appears to promote learning in both disciplines for students with low prior knowledge, even if they were not able to complete all the curricular activities.

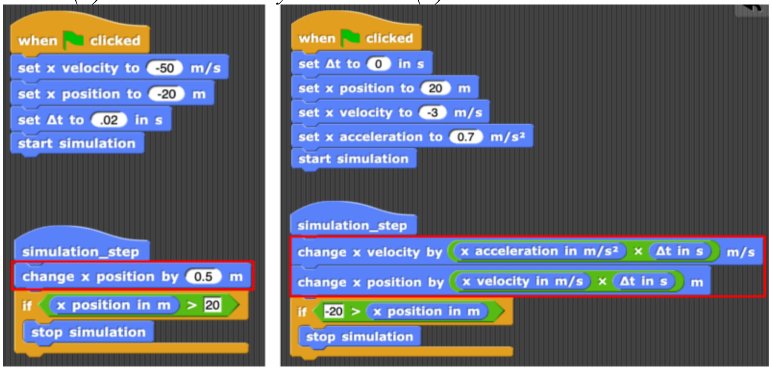
Our analysis of Sam's modeling activities reveal that they worked deliberately on the one-dimensional accelerated modeling scenarios. Sam conducted a high number of total actions on the constant acceleration task

(313 actions, 82nd percentile). Sam also performed just 2.26 non-play actions per play action (10th percentile), indicating an approach involving frequent testing. The mean ratio of non-play actions to play actions on this modeling task was 5.04, so Sam tested their model with more than double the frequency of the typical student.

Figure 3 shows Sam's CMs for the constant velocity and constant acceleration tasks. In Figure 3(a), Sam has "hard coded" a specific value of position change in the simulation step (outlined in red), rather than specifying a kinematic expression involving the velocity variable. As a result, Sam would have observed through testing that changing the velocity value would have no impact on the truck's simulated velocity, and this model could not be used to solve a different problem involving a different initial velocity. We observed this error to be relatively common among students in the initial stages of modeling. In Figure 3(b), Sam subsequently improved the coding of the simulation step by expressing the velocity and position changes in terms of the acceleration and velocity values, respectively, so these variables are updated with each iteration of the simulation step (outlined in red). This improvement of the model is consistent with the nature of Sam's pre/post improvements on both the CT test (iteration) and the physics test (accelerated motion in one dimension). Although Sam was not able to achieve a completely correct model for this particular modeling scenario, we conjecture that these modeling experiences—involving model development, testing, and debugging—contributed to the corresponding improvements on the physics and CT pre/post assessments.

Figure 3

Sam's (a) constant velocity model and (b) constant acceleration model.



```
when clicked
set x velocity to -50 m/s
set x position to -20 m
set Δt to .02 in s
start simulation

simulation_step
change x position by 0.5 m
if x position in m > 20
  stop simulation
```

```
when clicked
set Δt to 0 in s
set x position to 20 m
set x velocity to -3 m/s
set x acceleration to 0.7 m/s²
start simulation

simulation_step
change x velocity by x acceleration in m/s² × Δt in s m/s
change x position by x velocity in m/s × Δt in s m
if -20 > x position in m
  stop simulation
```

(a) (b)

Note. A zero value of Δt (which appears in the model on the right) is assigned by the environment to a default non-zero value.

Discussion and implications

Our study provides evidence of the promise of effectiveness and classroom feasibility of the KCM unit. Four teachers (only one of whom had a programming background) implemented the unit effectively in a single week after receiving a modest amount of training. Our study population included many students from historically excluded STEM groups and with no prior experience in programming, but students were still able to demonstrate significant pre/post gains in both physics and CT, with low prior knowledge students demonstrating the highest gains. The study addresses gaps in the research literature related to the effectiveness of integrated science and CM instruction in typical instructional contexts and with typical teachers.

We offer several conjectures for the successful outcomes we observed. First, implementing the unit following students' typical kinematics instruction likely facilitated their learning of the programming concepts because students did not have to contend with new science and programming concepts simultaneously. Second, we designed the unit to minimize the amount of time students would need to spend learning and implementing programming constructs by employing the DSML and by designing a sequence of modeling activities that each builds on code from the previous activity. Our study adds to the existing body of research that illustrate the benefits of domain-specific modeling constructs for science learning (e.g., Hutchins et al., 2020; Basu et al., 2016; Wilkerson et al., 2015) and testing and debugging computational models (Shin et al., 2021). Third, the KCM unit included two distinctive features that might have uniquely supported students with understanding the nature of the CMs. The flipbook activity provided a tangible representation of the motion simulation and the Δt variable, which was observed as a challenge in previous studies with C2STEM (e.g., Hutchins et al., 2020). In addition, the code comprehension activity, which was anchored to a kinematics context, replaced a previous programming activity intended to introduce programming constructs in a familiar geometrical context for students lacking prior knowledge of kinematics. Because our students had already received some instruction in kinematics, our activity might have more efficiently helped students develop an understanding of the domain specific blocks and further clarified the nature of the Δt variable.

Finally, we discuss implications for classroom enactment. Our participating teachers uniformly found observing researchers enacting instructional approaches to be helpful, consistent with established teacher professional learning models in computer science (e.g., Goode et al., 2014). Teachers were even able (and eager) to make in-the-moment pedagogical adjustments to researchers' teaching practices based on their shared prior experiences with students. In interviews, teachers pointed to numerous benefits of CMs relative to their typical instruction. These benefits included the ability to engage students who were unengaged by typical instructional approaches, the authenticity of students creating their own artifacts, and the autonomy students had in working through the modeling tasks. Teachers also noted that there would have been a greater return on their investment in teaching CMs if they were to teach a subsequent CM unit on another topic, because students would have already gained familiarity with C2STEM and the nature of CMs. Despite initially being willing to use C2STEM for only a single week, the teachers were open to the idea of implementing another unit later in the year once they had implemented the KCM unit. These insights illustrate the potential for short CM units to constitute a low risk, high reward opportunity for science teachers to try out computational approaches.

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Expanding What Counts as Scientific Investigations in the Era of the Next Generation Science Standards

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Abstract: Science education reforms advance an epistemology of investigation as hypothesis-driven tests of theory. We argue that this is a narrowly drawn image of investigation that leads to lost opportunities for learning and teaching science. These include opportunities to develop an investigator's skills and conceptual understandings and situate investigatory practices within a broader scientific epistemology. This study portrays examples of the day-to-day investigations involved in a non-laboratory, scientific workplace: a neighborhood coffee roastery. Through microethnographic analyses we show that professional coffee roasters accomplish the same goals that science education reforms seek to achieve, and that these goals take different forms. We argue that coffee roasters' uses of investigatory practices toward non-laboratory, everyday ends expand our views of what counts as scientific investigations in the current era of reform.

Introduction

Science education reforms advance an epistemology of investigation as hypothesis-driven tests of theory (National Research Council, 2012). We will argue that this is a narrowly drawn image of investigation that leads to lost opportunities for learning and teaching science. First, an emphasis of investigation (in the NRC's terms, encompassing what is conventionally called experimentation) as theory testing minimizes the role of human agency in scientific knowledge production (Gooding, 1990), implying a view that theories, not humans, motivate scientific action (Radder, 2009). Second, investigations allow for the co-development of embodied investigatory skill and conceptual development (Maslen & Hayes, 2022) which are erased by theory-testing perspectives. Lastly, researchers have paid less attention to the interdependence of investigation and related scientific practices (e.g., modeling) in the practice turn era (Ford & Forman, 2006; Manz et al., 2020). Rather than a central driver within a broader scientific epistemology, reform documents treat investigation as a process to *confirm* existing theories and demonstrate content understanding (Hodson, 2014). There is thus a need to better understand *in situ* practices of investigation and their relevance to the current era of science education reform.

Our choice of "in situ" practices requires elaboration. First, ethnographers of science have long argued that leading images of scientific activity are partial and distorted. These images "have been culled from interviews with eminent ex-scientists or from other public pronouncements about the nature of science" (Woolgar, 1988, p. 86) and advance reconstructions of science as methodical, systematic and the logical outcome of linear scientific procedures. Ethnographic field studies of science involving the *in situ* observation of scientific activity reveal less linear and logical and far more social ways of scientific knowledge production (e.g., Latour & Woolgar, 1987). Such ethnographies make visible the embodied, material, and social ways of working ("practices") which are often written out of publications (Gooding, 1990). Second, we argue that scientific practices are not limited to the actions of professional scientists (Conner, 2005; Secord, 1998; Shapin, 2012) and that a broader view of investigation from other settings can recover the rich diversity of science in our lives. To expand our imagery, we advance findings from a multisite, ongoing project that examines the people, practices, and cultures of *non-laboratory, scientific workplaces*. We argue that this approach, and similar examinations of scientific activity outside of the laboratory, can reshape our views of how and why science is conducted, and ultimately can and should impact the ways that science is taught and learned in schools. Our objective in this paper is to portray examples of the day-to-day investigations involved in a non-laboratory, scientific workplace. Our program of work begins here with the practices of investigation enacted by professional coffee roasters.

This paper's theoretical frame for investigation comes from the National Research Council's *A Framework for K-12 Science Education* (2012). The consensus report reads, "Scientists and engineers investigate and observe the world with essentially two goals: (1) to systematically describe the world and (2) to develop and test theories and explanations of how the world works" (p. 59). Ethnographies of science, on the other hand, show that scientists investigate for goals beyond these two (cf. Knorr-Cetina, 1981; Lynch, 1985; Woolgar, 1988) and some philosophers of science view theory-testing as actually hindering scientific advancements (e.g., Feyerabend, 1975). Additional goals of investigation include scientists' attempts to simply "make things work" (Knorr-Cetina, 1984) and develop their own experimental skill (Gooding, 1992). However, and because we wish to locate our work inside ongoing reform conversations, we adopt the NRC's language.

In the following sections we will view coffee roasters' practices through a lens of Planning and Carrying Out Investigations, the third of eight Science and Engineering Practices offered by the *Framework* (NGSS Lead States, 2013). All K-12 learners, according to the *Framework*, should be able to do these seven things as part of investigations by graduation: (1) formulate questions (2) and theory-based hypotheses, decide on (3) tools, the (4) type of data, and (5) amount of data, and plan a procedure that (6) identifies variables and (7) controls (NRC, 2012, p. 60).

There are strong competing images of *what* science *is*, and we do not seek to add fuel to those ongoing debates. As such, in this paper, we do not argue that coffee roasting *is* science. Rather, we argue that *all* of the NRC's goals of investigation are involved in coffee roasting. The former is an intractable philosophical debate that distracts from the broader aims of our project: to expand our scientific imagery toward re-imaginations of science education. The latter is not a question of philosophy primarily, but one of empirical evidence.

In this paper we empirically demonstrate one roaster’s application of the goals as he develops a new coffee product. Through our analyses we will show that the science *in* coffee roasting has implications which extend beyond new perspectives of investigatory practices. For example, the scientific practices in roasting demonstrate the real-world value of scientific knowledge and know-how—answering questions teachers routinely get and often dread, such as, “When will I ever need to know this?” More broadly, presenting cases of scientific knowledge and practices of *non-laboratory work* connects with the *Framework’s* "goals [that] are for all students, not just those who pursue careers in science, engineering, or technology or those who continue on to higher education" (p. 9). The practices involved in coffee roasting thus speak to a vision of science education for *all* learners, and especially those roughly 90% of American K-12 students (NSF, 2022) who do not pursue normatively recognized science careers.

Methods: Research context

The principal roastery in this paper is in a small Midwestern college town. Sam and Mimi operate an 800-square-foot roastery as a “community-oriented coffee company.” This sentiment is reflected in the roastery’s neighborhood location and literal opened doors, through which customers often visit to fill their reusable coffee bean containers, or to join weekend “sensory evaluation” education experiences. Sam contrasts this community feeling with prior employment as a “production roaster” at large-scale, “soulless,” industrial coffee roastery. Sam roasts 180 pounds of coffee three days a week (MWF) and Mimi handles the business’ logistics to serve its coffee houses, numerous wholesale accounts, and online orders. On the weekends they attend farmers’ markets to interact with the public and teach various beginning-to-advanced coffee tasting and roasting courses. On Tuesdays and Thursdays, Sam and Mimi travel to establish new accounts and experiment with new coffee products and services, such as the day's sample roasting of a new coffee from Peru.

Methods: Data collection and analysis

We began participant observation (Becker & Geer, 1957) with Sam and Mimi in May, 2022. We have since participated alongside and observed Sam and Mimi during roasting sessions, sensory evaluations, barista trainings, and coffee classes. This paper draws from a broader data corpus that consists of audiovisual data (Erickson, 2006), semi-structured and photo-/video-elicitation interviews (Harper, 2002), as well as field notes, jottings, memos, and annotated photographs (Emerson et al., 2011). In combination with participant observations at additional roasteries, these sources represent roughly 200 hours and 250 pages of data. In this paper we present microethnographic analyses (Streeck & Mehus, 2005; Stevens & Hall, 1998; Hall & Stevens, 2015) of Sam’s investigatory practices recorded on video over the course of an afternoon. What was captured during this afternoon is representative of what we see in the broader data corpus. These analyses include Sam’s non-verbal actions, verbal explanations of his actions, and our interpretations of how these actions allow for the completion of his work. Lastly, Sam reviewed our findings and incorporated his insights when possible.

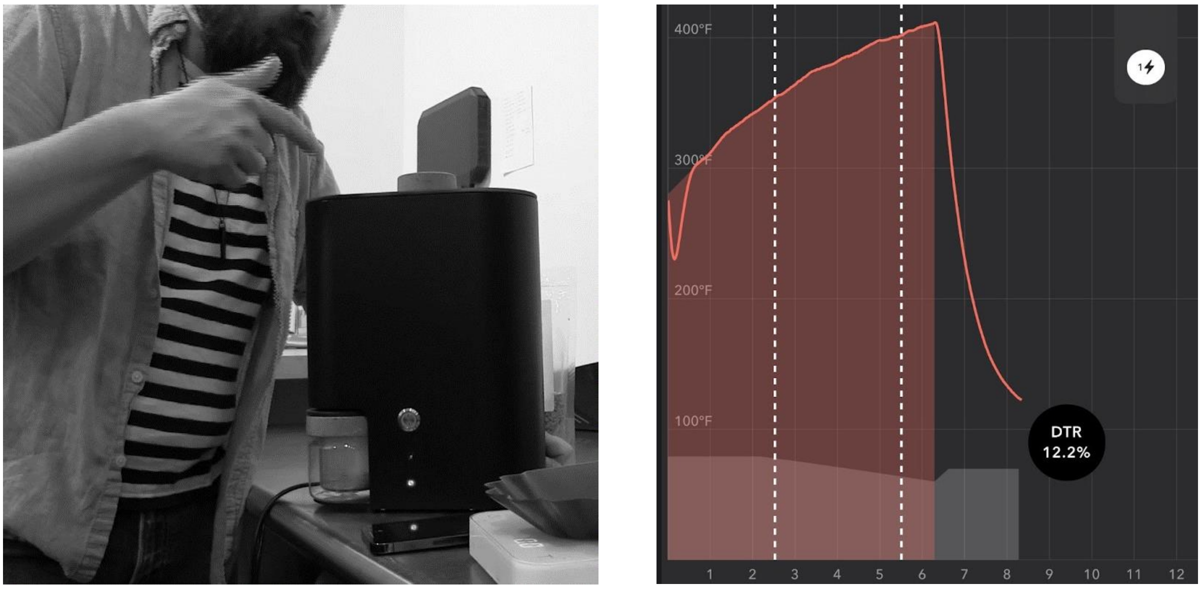
Findings: Sample roasting

The investigation we explore is a sample roasting session, and a brief introduction is needed. Sam’s raw, green coffee ranges from $4 to $7 per pound and he buys beans in thousand-pound shipments. The unknown quality and characteristics of the raw coffee makes each purchase something of a gamble. To minimize risks, Sam sources 300-gram samples from coffee importers, develops various "roasting profiles," performs sensory evaluations by smelling and tasting the coffee, and ultimately decides to purchase it in bulk or not. Sam invited us to observe sample roasting so that we could understand the entire scope of his workflow: from sample roasting and purchasing, to fine-tuning “retail roasts,” educating the company’s baristas, and selling the coffee. The data below are drawn from a sample roasting session which Sam described as “literally the very first step” in his process. The machine that Sam uses in his daily operations is a 26-pound capacity IR-12 Diedrich and is thus too large for sample roasting. Instead, Sam uses a 50-gram PRO50 Ikawa sample roaster (Figure 1, left). Sam's down-scaling of tools resembles microscale investigations in laboratories:

> Which is why it's nice using the Ikawa. You can try multiple things and you're using only 50 grams per batch. Where if I wanted to have that experimentation on the Diedrich I'd have to use 60 pounds for three different sample roasts. And that's expensive for me, and importers, and farmers.

Figure 1

Sam's Ikawa Roasting Machine (left) and "Roasting Profile" (right).



The sample roasting session (hereafter "investigation") is motivated by Sam's concern that his existing "lineup is really small compared to most roasters." The roastery's four coffees don't meet consumers' wide-ranging expectations. To fix this, Sam wants to create a rotating blend. "My goal is...a roaster's blend...like a rotating blend that we just come up with here. We probably won't even put the origin on the bag...So people always know it's a rotating blend." Expectations has two meanings here. The first is what a roastery is expected to offer in terms of coffee varieties; the second is an alignment between consumers' and roasters' sensory expectations. The latter informs many of Sam's practices:

> This is a coffee, that, if I do like it, I'll probably buy it to create a new blend for [current company]. It'll be a mixture of this Peru and a, hopefully, Burundi. I'm starting with a Peru and a Burundi, something that I did with [previous company] back in the day. I was just spitballing, and I was bored, and I blended these two coffees together and it was just ((gestures with hands)) delightful. It was so good. You know. You get the nuttiness and caramels of a Peru, and you get those higher acids, little bit of a tea and herbal thing from the Burundi. It was so nice. I called it Perundi ((laughter)). Yeah, it worked out pretty well.

With a *question* to guide his work (SEP3 goal 1), "What's the best way to roast this Peru?", Sam plans a *procedure* (SEP3 goals 6 and 7). A procedure in coffee roasting takes the form of a "roasting profile" (Figure 1, right). Profiles are sets of time and temperature values that roasters design for each individual coffee. As another roaster in our study has said, "Each coffee demands something different. It's like they have their own personality." For Sam, roasting profiles are graphical representations of these time and temperature values (Figure 1) and he annotates these graphs with crucial decisions made while roasting. Sam's annotations allow for an iterative process with the ideal procedure becoming the final "standard profile" (see Gloess et al., 2014 for laboratory investigations of roasting profiles). Sam begins by selecting a procedure from Ikawa's online repository. To refine his search, Sam looks for a profile for Peruvian coffees, "I know we've had a Peru before.

I'll do a couple roasts of this. The first one I'll do [is] a standard, ‘oh if you don't know anything about this coffee, this is a good starting point.’” Sam is unable to find a profile for Peruvian coffees in Ikawa’s database. Instead, he selects one from a trusted source, coffee consultant Rob Hoos, who has uploaded his procedures to Ikawa. “The point of this roast, according to Rob, is...to emulate...a real time roast that would have all your sets of drying, browning, and development.”

Sam has chosen his *tools* for this initial investigation (SEP3 goal 3). Moreover, we view his decisions to use the smaller-scale Ikawa and a roasting profile from coffee consultant Rob Hoos as framing a *theory-based hypothesis* (SEP3 goal 2) in ways that move beyond the NRC’s goals. Sam does not simply think about what kind and how much data to collect. Rather, his first strategy, selecting a profile and roasting a coffee based on its origin, requires discipline-specific knowledge of coffees that originate from the same country. This is what historians and philosophers of science term *theoretical presuppositions*: “Such commitments cannot *all* be optional, nor can they be treated as if they were distorting ‘biases.’ Rather they are the sine qua non of beginning an experiment—as well as ending it” (emphasis in original, Galison, 1987, p. 4). Sam’s second strategy, selecting a profile based on someone else's expertise, indicates trust in the broader organization of shared disciplinary knowledge—a phenomenon some ethnographers of science call “epistemic cultures” (Knorr-Cetina, 1999). Both decisions display a continuum of knowledge and trust of competence that pervade the discipline of coffee roasting. Sam’s reliance on prior knowledge and a community of practitioners as entry points into his investigation underscore reasons for investigation beyond theory testing (Radder, 2009). For instance, Sam’s work highlights the role of human agency in experimentation (Gooding, 1992) as a way to “make things work” (Knorr-Cetina, 1984). To summarize Sam’s investigation so far: he is driven to re-create the Peru’s “nuttiness and caramels”; has chosen appropriate materials (the Ikawa rather than the Diedrich; SEP3 goal 3); and decided on a procedure (Rob Hoos’ roasting profile). Sam’s choice of profile reveals the relevant types of data (SEP3 goal 4) he requires in this investigation, such as quantitative time and temperature data, as well as qualitative data of the Peru’s “drying, browning, and development” (Folmer et al., 2017).

Sam not only *identifies relevant data* (SEP3 goal 4) but integrates these into a broader investigatory repertoire involving his senses. Roughly six minutes into the nine-minute roast, he leans into the Ikawa, places his left ear above the machine's roasting chamber, and says, “I'm gonna try to listen for first crack.” As the liquid water inside the Peruvian beans begins to boil, transition into gas and expand, the beans become visibly larger and crack open like popcorn. The relationship between temperature and “first crack”, as detected by Sam's sense of sound, is important to future roasts with the Peru: “You want to be able to taste all the nuance of the coffee. That will give you an idea of, [should I] take this a little darker and give it more body?” First crack is thus a reference point that Sam must establish in his aim to highlight the Peru’s characteristics. Sam does not want to roast beyond first crack as that would impart smells and tastes from the roasting process, thereby masking the qualities inherent only in the beans. Once he knows the Peru’s first crack temperature, he can adjust parameters to optimize different characteristics in the coffee. Discerning first crack is not easy: “I heard one little pop. That's what I call a ghost pop. I'm gonna wait until we hear a really consistent ((interrupts statement to listen in silence)).” Seconds later, Sam annotates the graph with what he believes to be first crack (white lines in Figure 2), thereby producing a piece of knowledge in the multi-step process of developing a new rotating blend. The ambiguity of first crack is not a result of Sam’s senses, but rather chemical reactions’ stochasticity. All roasters in our study note that few roasts behave identically, even those with seemingly identical beans. In this episode Sam identifies sound as *data type relevant* to his investigation (SEP3 goal 4) and his pausing for more sounds identifies a *relevant amount of data* required in his investigation (SEP3 goal 5).

Sam’s sensory discernment (Goodwin, 1994) of first crack resembles many scientific practices in the face of nature’s recalcitrance (Gooding, 1992). For example, these practices are found in Goodwin’s case study of geochemists (Goodwin, 1997) who use their senses to determine when a chemical reaction should be terminated. For Sam, the variability in roasts causes ambiguity in first crack and leads to abundant evidence that he is exercising his human agency: hesitation, uncertainty, finer discernment, and subsequent identification. Sam’s practices so far seem to challenge images of scientific activity that advance accounts of objective, meticulous adherence to rigidly followed procedures. However, this “is another artifact of the disembodied, reconstructed character of retrospective accounts [of scientific activity]” (Gooding, 1992, p. 68).

Sam revises his procedure in light of new data. To do this, he inspects the roast’s time and temperature data and analyzes what roasters call the rate of rise: the average rate of change in temperature computed over 30 second intervals. Sam notices that the rate of rise headed toward a negative value. On a previous day he said, “When we're getting close to the end ((points at computer monitor)) you don't want this number, your rate of rise, to drop below 0.” A negative rate of rise, according to Sam, means that “essentially nothing is happening. There's no activity going on...there's less reactions happening because of the low energy.” In this sample roast, Sam interprets the negative rate of rise to mean that the profile was probably not meant for a Peru: “That's one thing I noticed about Rob's profile is that the rate of rise dipped into the negatives there ((points at graph; Figure 2, left)). So I think that could have potentially stalled this coffee and maybe on a different coffee that rate of rise wouldn't have dipped...Maybe an Ethiopian?" Sam interprets data (time, temperature, sound, rate of rise; SEP3 goal 4) and creates new knowledge: the Peru requires a changed profile for a positive rate of rise.

Revising investigations in light of new evidence is notably missing from the NRC's seven goals. We suggested that too narrowly drawn images of investigation lead to lost opportunities for teaching and learning science. This is one such opportunity. Revising investigations based on new evidence is a hallmark of scientific practice (e.g., Gooding, 1990) and is argued to be a causal mechanism underpinning revolutions in scientific theories (Kuhn, 1970). However, Sam demonstrates that revising investigations has utility and meanings in addition to theory testing. For instance, Sam's revisions are made possible by his investigatory skill—in particular, his sense of hearing and identification of first crack. Second, Sam ties his revisions to conceptual understandings, exhibited by his analyses of the roast's rate of rise ("There's no activity going on...there's less reactions happening because of the low energy"). Related, Sam's revisions are dependent on his analyses, showcasing an interdependence of practices that is underdeveloped in the NGSS era (Manz et al., 2020).

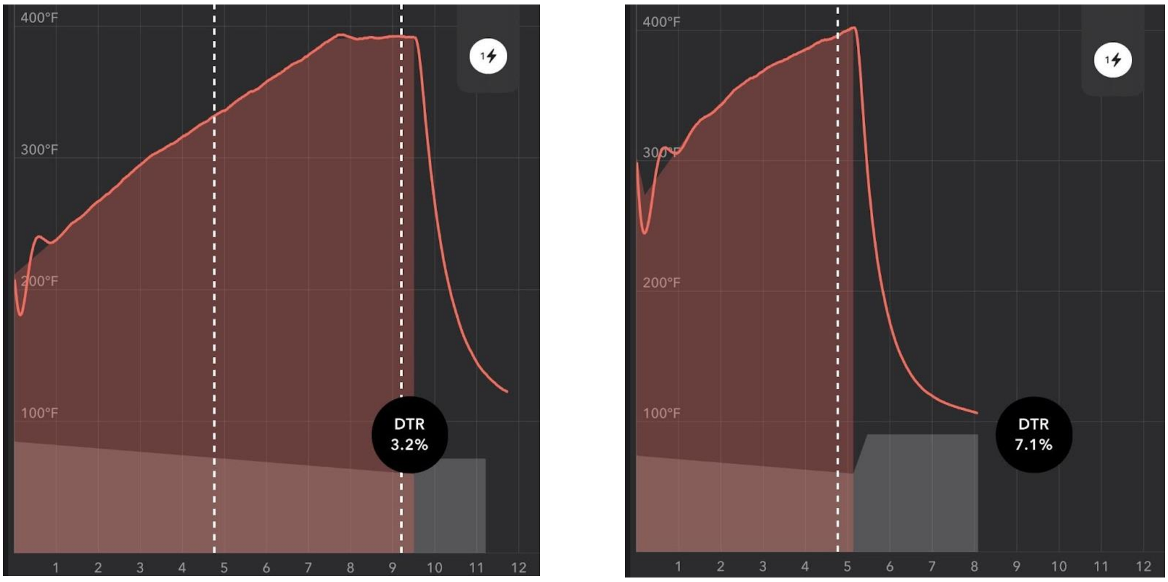
Sam's "Maybe an Ethiopian?" displays the tacit knowledge he has developed from years of roasting. This knowledge "is as much an art of doing as it is an art of knowing" and has long "remained unspecifiable at the very heart of science" (Polanyi, 1962, p. 56). While not a goal of SEP3, Sam's sensory discernment between "ghost pops" and "consistent" first cracks, analysis of rate of rise, and ability to integrate these toward revisions to his procedures underscore the role of knowledge and skill in investigations. One wonders how the disembodied goals of SEP3 (asking questions, identifying data and variables, and so on) are differentially achieved by an investigator's ability *and* desire to answer those questions and identify those data. More broadly, Sam's investigatory practices cause us to re-ask the question of how human skill impacts the quality and quantity of data that can be collected, and how human skill impacts subsequent revisions to investigations. Further, these data and revisions are made possible by Sam's skills *and* interest and promote conceptual development that are core outcomes of school science investigations (Hodson, 2014).

We observed interdependence between Sam's investigatory skills and his conceptual understandings. During his post-roast analyses Sam pauses and says, "...honestly, before I started doing this I should have…tested the density of this coffee and the moisture content…I'll do that on another day. I'll test everything first and really hone in on what I think will be a good profile for it [the Peru]." These data (SEP3 goal 3), according to Sam's theory of roasting, impact a roast's "charge temperature" (SEP3 goal 6: identification of variables). Sam says that "the more dense something is, the higher temperature it can withstand." Thus, if this Peru is more dense than the coffee Rob Hoos developed his profile for, then Sam has to adjust the initial temperature of the roast: "If this was a tiny little peaberry [a type of coffee bean], that's super tightly densely packed, it's gonna need more heat, more energy, to penetrate the bean. So, yeah. It will tell me the starting point of the coffee." Laboratory studies confirm Sam's comments about density and moisture content affecting a roast's heat distribution, and likewise recommend changes to charge temperatures to maintain consistency (Ogunjirin et al., 2020). Sam did not measure the density or moisture content of this Peruvian coffee, despite articulating that he should have and will in the future. This once again highlights the methodological necessity to observe scientific activity as it unfolds and restore what is often written out of narrative reconstructions (Gooding, 1990) and other influential images of science.

Sam produced new knowledge about how to roast Peruvian coffees, learned from his post-roast analysis, and revised his procedure in response. "My goal is to add more temp on there" to "get a nice rolling crack for this coffee." Sam's revisions allow him to compare roast #1 with roast #2 (SEP3 goal 5) and experience all of the Peru's nuance in a tasting session that will follow (SEP3 goal 4). To add more temperature to the roast, Sam literally clicks and drags the end point of the time-temperature graph in the Ikawa app (Figure 2). A higher temperature means that oils and related organic molecules in the beans will undergo additional chemical reactions and produce a wider range of flavors, and that already-ongoing reactions will occur at a greater rate and over a longer period of time (for an overview of the organic chemistry of roasting see Folmer et al., 2017). Sam makes his new knowledge and revisions explicit:

> So what I want to do with that info is…I want...a profile now that goes a little bit deeper into the roast. Shorter, but higher end temp. The end temp on this one was only 394[°F]. So, I don't think it really had enough energy to really get a nice first crack going…I think it will still give me a good idea of the potential that this coffee has. So, I'm gonna go edit ((clicks edit)) and I can adjust the curve here ((drags curve on Ikawa app)). My goal is to add more temp on there. So I'm just gonna [drag it up]. There we go...And now we're gonna try this one out ((laughs)) and see.

Figure 2
Sam's first profile from Rob Hoos (left) and the revised profile (right). Sam shortened the roast time from 9:31 to 5:08, increased the charge temperature from 210°F to 302°F, and raised the target end temperature from 392°F to 403°F. The revisions resulted in greater development time ratio (DTR) by 3.9% (from 3.2 to 7.1).



Sam's revisions provide a snapshot of investigation in a longer arc of work, revealing interdependencies between practices of investigation and interpretation (Manz et al., 2020). Here, he analyzes data from roast #1 to make sense of roast #2: "...we started getting ghost pops on that last round around 392[°F]. Right now we're at 391. ((leans in and listens)). And we have a lot more energy right now than we had in the last roast." Sam demonstrates this arc as the Ikawa reaches its target end temperature and begins to cool down: "There we go. So it was subtle, but it was definitely ((gestures with hands)), I could hear a little bit more activity going on. It [rate of rise] definitely didn't go negative, so, I'm expecting more vibrancy out of this roast." Sam's next steps involve the integration of sensory data with time and temperature data. These analyzes will allow Sam to confirm his claim that the second roast will be more "vibrant" than the first. Sam will do this by smelling and tasting the coffee: "I'm saving the remainder of the green for after cupping [tasting] these so I can make some adjustments as needed." With the information from a sensory evaluation, Sam will carry out more sample roasts and ultimately decide if this Peru fits his vision for the roastery's first rotating blend.

We next demonstrate how Sam *uses controls* in his investigations (SEP3 goal 7). Roughly 30 minutes after the episode above, Sam and the first author carried out a sensory evaluation by tasting coffees. During that tasting, the first author asked Sam, "How does cupping impact your roasting practices?" He responded:

> So, I think, you know, especially with this Guatemala [a coffee Sam has been experimenting with for two months], I think it's a great example. You know, I would say, only changing one thing at a time. Having controls. And, you know, not changing too much. I really want to make this ((points at graph)) basically the exact same except for bringing up my energy here ((moves finger to right)). So that's the one change I'm making, just so I can ensure that change is accurate. You know. I don't want to make too many changes and say, 'Well, what was the real cause for this?' So, just having those controls there. Yeah, I think that's the big thing.

Table 1
Summary of Sam's Demonstration of the Seven SEP3 Goals

SEP3 Goal	Selected Evidence
1: Questions	"What's the best way to roast this Peru?"
2: Hypotheses	"Oh if you don't know anything about this coffee, this is a good starting point."

3: Tools	"Which is why it's nice using the Ikawa. You can try multiple things and you're using only 50 grams per batch. Where if I wanted to have that experimentation on the Diedrich I'd have to use 60 pounds for three different sample roasts."
4: Data Types	"I should have…tested the density of this coffee and the moisture content"
5: Data Amounts	"I'm saving the remainder of the green for after cupping these so I can make some adjustments as needed."
6: Variables	"If this was a tiny little peaberry, that's super tightly densely packed, it's gonna need more heat, more energy, to penetrate the bean. So, yeah. It will tell me the starting point of the coffee."
7: Controls	"You know, I would say, only changing one thing at a time. Having controls."

Discussion

Our objective in this paper has been to portray examples of the day-to-day investigations involved in a *non-laboratory, scientific workplace*. We began with the practices of investigation enacted by Sam, a professional coffee roaster. We have been careful to avoid the pitfalls of discussing whether Sam's work *is* science or not, an unhelpful, unanswerable ontological question or an effectively political one. Asking the "what science really is" question distracts us from our broader purpose: to *expand* our imagery of scientific practices toward re-imaginations of science education. Toward this end, we showed how Sam's practices met all seven of the NRC's goals for investigation.

We have shown Sam's practices for two reasons. First, science education reforms advance an epistemology of investigation as hypothesis-driven tests of theory. We argue, and Sam demonstrates, that investigations have utility and meanings beyond the testing of theories. These include opportunities to develop an investigator's skills, conceptual understandings, and situate investigatory practices within a broader repertoire of scientific practices. Second, we argue that scientific practices are not limited to the actions of professional scientists and that images narrowly drawn *only* from these sources fail to capture the rich diversity of science in our lives. Sam demonstrates the importance of investigatory practices in his work.

Our demonstration of Sam's use of scientific practices toward real-world, everyday ends is perhaps our most significant contribution. The *Framework's* "overarching goal…for K-12 science education is to ensure that by the end of 12th grade, all students have some appreciation of the beauty and wonder of science" (p. 1). A central argument in the *Framework* is that K-12 science education fails to achieve this outcome, because it is not organized systematically across the grades, focuses on breadth over depth, and does not provide opportunities to "experience how science is actually done" (p. 1). To this list we add that K-12 science education fails to recognize the beauty and wonder of science that exists outside of the laboratory, and that this failure represents tragic, lost opportunities to connect with the roughly 90% of K-12 students (NSF, 2022) who do not pursue normatively recognized science careers.

Continued conversations about how science is conducted are needed, as these will influence how we teach and learn science (NRC, 2012), will influence what images of scientific practice are elevated, effaced, and ignored. Our study, the first of many planned investigations of *everyday scientific practice*, leverages the practice turn (Ford & Forman, 2006; Knorr Cetina et al., 2001) to step outside of the lab into the wider world of scientific work. Sam's diverse forms of investigatory practice, as inextricably tied up with personal and commercial concerns, are suggestive for new directions in understanding how and where science happens, and why science can be meaningful and relevant in the pursuit of *non-laboratory, everyday concerns*. We are inspired by Sam's work to imagine potential transformations of science education in the era where the practice turn guides us to continuously renew and expand our images of science (Davey & Stevens, 2023; Stevens et al., in preparation).

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Explanatory Refutation Texts Increase Epistemic Trust in Climate Scientists and Anthropogenic Global Warming Acceptance

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Abstract: Trust is fundamental to the non-experiential learning of complex scientific knowledge that informs societal decision-making (e.g., about climate change). Global warming (GW) beliefs and attitudes often reflect one's trust in climate scientists as reliable information sources, so fostering GW knowledge includes addressing misconceptions that can inhibit such trust. Using a pretest-posttest control group design (with an extra posttest-only treatment group that eliminated experimenter-demand concerns), we herein showed that two (long/short) brief explanatory, persuasive, refutation texts addressing climatologists' research practices increased learners' (a) trust in climate scientists (and scientists overall) and (b) acceptance that anthropogenic GW is occurring and concerning. Our experiment's results support prior findings that people revise their GW beliefs—without polarization—upon encountering crucial, valid, and germane, information. These findings expand empirical evidence demonstrating the utility of directly confronting epistemic misconceptions (e.g., about scientists'—especially climatologists'—reward structures) using explanatory, persuasive, refutation texts.

Introduction

Confidence in scientists among the US public is typically high and on par with their confidence in their military (Funk et al., 2019): 86% of residents have "a great deal" (35%) or "a fair amount" (51%) of confidence that scientists act in the public's best interests. However, trust in scientists varies by scientific field, and this variability is prominent for socio-scientific issues (SSIs), such as pandemics (Evans & Hargittai, 2020), evolution, and global climate change (e.g., Ranney, 2012; Ranney & Clark, 2016). About 25% of Americans "somewhat" or "strongly" distrust scientists as sources of global warming (GW) information (Leiserowitz et al., 2011). Given this landscape and the need for well-informed citizens/consumers, communicators have analyzed the factors—in a message, a messenger, and a recipient—that influence trust. Various strategies improve the effectiveness of climate change communication (Nisbet, 2009), including increasing people's trust in scientists (e.g., Goodwin & Dahlstrom, 2014). The following two subsections briefly survey literatures that informed the current experiment's design, especially those involving (a) epistemic trust and (b) kinds of texts that change minds and counter misinformation.

Elements of trust and epistemic trust

Mayer et al. (1995) define trust as "a function of the trustee's perceived ability, benevolence, and integrity, and of the trustor's propensity to trust," with (a) *ability* being the trustee's domain competence/expertise, (b) *benevolence* being the extent to which a trustee is seen to act in the trustor's best interest (beyond the trustee's personal benefit), and (c) *integrity* referring to the trustor's sense that the trustee follows principles acceptable to the trustor. Origgi (2004) describes *epistemic trust* as trust in a source's knowledge-reliability in a specific domain (vs. trusting someone to keep a secret or watch your laptop). Extending epistemic trust to science/scientists, Hendriks et al. (2016) characterize it as "trust in the knowledge that has been produced or provided by scientists." Epistemic trust permeates the acquisition of vicarious knowledge because it is difficult for non-experts to gain a first-principles understanding of many scientific phenomena. To make well-informed decisions about SSIs, laypeople should establish the trustworthiness of various knowledge sources (scientists, journalists, etc.); thus, their scientific beliefs about a field are often closely tied to their trust in that field's science/scientists.

Trust in scientists' competence, integrity, methods, and motives crucially shapes public opinions on climate action (MacInnis & Krosnick, 2016). Anthropogenic global warming (AGW) *acceptance* (a) significantly correlates with *trust in climate scientists* (Hmielowski et al., 2014) and (b) is causally related to *awareness of AGW's scientific consensus* (van der Linden et al., 2015). Indeed, one's trust in scientists moderates the relationship between knowledge of, and concern about, GW: Malka et al. (2009) report that knowledge is positively associated with concern among people who at least moderately trust scientists, yet knowledge is *uncorrelated* with concern about GW among those who are distrustful of what scientists say about the environment. Climate change skeptics—and many groups with vested fossil fuel industry interests—often claim that climate scientists push AGW narratives to get funding (Boussalis & Coan, 2016; Mann & Toles, 2016). Further, Funk and Kennedy (2016) note that 31% of US adults believe that climate scientists understand global climate change's causes "not too well" or "not at all." More saliently for the present study, they also note that only 23% of US adults—and only a tiny 7% of conservative Republicans—believe that climate change research findings are influenced by *concern for the public's best interests* "most of the time." These data show Americans' nontrivial distrust of climate scientists over all three aspects of epistemic trust: expertise, integrity, and benevolence. Therefore, items comprising our experiment's trust instruments cover all three aspects.

Using texts for conceptual/epistemic/attitude change and countering misinformation

Enhancing public understanding of, and engagement with, SSIs often entails (a) conceptual change in understanding a scientific phenomenon, (b) attitude change about the emotion or valence an SSI evokes, and (c) epistemic change about the nature of science knowledge and practice (Sinatra et al., 2014). Consider how different kinds of texts can shift knowledge and attitudes. *Refutation texts* are a text-genre in *misconceptions-based learning* that are designed to spur conceptual change. These texts state the learner's (presumed or actual) incorrect belief about a concept to make them cognizant of that belief—and then contrast it with more plausible, scientific alternatives (Tippett, 2010). Refutation texts can artfully counter readers' prior beliefs non-threateningly and invite attentive processing: in a meta-analysis of text-based, instructional strategies, Guzzetti et al. (1992) found refutational expository texts to be more effective than traditional expository tests (with a mean effect size of 0.22). *Persuasive texts* are designed to alter readers' *attitudes* about an issue (often emphasizing such alterations over knowledge changes), typically having a claim, then evidence supporting the claim, and a warrant linking the claim to the evidence. Persuasive texts tend to be effective if they counter readers' initial beliefs, promote mindful processing, and motivate readers to revise their beliefs (Chambliss & Garner, 1996).

This experiment also draws on work on communication strategies designed to combat misinformation. Such *agnotology-based learning* involves teaching techniques to examine and critique misinformation (Cook, 2019). Lewandowsky et al. (2012) showed that disconfirming misinformation alone may not end its influence: it is crucial to fill the coherence gap left by the disconfirmed beliefs with a plausible, alternative narrative. As noted, many who deny GW cast doubt on climate scientists' motives and findings (Oreskes & Conway, 2011). Cook (2019) classified such "attacks on the integrity of climate scientists" as a climate misinformation rhetorical strategy. Our experiment's texts directly counter flaws in claims about climatologists' purported over-devotion to financial or social-acceptance goals—which, among other things, helps readers empathize with climate scientists.

Inoculation-messages can also counter misinformation (Cook et al., 2017). When shown flawed logic or specific misinformation instances (e.g., *fake experts* feigning a lack of scientific consensus on GW), people are cognitively inoculated against similar deceptive tactics they may see in the future. Explicitly debunking misinformation (e.g., countering misleading claims based on cherry-picked information) is effective when designed aptly and repeated often. If misused or poorly constructed, trying to debunk may worsen matters (Farmer & Cook, 2013)—for instance, it may cause a *backfire effect* (i.e., should a false idea become more accepted than the facts that counter it). Beyond correcting the money-libel and clan-appeasing aspersions, our intervention text may also inoculate against other forms of misinformation that target climate scientists' integrity.

Refutation texts and persuasive texts have shifted climate change attitudes (Thacker et al., 2020) and aided climate change conceptual changes (Nussbaum et al., 2017). Other explanatory texts have increased both GW knowledge and concern (e.g., Velautham et al., 2019; Ranney & Velautham, 2021). Refutation-based interventions (Chang et al., 2018) have focused on climate change's causes and misconceptions, but intervention texts targeting misconceptions that contribute to climate change denial have not directly addressed scientific research's reward system. Individual scientists have tried to dispel the mere-greed myth by detailing their funding (Mandia, 2010). Others have emphasized science's incentive for proving one's peers wrong (Mann & Toles, 2016), which our intervention subsumes (among other elements). In full, our experiment's intervention text is designed to persuade readers that GW is real and man-made—mostly by refuting the (largely false) idea that climate scientists exaggerate AGW for personal gain (Boussalis & Coan, 2016; Oreskes & Conway, 2011).

Experiment

We herein assessed the utility of two brief intervention texts (long and short) in yielding (a) conceptual-and-attitudinal changes (as measured by readers' anthropogenic Global Warming Acceptance [GWA]), and (b) epistemic change (as measured by readers' Trust in Scientists [TiS] and Trust in Climate Scientists [TiCS]). Our three primary hypotheses (H1-H3) were: that the (a) long and (b) short texts would increase readers' TiS (H1), TiCS (H2), and GWA (H3). H1 and H2 reflect predictions that trust in (general and climate) scientists will increase due to crucial new epistemic information refuting misconceptions about climatologists' motivations. H3 reflects the idea that GWA and TiCS increases ought to co-occur, because trusting climatologists means that their AGW claims gain credence. A secondary hypothesis (H4) is that our texts succeed with liberal *and conservative* participants (i.e., with no polarization—as Ranney et al., 2019, etc., have found for other brief GW interventions).

Participants

A diverse set of 419 online (*Qualtrics Panels)* adult US participants were pre-selected to roughly reflect three US distributions that were counterbalanced across all conditions: age, education, and political affiliation. It was thus a more balanced/diverse sample than is typical of most studies (e.g., those using Mechanical Turk, whose samples tend to be younger, more liberal, and more educated than US adults). Our median participant was middle-aged with some college credit (but no post-high-school degree). Political affiliations reflected the US's (somewhat labile) proportions, with 36.3% Democrats, 35.6% Independents, 27.4% Republicans, and 0.7% Green/Libertarian/Other participants. Our campus's institutional review board approved this study. Qualtrics received $4.50 per not-excluded participant, half of which went to individuals—with the actual value (whether cash, gift card, or other cash-substitute) being proprietarily determined by Qualtrics and its panel provider(s).

Design

Participants were randomly assigned to one of four conditions: (a) a Pretest, Long intervention-text, plus Posttest (PLP) group, (b) a Pretest, Short intervention-text, plus Posttest (PSP) group, (c) a No-Pretest, Long intervention, plus Posttest (NPLP) group, or (d) a control-text group. We hypothesized (H1-H3 above) that PLP (H1a-H3a) and PSP (H1b-H3b) groups would show pretest-to-posttest gains for all outcome variables (TiS, TiCS, and GWA), relative to the control group. The PSP group effectively assesses a dosage hypothesis regarding whether roughly halving the text's words (vs. PLP) would still yield such gains. The NPLP group served to detect any pretest sensitization suggesting (in the PLP or PSP groups) either an experimenter demand or a consistency bias. Such a pretest-treatment interaction would mean that a pretest increased or decreased participants' sensitivity to an experimental text (i.e., people getting pretests sometimes show more or less gain compared to a no-pretest group). Spurious gains to please experimenters were greater threats to our experiment's validity than reduced gains, so we hypothesized (H5) that the NPLP posttest scores would not be significantly below the PLP posttest scores, indicating no experimenter demand effect. The NPLP condition also allowed replication of a longer-text treatment effect beyond the PLP group: we hypothesized (H6) that the NPLP posttest scores would exceed the other groups' pretest scores, which would indicate yet another treatment main effect for the (long) intervention text.

Procedure

Participants gave informed consent before receiving material for their randomly assigned group from a Qualtrics link. Each pretest and posttest included 30 items over four online presentation-pages. Participants failing to complete the experiment or pass quality checks were replaced from the panel pool. Those who responded correctly to at least one out of two items in each of these were retained: a) two attention-check items mingled into pretest items, b) two attention-check items mingled into posttest items, and c) two comprehension check queries right after the (control or intervention) text. Speeding checks on the total time spent were also enforced: those spending less than half the median time for their assigned condition were excluded. Finally, anomalous indicators—such as (1) page latencies (i.e., local speeding), (2) very low within-participant variance, and (3) internal incoherence among responses to similarly-worded or negatively-phrased items—were examined to remove random, *straightliner*, and inattentive responders. Demographic information was solicited after the posttest.

Materials (texts and instruments)

Two intervention-text versions with the same brief, core, message were used: the PSP group's Short (i.e., roughly condensed) 253-word version—and the PLP and NPLP groups' Long 483-word version. (The control text was a similarly engaging 500-word summary of the film *Mary Poppins*.) The intervention texts countered hoax-ideas that are common in some subpopulations—such as that climatologists bolster their field's status quo to get grants/accolades—by highlighting that *real* scientists' fame reflects the field-altering shock of their findings. A part of the short version highlights this: "Scientists also don't just accept global warming because they want to get along with other scientists. That's mostly the opposite of how scientific rewards work. Scientists treasure any chance to show that the vast majority of their peers are incorrect: that's how Einstein-types achieve fame. [...] About 98% of climate scientists accept human-caused global warming even while wishing it were false—and having incentives to disprove it. This reflects the very high probability that climate change is truly happening."

A scientist can earn trust and engage doubtful audiences by showing vulnerability and highlighting a willingness to sacrifice (Goodwin & Dahlstrom, 2014)—for instance, through a commitment that clearly shows that the scientist has something to lose. Our texts do so by (beyond their other features) describing a scientist (this piece's third author) who often publicly pledges to quit all climate-related activities and return all climate-related funds he has received if "someone could please" disabuse him of his beliefs that GW is occurring and human-caused; he developed the texts' prose over dozens of lectures with sometimes-dubious audiences (e.g., one in a bar in Texas, USA). The texts quote him, including: "Indeed, virtually all climate scientists absolutely wish that global warming were not happening—especially if they're parents!" He elaborates that anyone who *can* disconfirm GW *would*, as the person would win a Nobel prize, become the "most famous scientist ever," and get "wildly rich" (from fossil-fuel companies, etc.). The texts are available on our group's academic site (at https://convinceme.com/downloads/papers/SenthilkumaranVelauthamRanney2023-ICLS-ExtraMaterial.pdf) and our group's public-outreach site (at https://www.howglobalwarmingworks.org/trust-in-scientists.html—along with some of our other brief materials that have been shown to increase global warming acceptance/concern).

An eight-item TiS instrument and an eight-item TiCS instrument were developed (with items adapted from Nadelson et al., 2014) and validated prior to this study. Both were highly reliable (Cronbach's $\alpha = 0.75$ and 0.90, respectively), and their sum-scores correlated (r = 0.69 and 0.87, respectively) with those from an eight-item GW Acceptance instrument from our prior experiments (e.g., Velautham et al., 2019), further supporting their validity. The GWA instrument measures how much people believe that (a) GW is occurring and largely human-caused, (b) GW's effects are a serious threat, and (c) GW's effects are concerning. All items were rated on a 1-9 scale from "extremely disagree" to "extremely agree" (with verbal labels at each number). An example of a TiS item is: "Scientists honestly look for flaws in the methods and findings of other scientists." A *negatively*-phrased example of a TiCS item is: "Climate scientists do not accurately convey their findings." An example of a GWA item is: "I am confident that human-caused global warming is taking place."

Statistical-analysis rationale

Because univariate effects were of central interest in comparing changes among experimental groups for our pretest-posttest design, we bypassed a MANOVA to directly use univariate ANOVAs on each outcome variable. Intercorrelations among the outcome variables on the pre-tests (covering Control, PLP, and PSP groups' data) ranged from .65 to .82 and on the *post*-tests (covering all four groups' data) from .69 to .84. We used (per Smolkowski, 2019) a change (posttest minus pretest) score approach over an ANCOVA on posttest scores or a repeated-measures ANOVA. We used the Holm-Bonferroni correction, given multiple-comparisons and Type 1 error, such that the experiment-wise α was .05. We first performed one-way ANOVAs on each outcome variable; for ANOVAs revealing a statistically significant between-groups difference, we performed post-hoc Dunnett's tests. For the NPLP group, we compared its posttest scores to (i) the PLP group's posttest scores (to rule out experimenter demand), and (ii) the other groups' (PLP+PSP+Control combined) pretest scores (for replication).

Results

Gains for both trust-text treatments for all within-participant measures

Table 1 shows pretest (if applicable) and posttest group means (out of 72) for GWA, TiS, and TiCS. (Each group's data for all outcome variables were reasonably symmetrically distributed—with few outliers on one or both tails.) As hypothesized, the PLP (H1a-H3a) and PSP (H1b-H3b) groups showed posttest gains for all three outcome variables. Focusing on Table 1's *changes*, Table 2 shows means and *SDs* of the change scores for the three GW and trust measures from groups who had a pretest (control, PLP, PSP). The PLP group, with its longer-than-PSP text, tended to yield the largest gains on the measures, and the control group showed basically no changes.

Table 1

Pretest and Posttest Means and (italicized) Standard Deviations of Outcome Variables by Condition

Group	n	GWA Pre		GWA Post		TiS Pre		TiS Post		TiCS Pre		TiCS Post	
		M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*
Control	113	52.4	*14.7*	51.7	*15.1*	49.7	*9.3*	49.8	*8.8*	49.1	*11.5*	49.6	*12.6*
NPLP	91	-	-	56.5	*12.8*	-	-	53.0	*9.2*	-	-	53.7	*10.7*
PLP	104	47.5	*16.0*	50.5	*16.2*	48.9	*10.1*	51.0	*10.4*	46.0	*13.5*	50.7	*13.5*
PSP	111	49.7	*17.1*	51.6	*16.6*	49.2	*9.3*	51.7	*10.3*	47.1	*14.0*	51.3	*13.8*

Note: Max. possible score on each of these measures was 72 (i.e., 8 items each on 1-9 scales); - = no pretest

Dunnett's test (df = 325) showed that the PLP (p < 0.00001, Cohen's d = 0.77) *and* PSP groups' GWA gains (p = 0.00013, Cohen's d = 0.54) were significantly greater than the control group's change (by 3.7 and 2.6 points, respectively). This test builds on a significant difference among those three groups in a one-way, between-subjects ANOVA on *GWA-change-score*: F(2,325) = 17.16, p < 0.00001. The same pattern was obtained for the TiS gains: Dunnett's test (df = 325) showed that the PLP (p = 0.00958, Cohen's d = 0.38) *and* PSP groups' gains (p = 0.0018, Cohen's d = 0.45) were significantly greater than that of the control group (by 2.1 and 2.4 points, respectively). The one-way between-subjects ANOVA of the *TiS gains* warranting the test showed a statistically significant difference among groups: F(2,325) = 6.53, p = 0.00166. As with GWA and TiS, a one-way between-subjects ANOVA of the TiCS gains showed a statistically significant difference among groups: F(2,325) = 15.93,

$p < 0.00001$. The follow-up Dunnett's test ($df = 325$) showed that the TiCS gain of the PLP group (4.2 points) differed significantly from that of the control group ($p < 0.00001$, Cohen's $d = 0.69$), and the TiCS gain of the PSP group (3.7 points) showed a significant difference from the control group ($p = 0.00001$, Cohen's $d = 0.61$). These results show that both the intervention-text's longer (H1a-H3a) and shorter (H1b-H3b) versions successfully increased readers' global warming acceptance and trust in climate (and generic) scientists; in other words, even the smaller, 253-word, "dose" of our intervention was successful.

Table 2

Change Scores by Condition (Posttest minus Pretest, rounded to nearest 0.1)

Group	N	GWA Gain		TiS Gain		TiCS Gain	
		M	***SD***	**M**	***SD***	**M**	***SD***
Control	113	-0.7	*4.1*	0.0	*4.4*	0.5	*5.1*
PLP	104	3.0	*5.6*	2.1	*5.8*	4.7	*6.3*
PSP	111	1.9	*4.5*	2.4	*5.9*	4.2	*6.5*

Note: The NPLP condition did not have a pretest.

Replicative gains for all NPLP measures (and no experimenter demand)

Table 3 shows the NPLP posttest scores' means and standard deviations (presented earlier in Table 1), along with the means and standard deviations of the pretest scores of the other three conditions combined, and (broken out of that combination) the PLP posttest scores. We performed two main comparisons with the NPLP condition's data: one assessing experimenter demand (H5), and another assessing coherence with the PLP data (H6).

Table 3

Relevant Between-Group Summary Statistics for NPLP Posttest, PLP Posttest, and Combined Pretest Scores

Group	n	GWA Pre		GWA Post		TiS Pre		TiS Post		TiCS Pre		TiCS Post	
		M	***SD***	**M**	***SD***	**M**	***SD***	**M**	***SD***	**M**	***SD***	**M**	***SD***
Combined	328	50.0	*16.0*	n/a	*n/a*	49.3	*9.5*	n/a	*n/a*	47.4	*13.0*	n/a	*n/a*
NPLP	91	-	-	56.5	*12.8*	-	-	53.0	*9.2*	-	-	53.7	*10.7*
PLP	104	n/a	*n/a*	50.5	*16.2*	n/a	*n/a*	51.0	*10.4*	n/a	*n/a*	50.7	*13.5*

Note. "Combined" = groups with pretests (PLP, PSP, & Control). Mean maximums = 72; n/a = not-applicable; - = no pretest.

We found no evidence of experimenter demand: NPLP and PLP posttest scores were compared with a one-sided equivalence test (i.e., a noninferiority test), with a decrease (PLP minus NPLP) of less than 1 point (of a possible 72-point sum) per measure considered negligible. The null hypothesis was that (*PLP-post – NPLP-post*) > 1 (i.e., experimenter demand exists), and the alternate hypothesis (H5) was that (*PLP-post – NPLP-post*) <= 1 (i.e., no experimenter demand). Our results showed no experimenter demand effect for any of the measures. For example, the 95% CI [-6.39, 0.46] for the TiCS PLP-NPLP posttest score difference does not contain 1, indicating *no* experimenter demand effect ($p=0.0117$, Cohen's $d= 0.32$). Similarly, *no* experimenter demand effect was found for either the TiS scores ($p=0.0196$, Cohen's $d = 0.30$, 95% CI [-4.73,0.85]), or the GWA scores ($p=0.0005$, Cohen's $d=0.47$, 95% CI [-10.07, -1.87]). If anything, the data indicate that taking the pretest and becoming sensitized to the variables under study reduces the text's effectiveness, demonstrating *lower* gains than would otherwise be obtained without pretest sensitization. This is the *opposite* of what one would expect had participants induced the hypotheses and tried to please the experimenters with biased ratings on the posttest.

Supporting hypothesis H6, the NPLP group's long text replicated significant gains (of moderate effect size) for all three measures—GWA, TiS, and TiCS (~6.5, ~3.7, and ~6.2 points, respectively): NPLP showed such significant gains for GWA ($t(176.7)=4.07$, $p=0.00007$, Cohen' $d=0.42$), TiS scores ($t(417)=3.26$, $p=0.00119$, Cohen's $d=0.39$), and TiCS ($t(417)=4.19$, $p=0.00003$, Cohen's $d=0.50$) relative to the combined groups' pretest scores. (NPLP posttest scores were compared to the pretest scores of the other three groups [combined] using an independent-samples t-test [two-tailed] for each gain variable. The GWA scores were compared assuming unequal variances, and the TiCS and TiS scores were compared assuming equal variances, as per Levene's test.)

No polarization, either regarding belief level or political affiliation

Supporting hypothesis H4, we found *no* evidence of our texts causing polarization (cf. Lord et al., 1979)—using three lenses: initial belief level, political affiliation, or conservatism. Neither those with low initial belief /attitude levels—nor those identifying as Republican or conservative—showed polarization or a backfire effect.

Regarding beliefs and attitudes, participants scoring 24 or lower (33% of 72) summed points on the GWA or TiCS *pre*tests numerically *increased* their mean post-intervention scores. Such "bottom-thirders" did *not* show the losses that polarization would predict. Indeed, PLP and PSP bottom-thirders yielded +8.0 and +3.4 respective

TiCS point-gains above pretest levels (and +1.2 and +3.3 respective GWA point-gains). (No PSP/PLP participant scored 24-or-under on the TiS pretest, so we report no TiS changes; likewise, NPLP had no pretest, so that group could show no polarization.) Turning to political affiliation, Republicans (a separate AGW denial correlate) did *not* exhibit the losses that would indicate polarization—indeed, they yielded *gains* on *all three* measures for both relevant groups: PLP (+3.1, +2.3, and +4.9, respectively, for GWA, TiS, and TiCS) and PSP (+3.1, +3.6, and 7.0, respectively, for GWA, TiS, and TiCS). Similar gains were found for Democrats and Independents, yet gains for Republicans (who had the lowest mean *pretest* scores) were generally the highest.

We can assess (the lack of) polarization more directly than with bottom-thirders and political party: The correlations between GWA/TiS/TiCS changes and (separately, economic and social) conservatism were all close to zero (with r's ranging from -0.06 to +0.18). The largest of these six correlations, between GWA-change and social-conservatism, was still weak (ρ=0.184, with a 99% CI of [0.01,0.35]). However, it—like most of the other (weaker) change-conservatism correlations—was *positive*, and thus (as above) in the opposite direction that polarization would predict. Likewise, for all nine levels of self-rated economic conservatism among PLP and PSP participants, mean changes (on TiCS, TiS, and GWA) were positive for 52 of the 54 (9x6) sub-cells—and the remaining two sub-cells showed losses of less than 0.5 points. (Results for *social* conservatism, which we have found are typically less linked to AGW denial, were similar.) Indeed, our *extreme* conservatives (with self-ratings of 9 of 9), exhibited gains for all three (GWA, TiS, and TiCS) measures for both PLP and PSP conditions.

Discussion

Political discourse often focuses on one's finances or affiliations, so it is not shocking that some people criticize climate scientists by suggesting that they largely follow greedy or tribal motivations. This libel (i.e., when knowingly false) is spread by special-interest groups (Oreskes & Conway, 2011)—and their agents/lobbyists—who oppose climate-friendly reductions in greenhouse gas emissions (and deny AGW's reality or huge scale). It is further intensified by some political influencers who portray climate scientists as enemies—heightening in/out-group separations that social-media algorithms tend to amplify. What our Trust-texts cultivate, though, is a humanizing empathy about being in a climate scientist's shoes (e.g., "Were I a climatologist, I'd want to aid society by providing veridical, actionable, information—even if I got pushback."). The interventions herein help people both cognitively and emotionally understand that virtually all climate scientists: (1) fervently wish global warming were false and (2) would gladly disconfirm GW if they could—due to the almost-unimaginable rewards they would reap. Our data show that readers are changed by this narrative, and in 253 words (let alone the longer, 483-word text) our experiment successfully increased (a) the more proximal construct of Trust in Climate Scientists *and* the more distal constructs of (b) Trust in Scientists overall and (c) Global Warming Acceptance.

In addition to our findings that both of this experiment's brief texts increased belief ratings for the TiCS, TiS, and GWA measures, the no-pretest group (NPLP) showed that the gains in normative beliefs were (a) not due to experimenter demand and (b) further replicable (i.e., the NPLP results replicate the PLP—and implicitly, the PSP—results). In sum, all six of our hypotheses (H1-H6) found support in the data. The findings both bolster extant research on evidence-based strategies to combat misinformation and support our (and Hmielowski et al.'s, 2014) strong link between trusting climate scientists and accepting their AGW findings. The results also show that explanatory persuasive-refutation texts can succeed without yielding polarization or backfire effects: most participants across each of several relevant spectra showed *gains* for all dependent variables (TiCS, TiS, and GWA). The gains are even robustly found across participant sub-spectra that are, *a priori*, most indicative of potential GW deniers—namely participants who had up to three indicators of strong content-skepticism (i.e., high conservatism, Republican [and Independent] affiliation, and low trust or GWA pretest scores).

Although we used common techniques to improve data reliability, they are not without external validity concerns. Attention and comprehension checks aid in reducing statistical noise, but they modify the inferential target to a subset of the population: people who complete the experiment and pass all screeners may differ from those who do not—especially in public-attitude studies (Aronow et al., 2019). Dropouts and inattentiveness in online studies may often be due to extraneous reasons, but a would-be-participant who exits upon viewing the pretest questions or an intervention text—or fails the quality checks—may denote (a) a difficulty in understanding the text and instructions, or (b) a reluctance to engage with the topics of GW and/or climate scientists.

Beyond addressing a common misconception among deniers, our texts also communicated science's incentive structure. SSIs make an excellent context for nature-of-science learning (e.g., Eastwood et al., 2012), and knowledge about the nature of science increases public acceptance of science regardless of identity factors (Weisberg et al., 2021). Our results indicate that explaining *science's motivations and methods* to the public can increase learners' trust in scientists, their expert findings—and hopefully their wisest recommendations.

Conclusions

This experiment supported six hypotheses (H1-H6) that advance climate change cognition. Its trust-text genre brings to 12 (detailed in Ranney & Velautham, 2021, and Velautham, 2022) the ways in which our lab's brief materials have been shown to boost AGW acceptance/concern. Other ways include statistics about climate change (even marbled with misleading statistics), related statistics (on energy efficiency, electrification, and reducing meat), graphs of Earth's warming (vs. the US stock market rise), statistics reducing nationalism, texts about high CO_2's cognitive harms, information about GW's physical and economic effects (e.g., sea-level rise), activities involving selecting climate change solutions, and texts and videos about global warming's mechanism or effects.

This experiment cannot escape the context of US subgroups who struggle to understand and access diagnostic information. From public health guidelines (e.g., slowing COVID-19's spread with masks) and US election-results denial to climate change mitigation and adaptation, people vary in how much they trust experts (Evans & Hargittai, 2020; Leiserowitz et al., 2011). Given the proliferation of misinformation in mass media and its effect in undermining trust in domain experts, it is crucial to make accurate, relevant, and non-polarizing information (such as those used in our texts) widely available—and repeated through multiple sources—to bolster trust and improve public science understanding. Not *all* scientists (whether they work on climate *or* fossil-fuels) are beyond reproach. Some are tempted to overstate or obscure in reporting, and some even fall from grace; legal and peer-review systems are imperfect. But history—and science-driven technologies—have shown that science largely, if not fully monotonically, eventually gets it right. Our findings demonstrate that reading even 60 seconds' worth of the shorter (PSP) text significantly changes minds about some of the most important elements of our era: scientific veracity—and its role in informing humanity about a potentially cataclysmic future.

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Productive Disciplinary Engagement and Expansive Framing as Foundations of Teacher Education

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Abstract: Helping teachers move beyond the pedagogical practices they experienced as students represents an enduring problem in teacher education. Even when they experience more creative alternatives during preparatory coursework, they often have trouble transferring these approaches to their clinical practice. This paper systematically reviews scholarship on two constructs from the situative tradition, *productive disciplinary engagement* (PDE) and *expansive framing*, that hold potential for promoting instructional transformation and transfer. We find that both constructs illuminate core issues in teacher learning, but that, as pedagogical tools in themselves, expansive framing is more easily taken up by teachers than PDE is. We conclude by advancing a view of theoretical synergy between the two frameworks that could hold promise for future efforts towards encouraging instructional transformation and transfer.

Introduction

In recent years, learning scientists have increasingly acknowledged the importance of teacher education, learning, and development for bridging learning research and educational practice (e.g. Chen et al., 2020; Superfine et al., 2022). One key challenge scholars have identified relates to instructional change: Teachers who as students experienced an "apprenticeship of observation" (Lortie, 1975) that consisted mostly of rote instruction have difficulty envisioning a more stimulating alternative. A second, related problem has to do with transfer: Reform-based strategies learned in teacher education programs (TEPs) or professional development (PD) courses often are not taken up in classroom practice (Dreer et al., 2017; Fishman et al., 2022). In short, so-called traditional instruction proves stubbornly resistant to change.

Teacher education scholarship offers no shortage of responses to these twin challenges of instructional change and transfer—for example, engaging with teachers' epistemic beliefs, providing clearer modeling, or staging rehearsals within TEP coursework (see, e.g., Grossman, 2018; McDonald et al., 2013; Monte-Sano & Budano, 2013). This paper offers a "conceptual contribution" (ISLS 2023 CFP) to learning sciences scholarship by examining the affordances of two constructs developed by the late Randi Engle and colleagues: *productive disciplinary engagement* (PDE; Engle & Conant, 2002) and *expansive framing* (Engle, 2006; Engle et al., 2012). Through a systematic review of literature applying these frameworks to teacher education, we find significant potential for promoting instructional change and transfer in creative new ways.

Theoretical framework

Drawing on theories of situated cognition (e.g., Greeno, 1998), Engle and Conant (2002) advanced the term *PDE* to refer to impassioned and productive engagement in disciplinary activity. They proposed four design principles for prompting such engagement: (a) *problematize* disciplinary content from students' own perspectives and experiences, (b) confer them *authority* to pursue these problems, (c) hold them *accountable* to their peers and to disciplinary norms, and (d) provide access to relevant *resources* needed to accomplish these goals. Examples of PDE include student design of a robot (Verma et al., 2015), impassioned whole-class discussions of historical events (Freedman, 2020), and debating the proper classification of the species *orca* (Engle & Conant, 2002). These sorts of productive, student-driven inquiries starkly contrast with the instruction most teachers experienced as students. A key question guiding our review then, is, "What learning outcomes result from teachers experiencing PDE during pre-service or on-the-job training?" For instance, does this lead them to employ PDE principles in their own classrooms?

Engle (2006; Engle et al., 2012) later offered *expansive framing* as a situative means of promoting the transfer of learning across settings. To frame a learning context expansively means to forge links between the activity occurring there and the activity that occurs (or has occurred) in other meaningful contexts, thereby creating what Engle called "intercontextuality." For example, rather than reminding students that material covered will be useful for an upcoming test, a teacher might help them connect that material to prior outside experience and reflect on potential uses in community, career, civic, or other settings. Intercontextuality is also thought to emerge when students are positioned as *authors*, capable of applying their ideas broadly across contexts. Our review, then, searched for evidence that expansively framing the work undertaken in a teacher education setting might promote more robust transfer to a classroom instructional setting. As with PDE, we also asked how teachers might learn to utilize expansive framing in their own practice.

While the frameworks for PDE and expansive framing are distinct—the former focusing on engagement and the latter on transfer—they do connect in important ways. As already noted, building students' authority or capacity for authorship is central to both frameworks. Further, problematizing a topic entails *transferring in* conflictual knowledge (e.g., noticing that a zookeeper's classification of orcas conflicts with a classroom reading; Engle & Conant, 2002). Problematizing often also entails recognizing a topic's import beyond school. In this sense, expansive framing may enhance PDE and vice versa. The close connection between the two frameworks is why we consider them in tandem in this review, even though scholarship has tended to pursue each separately.

To briefly summarize, our review found that: 1) both PDE and expansive framing can support teacher learning, 2) as an instructional approach, expansive framing lends itself for teacher use more easily than does PDE, and 3) use of expansive framing could help teachers better transfer use of PDE principles to clinical practice.

Method

As part of a larger systematic review, we used Google Scholar to identify 2714 publications (as of June 2022) containing the terms "productive disciplinary engagement" or "expansive framing" or citing Engle's scholarship. Two team members independently coded each publication as unpublished/irrelevant/inaccessible (450), not in English (287), passing reference to Engle's work (800), supporting reference (803), or include (374), with an interrater agreement of 78% (Cohen's kappa = .72; disagreements were resolved by the more experienced reviewer). Passing references were those that cited Engle without incorporating her ideas, while supporting references were those that drew on her ideas only peripherally. Publications marked for inclusion engaged substantively with PDE, expansive framing, or both. For the current paper, we flagged the included publications that dealt specifically with teacher education or teacher learning: 12 journal articles, two book chapters, one conference proceeding, and one monograph. Nine of these publications focused on PDE, while five focused on expansive framing, and one addressed both frameworks.

Findings

Engle's work has been taken up both in teacher education programs and in PD opportunities for practicing teachers. Generally speaking, the causal mechanisms implied by each theory—that the four guiding principles promote PDE, and that expansive framing promotes transfer—appear to hold for pre- and in-service teachers, as prior research has shown with K-12 students (see Engle, 2012). The literature illustrates the PDE principles' potential for engaging emerging teachers in case analysis, scientific modeling, and collaborative inquiry—and it shows how expansive framing can promote transfer of content knowledge and pedagogical practices from coursework to the field. Some studies went so far as to promote teachers' use of PDE and expansive framing *themselves* as pedagogical practices, though none did so explicitly (an issue we return to in the Discussion). We begin with studies that employed the frameworks as vehicles for teacher learning, followed by studies that treated the frameworks as pedagogical tools for teachers to use in their own right.

PDE and expansive framing as vehicles for teacher learning

In the first application of the PDE framework to teacher education, Engle and Faux (2006) compared two instantiations of case-based instruction in an educational psychology course. One instructor (Engle) focused on getting her students to use psychological constructs to illuminate the cases—which presented managerial, curricular, and other dilemmas drawn from real classrooms. By contrast, the other instructor (Faux) placed greater emphasis on the students exploring the cases from their own perspectives as practitioners. In this sense, Engle's class section fostered greater disciplinary accountability but diminished students' opportunities to problematize the case material or establish a sense of authority, whereas Faux's section showed the opposite pattern. As an instructional method, case analysis holds high potential for helping prospective teachers connect theory to practice, yet Engle and Faux's study illustrates how the strategy can often fall short of that goal—either by devolving into an academic exercise of matching theories to cases (as occurred in Engle's section), or by sparking discussion of personal experiences unilluminated by learning theory (as in Faux's section). In this way, the PDE framework proved a fruitful tool for analyzing a pedagogical practice within teacher education, with an eye towards improvement. Based on the study's findings, the authors began exploring ways to first establish students' authority before later adding in elements of disciplinary accountability.

Lipponen and Kumpulainen (2011) took up this issue of building PSTs' sense of agency. To do so, they engaged the PSTs in a collaborative inquiry into Middle East conflicts during an 8-week TEP course. The PSTs were to construct, negotiate, re-negotiate, and contest accountability and agency within their inquiry groups—among peers and with their teacher educator. Analysis of classroom discourse confirmed that as the teacher educators stepped back from their traditional authoritative roles, the PTSs came to share authority and act as "accountable authors" (p. 816), in line with the PDE principles. Similarly, Juutilainen et al. (2018) used "home groups" to build PSTs' sense of agency. The home groups created a space for the PSTs to acquire emotional safety, learn to function as a team, and renegotiate power dynamics between students and the teacher. Well-functioning home groups proved a fertile ground for active knowledge construction and the negotiation of power and authority within the group, though some reported negative features such as inequality among group members. Overall, participants reported that the home groups successfully built their sense of agency. As with Lipponen and Kumpulainen's study, however, it remains unclear whether the participants went on to enact similarly collaborative and authentic learning experiences in their own classroom practice.

The aforementioned studies illustrate the PDE framework's potential for enhancing teacher preparation coursework. By promoting problematizing, distributed authority, and disciplinary accountability, teacher educators can engage their students in the kind of authentic inquiry the latter might seldom have experienced in their own schooling—thus expanding their view of what is possible. Such inquiry can also have discrete learning outcomes, such as more adeptly applying learning theory to illuminate problems of practice (Engle & Faux, 2006).

Our review found expansive framing also to carry potential for promoting teacher learning, although here the emphasis was on transferring concepts learned in coursework to the field. Van Duzor (2011) described a PD course that used expansive framing to encourage K-8 teachers to transfer chemistry concepts and inquiry methods to their professional practice. The authors drew on Engle (2006) to characterize the course's framing of time and participation as creating intercontextuality between the PD and its context of use. For example, in a weekly journal, the participants reflected on how they could apply ideas from the course in their clinical settings. Analysis of the journals illustrated broad success of the program: The participants discussed incorporating content and teaching strategies from the PD into their current and future practice, even extending and adapting them to fit their students' needs. As a single case design, however, the study offers limited evidence that it was expansive framing *per se* that yielded these results, nor could the authors say with confidence that the participants actually did in practice what they said they would in their journals.

Extending the concept of transfer, Dohn and Hachman (2020) focused on PSTs' transformation of knowledge between educational and professional settings. The authors sought for PSTs to transfer content knowledge, an associated teaching strategy, and underlying educational theory to a clinical setting. Using a design inspired by expansive framing, the teacher educators pursued these goals in two ways: 1) they explicitly told PSTs that knowledge from the TEP could be applied in their practicum teaching, and that reflections on their practicum teaching would in turn be discussed in their TEP, and 2) they had PSTs engage in and design activities that they would then use in their practicum. In the TEP course, PSTs engaged in a storytelling activity designed to teach about dramatic arc; they then used the same activity in a lesson with 5th graders at their clinical site. Immediately after, they reflected on the similarities and differences between the lesson as planned and enacted in the TEP and as implemented with 5th graders. The authors found that the PSTs transferred knowledge about dramatic arc and one strategy for teaching about it. Beyond that, PSTs adapted the lesson for the perceived situational demands of the classroom context, as they incorporated some of the underlying learning theory into their lesson. They did not seem to fully connect the theory to their instructional choices, however. The researchers speculated that doing even more to expansively frame the course might help students better see this connection between learning theories and instructional choices. In this study, then, certain types of knowledge (i.e., of disciplinary content and learning activities) were transferred, while other types of knowledge (conscious application of learning theory) were not.

Finally, Andrews et al. (2019) described an online, asynchronous course designed to extend expansive framing from something instructors do for their students to something students do among themselves. Given the scaffold of social annotation prompts that supported intercontextuality between course concepts (theories of learning) and future clinical practice, PSTs did take up expansive framing in their own discourse. Further, those who expansively framed more in their annotations tended to perform better on a final exam which was used as a proxy for transfer, leading the researchers to conclude that the PSTs' expansive framing did promote transfer of course concepts to their future practice.

The research described so far employed PDE and expansive framing as vehicles for teacher learning. Most did so quite successfully, suggesting that these frameworks can serve as powerful strategies for helping teachers learn disciplinary and pedagogical knowledge—and in some cases, transfer that knowledge to the field. Exploration into the extent to which the teachers used the frameworks as pedagogical tools *in themselves* was beyond these studies' scope—for none of them sought to *teach about* the use of PDE and expansive framing to promote student learning. In the following section, we summarize studies that did take this latter approach.

PDE and expansive framing as pedagogical tools for teachers' practice

Nine studies examined teacher educators engaging their students in PDE or expansive framing with the (implicit) expectation of similar approaches being used with *their own* students in their future classrooms. Generally speaking, attempts to encourage pre- and in-service teachers to adopt PDE principles in their practice were met with more limited success than attempts to get them to adopt expansive framing.

Ford and Wargo (2007) aimed for PSTs to engage in what the authors called "authentic disciplinary engagement" (essentially, PDE) in a science methods course. To facilitate that, the authors altered the "routines, roles, and responsibilities" (p. 134) governing the class to conform more closely with authentic science and asked the PSTs to negotiate the "nitty-gritty" details (p. 142) of designing, carrying out, and interpreting the results of an experiment. In terms of Engle and Conant's schema, the course sought to redistribute epistemic authority from the teacher to the community as a whole, thus promoting the scientific practices of peer review and critique. (Other PDE principles, including problematizing and accountability, clearly influenced the course design but did not factor into the authors' analysis.) The findings hold important implications for teacher education: While the PSTs proved capable of themselves adopting the scientific routines, roles, and responsibilities, they tended to view these as inappropriate for K-12 classrooms. Ford and Wargo's study points to the difficulty of transforming PSTs' views of what good teaching entails, even after participating in activities that uphold PDE principles.

Kawasaki and Sandoval's (2019) study represents another attempt to encourage prospective teachers to adopt PDE principles in their own professional practice—also with limited success. The authors designed a PD program aimed at aligning instruction with the Next Generation Science Standards (NGSS) and promoting accountability and authority among students. They argued specifically that teachers need to hold students accountable to their own and their peers' claims, as well as to disciplinary norms, to foster epistemic agency. Drawing on a single case study, Kawasaki and Sandoval found that the teacher struggled to cede epistemic authority and accountability to her students. The authors attribute this to the structure of many of the teacher's class lessons—rather than encouraging students to voice their own ideas about specific physics phenomena, the teacher introduced course concepts in the abstract and had students answer discreet, isolated questions related to their classroom lab activity. This lesson design positioned the teacher as the authority figure and the students as consumers of course content rather than as authors. Kawasaki and Sandoval concluded that their PD program failed to give the teacher the resources necessary to help her pursue PDE as an instructional strategy.

Windschitl and Thompson (2006) offered another less successful example of designing with and for PDE. In this case, the authors sought to build PSTs' appreciation for the epistemic roles that models, theory, and argument play in scientific inquiry. They aimed specifically for PSTs to devise their own models, which would then guide the design of experiments and interpretation of results. The authors linked these aims to PDE principles: in the science methods course they designed, PSTs would need to problematize phenomena and author ideas while remaining accountable to disciplinary norms. The findings were mixed. As learners, the PSTs showed they could use models to appreciate scientific complexity. When planning a unit of instruction at the end of the course, however, most PSTs did not use models as the underlying basis for designing and carrying out an investigation. Windschitl and Thompson conceded that, in its original form, their PDE-based methods course fell short of enabling teachers to integrate scientific modeling into their future instruction.

Based on these results, Windschitl et al. (2008) added two design principles to the PDE framework, calling their augmented system *heuristics for progressive disciplinary discourse* (HPDD). First, PSTs should see modeling of prototypical cases of disciplinary activity early on; and second, they should be given opportunities to take on discursive roles that allow them to practice this activity. To enact the first new principle, the revised course made explicit to students scientific knowledge's epistemic characteristics of being testable, revisable, conjectural, explanatory, and generative. To enact the second new principle, the course asked learners to inquire into the reasoning of their peers in various ways. After experiencing the newly revised course, 15 of 17 participants refined their preconceived notions of models, theory, evidence, and argument, in the desired direction. The following school year, 15 former participants (now student-teachers) were evaluated on applying the methods course concepts to their own teaching: Only 2 consistently used models in the desired fashion, while the rest made various degrees of progress in this direction. However, Windschitl et al. concluded that it was not the HPDD framework that was ineffective, but rather its application in the methods course that compromised transfer to the clinical setting.

Antink-Meyer and Parker (2021) also drew on the PDE design principles to inform PST instruction. In this case, the authors described their re-design of an Inquiry and Design course (IDC) taken prior to a science methods course. They developed three curricular features that each corresponded to at least one PDE design principle. At the end of the course, the PSTs were to design an engineering or science learning activity, which was evaluated on the extent to which it encouraged problematizing, giving students authority, and holding them accountable. The authors found that PSTs who took the IDC alongside a standard methods course designed activities that the authors deemed "student-centered" based on the rubric they used. They also found evidence that the IDC was successful in improving the PSTs' self-efficacy for teaching engineering. Based on these findings, the authors concluded that the IDC's curricular features were valuable for promoting engagement among the PSTs, and that those who took a prior or concurrent methods course were especially prepared to design student-centered learning activities that may promote PDE. The study shows promise for encouraging PSTs to foster PDE in future professional contexts by first having them experience PDE themselves in their TEP coursework.

Finally, Haverly et al. (2020) used the PDE framework to explore how novice teachers (in this case, two interns and one first-year teacher) can make space for students' sense-making. They suggested that equitable science classrooms are characterized by teachers distributing authority through shared ideas and treating these as *epistemic resources*. Through a comparison across the three classrooms, the authors concluded that newer teachers need better support to recognize idea-sharing moments as useful instances of sense-making, as opposed to ones of confusion or misunderstanding.

Compared to these mixed results in promoting PDE, attempts at getting pre- and in-service teachers to adopt expansive framing proved more successful. Stephens et al. (2022) reported on how an expansively framed PD program helped teachers make sense of new computer science (CS) concepts, while also fostering the teachers' own use of expansive framing in their practice. Over a 7-week course, teachers met with researchers weekly to collaboratively plan lessons from a computer science curriculum, *Expansively Framed Unplugged* (EfU). In a creative use of expansive framing, the curriculum leveraged learners' familiarity with board game play to introduce CS concepts that the learners would then transfer to coding activities. Researchers first established the curriculum's success in helping the teachers learn more about coding. They then tracked how the teachers incorporated the course's pedagogical practices in their own teaching. Analysis of teacher discourse with students showed that teachers enlisted the same expansive framing techniques they had learned and benefited from in their PD.

Benichou et al. (2022) studied teacher learning through an extended DBIR partnership for school-based citizen science. Citizen science involves framing settings and roles expansively such that participants become emerging authorities whose work adds to the knowledge of a broader scientific community. In a first iteration, teachers did not identify strongly with the practice and goals of citizen science, instead seeing the partnership as deepening their content knowledge and inquiry teaching practices. In a subsequent iteration, teachers worked more closely with scientists and had the opportunity to act as authorities in ongoing conversations among stakeholders across settings. They subsequently saw their work in the partnership as meaningful, not only to their own professional development, but also to outside scientific and educational communities. In addition, illustrative quotations from teachers showed that they expansively framed their own learning *and* teaching as they planned new school-based citizen science projects for students.

Finally, Hoidn's (2017) book on student-centered college classrooms voiced optimism about how expansively framed TEP contexts can promote teacher learning and transfer. Hoidn described several ethnographic case studies in which instructors drew on elements of both PDE and expansive framing. For example, teacher educators invited outside community members (experienced teachers, high school students, and young children) into their classes to share their own experiences in K-12 schools and to share insight on salient educational problems. Hoidn argued that this framing helped TEP students visualize how they might apply what they were learning to real-world classroom settings. The book also emphasized the extent to which learning is driven by students' questions and solutions that emerge as they struggle to make sense of course concepts, practice taking on authority, and defend their ideas in public discourse. Hoidn's case studies, then, suggest that PDE has significant learning benefits among TEP students, and that using expansive framing can encourage them to think about how they might use experiences from their TEP—especially those aligning with PDE—in future clinical settings.

Discussion

Several key trends emerged from this systematic review of studies applying the PDE framework and expansive framing to teacher education. First, the studies demonstrate positive effects of having pre- and in-service teachers experience PDE in their coursework, such as helping them apply learning theory to problems of practice (Engle & Faux, 2006). That said, experiencing PDE does not necessarily lead them to implement similar forms of instruction in their own classrooms. Studies that did encourage teachers to transfer the use of PDE into clinical settings were met with limited success (e.g., Ford & Wargo, 2007; Kawasaki & Sandoval, 2019; Windschitl & Thompson, 2006). Second, the available evidence suggests that expansive framing does appear to facilitate transfer of other disciplinary and pedagogical concepts from TEP or PD coursework to clinical practice (e.g., Stephens et al., 2022; Benichou et al., 2022). Future research could build on this potential, perhaps as one strategy for helping teachers more readily transfer their use of the PDE principles *themselves* into practice. Taken together, PDE and expansive framing offer promise for addressing longstanding challenges in teacher learning and transfer (e.g., Dreer et al., 2017; Fishman et al., 2022).

One question these findings raise is: Why were expansive framing principles more readily taken up in clinical practice than PDE principles were? It may be that implementing PDE requires more substantial shifts in teachers' epistemic orientations, whereas expansive framing can be practiced on some level simply by adjusting discourse—even while maintaining other, more traditional instructional approaches. Given the two frameworks' substantial overlap, we wonder if a strategy for facilitating the use of PDE in classrooms might be to first introduce teachers to expansive framing. If teachers develop the habit of encouraging their students to relate academic content to outside contexts and experiences, they are already fostering problematizing and authorship of ideas—two key elements of PDE. Other aspects of PDE might follow from there. Future research could look further into ways that PDE and expansive framing might be used together to support teacher learning and transfer.

Another explanation for the lack of teacher uptake concerns the ways the two frameworks were introduced in these studies. While the researchers based their interventions on PDE or expansive framing principles, most did not explicitly outline these principles for their teacher participants. Stephens et al.'s (2022) PD program encouraged teachers to use elements of expansive framing in their own instructional contexts and was ultimately successful. The authors, though, stopped short of demonstrating that the teachers formally used expansive framing as a cohesive instructional strategy. In this sense, the teachers experienced a specific kind of learning without fully appreciating the epistemological shifts required to foster such learning. This and other interventions fell short of helping the teachers understand PDE or expansive framing on a paradigmatic level and as a set of principled teaching strategies for future application in their classrooms.

That said, it is hard to tell just how well the teachers in these studies could apply these frameworks since almost none followed the teachers from the TEP or PD course into the field. Future research could prioritize longitudinal designs of this sort.

Conclusion

Based on our systematic review, we conclude that a nested approach to teacher education is worth exploring more rigorously: Designing teacher learning experiences as expansively framed applications of PDE, explicitly engaging teachers in understanding the design principles on an epistemic level, and directly encouraging them to apply PDE and expansive framing as pedagogical strategies when they plan for instruction themselves.

Framing teacher education expansively and with PDE's guiding principles clearly supports teachers' own learning. However, it is not in itself a guarantee that they appreciate the guiding principles explicitly, know how to design instruction in accordance with them, or that they should automatically want to do that. More research on if and how teachers transfer Engle's tenets into their own practice is needed to understand what is being done in the learning settings these educators create for their students—and why that is. Linking clinical observations to teacher learning that was originally designed for PDE and expansive framing could provide much needed insight. Until then, existing scholarship points to the immense potential of Engle's ideas for illuminating persistent challenges in teacher education.

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Infrastructuring Multilevel Connected Learning and the Agility for STEM Curriculum Innovation

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Abstract: Would teachers be able to respond with agility and remain on track in their education innovation initiatives in the face of unanticipated external disruptions? This study aims to understand whether and how teachers persist with the innovation efforts they have embarked on when macro-level crisis conditions hit, such as the emergency online teaching that was instituted for extended periods of time due to the COVID pandemic. This study uses the MultiLevel MultiScale (MLMS) model to analyze the infrastructuring efforts made by two schools that had engaged in the same school-university partnership innovation network before the COVID pandemic disruptions started but responded rather differently at the school level in the ensuing 1.5 years. The study finds that the infrastructuring work affected the scope within which teachers can stay on track with their innovation plans, and hence the resultant education innovation agility of a school.

Introduction

In an increasingly complex world, there are bound to be times when teachers and educators encounter fresh challenges and adverse situations that disrupt their plans as what we have experienced during the COVID-19 pandemic. For those schools that have been on track for developing innovative practices, how could they continue to steer education innovations when facing unanticipated threats and unstable situations? Education innovations such as the implementation of self-directed learning pedagogy entails changes in the practices of teaching and learning (Hew, et al., 2016). New practices might be lost easily if these are not accompanied by a continuous history of learning (Wenger, 1998). The capability to sustain education innovations in times of unanticipated crisis is necessary to persist in the strive for realizing significant advances in educational vision and values. This study explores how schools can be agile to stay on track with their educational innovation initiatives even in times of high uncertainties. This could contribute to building knowledge for educators and school leaders to think about how to sustain education innovations in times of crisis.

The call for steering education innovations in unstable situations resonates with the need for agility in the high-tech industries in order to make appropriate innovative responses as the industry exposes itself to unpredictable market volatility and change (Nissim & Simon, 2020). Agility entails flexibility in managing uncertainty (Stigler, 1939) for sustainable organizational change (Worley, et al., 2014), with the capacity to manage its resources in changing contexts to be able to innovate and secure valuable outcomes (Teece et al., 2016). In education, agility requires teachers to approach teaching and learning with a flexible attitude to develop new mindsets for implementing innovations and making change (Nissim & Simon, 2020). The agility also calls for the generation of innovative practices based on existing educational values and visions (Kidd & Murray, 2020). Thus, education agility can be conceptualized as the capability of spearheading change to realize the desired educational visions and education outcomes despite unanticipated obstacles in times of high uncertainties.

Research on agility in education has been focused on individual attributes such as agile leadership (Nissim & Simon, 2020) or individual learning agility (Lombardo & Eichinger, 2000; Özgenel & Yazıcı, 2021). While these studies show us the importance of individual capacity to spearhead education innovations in difficult times, we lack knowledge about the conditions for individuals to learn in sustaining education innovations under challenging circumstances. As teachers are key agents in changing practices, we are particularly concerned about conditions for their learning in times of stress. Wenger's (1998) communities of practice construct highlights the situatedness of learning in the workplace. Thus, conditions in the workplace are also learning conditions which could affect how teachers learn to achieve education agility. The conditions for situated learning (Lave & Wenger, 1991) through the negotiation of meaning in communities of practices are conceptualized as architectures for learning (Wenger, 1998). Teachers could be in multiple communities of practices and their learning interactions can be in different settings such as within the boundary of a community or crossing boundaries of communities for achieving aligned outcomes of education innovations (Stein & Coburn, 2008). Their learning can be affected by architectures for learning across different settings. A systems view is thus needed for understanding how to support teacher learning for changing their practices through changes in their situated environments.

Curriculum and pedagogical innovations introduce changes to the goals and practice of education, as well as the roles of teachers, students and other stakeholders that require changes in terms of organizational routines, support services, and technology infrastructure for them to become sustainable and scalable (Law, et al., 2021). The implementation of innovations is a dynamic process that requires continuous efforts on (re)designing infrastructures such as reform-related policies, allocation and management of human and technological resources, curriculum materials and school routines, etc. to ensure that the innovation stays on track. Such efforts are referred to as infrastructuring (Penuel, 2019). Within a systems view, the infrastructuring work could also be conceptualized as a process of *learning*—a process of evolving changes at different levels and parts of the system in the process of adapting to the broader environmental context. Law, et al. (2015) identified four key components within the context of educational innovations that are crucial to the scalability of such innovations—the organizational structure, interaction mechanisms, reification artifacts and technology—which they refer to as the architectures for learning (AfL). Infrastructuring work is about intentional adjustments in the architectures for learning. It is contextual and needs to respond to changes at different levels of the system.

While there cannot be a one-size-fits-all set of architectures for learning for any kind of innovation context, there could be principles to guide infrastructuring work for teacher learning to achieve aligned changes at different levels. Law, et al. (2015) put forward a Multilevel MultiScale (MLMS) model that can be used to analyze the architectures for learning within a research-practice partnership (RPP, Coburn & Penuel, 2016). The MLMS model also provides a set of guidelines for evaluating whether the architectures for learning contain weaknesses that might cause the infrastructuring efforts to fail in achieving scalability.

The purpose of our study is to explore the relationship between the efforts of infrastructuring on architectures for learning and education agility in terms of teachers' ability to persist on their course of educational innovation in situations of high uncertainties and volatility. The study was conducted within the context of a School-University partnership innovation Network for advancing self-directed learning in STEM subjects in Hong Kong (to be referred to as the SDL-STEM Network). When the COVID-19 pandemic first struck the city, these Network schools responded differently but most of them were able to get back on track for their set innovation goals at the end of a 1.5 years of disruption (Ko, et al., 2022). Two schools (X and Y) were selected from among those schools that got back on-track to resume their SDL-STEM innovation commitment for the purpose of this study. Both schools were similar in having engaged in the Network for years and showed demonstrable progress on their innovation trajectory before the pandemic. Teachers in School X developed high confidence in the face of uncertainties and had developed a larger scale of innovation implementation for SDL-STEM during the 1.5 years tracked by this study. On the other hand, the SDL-STEM initiatives were stalled in School Y initially, but teachers were able to implement a new SDL-STEM curriculum unit in the end and the school was prepared for scaling up related educational innovation with the introduction of a new subject in the new school year (2021-22). We analyzed the features of the infrastructuring work undertaken by both schools using the MLMS framework, as well as the motivations and goals underpinning their infrastructuring efforts, to explore whether and in what ways the infrastructuring features influenced the schools' agility in staying on track in the SDL-STEM innovation. We use the following two research questions to guide the investigation.

RQ1: What changes in the architectures for learning (i.e., the infrastructuring work) took place in the two schools from the start of face-to-face class suspension to the end of the study period?

RQ2: Is there a relationship between a school's infrastructuring work and associated teacher learning as well as the innovation outcomes in terms of the initial innovation goals?

Conceptual framework

Education innovations invoke changes in infrastructures as well as practices of learning and teaching. A change in infrastructures is needed to support changes in practice as learning is affected by the changing socio-historical contexts (Wenger, 1998) as well as the changing sociocultural and technical aspects of their situated environments in the system (Law, et al., 2016). With an ecological perspective, the adaptation and sustainability of changing practices require *changes as learning* at multiple levels such as policy, school, teacher and student levels in a system, and changes at one level could affect learning conditions at other levels (Davis, et al, 2013; Law, et al., 2016). While teacher learning is needed for developing new practices to shape learning conditions at the student level, their learning is also shaped by the changing infrastructures around them as informed by the situated learning theory (Lave & Wenger, 1991). Infrastructuring work is about the design of the conditions for the development of new practices in a system through changing the infrastructures. Infrastructures, for example assessment materials, school schedules, teacher professional development support, organizational routines (Penuel, 2019), are hidden substrates to ensure the smooth running of certain practices and standards within a community (Bell, 2019). They are taken for granted until they must be re-designed for building the appropriate capacity or conditions for the accommodation of new practices. The aim of infrastructuring work is not merely to sustain a single innovation but about building the capacity of people and systems for the changing practices (Penuel, 2019). Capacity building entails learning processes among different change agents and requires conditions for learning to align with the goals of the changing practices. The re-design of infrastructures cannot be a top-down process but should engage teachers in the inquiry and co-design process for it to contribute to capacity building (Penuel, et al., 2023). Positioning teachers and school leaders as learners for advancing education innovations, their agency and decision-making power are of great importance in the infrastructuring work.

We connect infrastructuring work (Penuel, 2019) with the concept of architectures for learning (Stein & Coburn, 2008; Wenger, 1998) as both are concerned about the design of learning conditions for capacity building and underpinned by sociocultural learning theories. The concept of architectures for learning focuses on supporting learning through the negotiation of meaning achieved via participative interactions and reification in communities of practice (Wenger, 1998). Law, et al. (2015) identified four key components of architectures of learning that shape participation and reification in learning interactions: organizational structures, interaction mechanisms, reification artifacts, and technology. Organizational structures such as subject departments determine who participates in decision making for specific levels of issues and who would take responsibility for effecting the action. Interaction mechanisms formalized through routines, such as co-planning meetings, facilitates people to get together and interact with regard to specific foci. Reification artifacts hold outcomes of prior negotiated meaning, propagate meanings, and create focal points for communication and negotiation (Wenger, 1998). Technology as a component of architectures for learning has its potential role as reification artifacts and as a platform for creating interaction mechanisms. These components could constitute categories of infrastructures for supporting learning in relation to specific work practices. We hypothesize that effective infrastructuring work should foster architectures for learning to give impetus to three building blocks for learning in practice as proposed by Wenger (1998): engagement, imagination, and alignment. Engagement means learners' contribution to the community they are in and their collaboration with others to achieve shared objectives. Imagination allows learners to explore and know where they are and to which direction they are moving. This relates to the sharing of visions in the community. Alignment allows learning communities to expand their horizons and cross boundaries to make contributions to broader objectives on a larger scale.

We use the MLMS model (Law, et al., 2015) as an analytical framework to examine how the infrastructuring work was carried out via the architectures for learning and how it affected teacher learning and education agility. The MLMS model with an ecological perspective gives a structure to examine infrastructuring work in terms of changing components of architectures for learning at multiple levels with a systems view. Cross-level interactions are necessary to ensure the alignment of reform goals (Stein & Coburn, 2008). The learning outcomes at one level could become or affect learning conditions at other levels (Law, et al., 2016). Hence successful alignment implies a series of connected changes at multiple levels. The MLMS model differentiates scales of learning interactions through defining the richness of idea diversity in the process grounded by the theory of knowledge building (Scardamarlia, 2002). The "scale" of learning interactions within the MLMS model refers to the diversity of interacting organizational units within the same level. The idea diversity becomes much richer with more members from diverse backgrounds co-participating in the design process. Members from the same community of practice share a similar history of learning for the continuation of within-unit practices but they have opportunities to learn new ideas for practices when they cross the boundary unit to interact with members from other units (Wenger, 1998). Cross-unit (i.e., cross-school/organization in this study) interactions thus increase the "scale" of the professional exchanges, facilitating more democratic sharing of diverse ideas and negotiations of meaning. However, schools are autonomous, self-governing entities regarding their own architectures for learning and cross-unit interactions cannot directly make decisions regarding within-school changes. To arrive at infrastructuring decisions that address the tensions experienced by teachers and school leaders at different levels, the innovation process requires the availability of within-unit mechanisms for co-participation and appropriate reification. Thus, the MLMS model provides a framework for analyzing infrastructuring work of schools with attention to teachers' and school leaders' agency in learning and making change.

Research method and design

Research context

The investigation reported here is situated in a larger design-based implementation research (DBIR) study in a 2.5-year charity-funded university-school partnership programme to advance integrated STEM education with pedagogical approaches informed by self-directed learning (Hew, et al., 2016; Knowles, 1975). The programme involved a network of 32 government-funded primary and secondary schools when the pandemic started, which was about a year after the project was launched. The design of the Network was informed by the MLMS model that architectures for learning at network, school (leadership) and teacher levels are necessary to support teachers' curriculum and pedagogical innovations to deliver self-directed learning (SDL) experiences for their students through curriculum units that span more than one STEM discipline (referred to as integrated STEM). At the start of the COVID-19 crisis, the Network re-designed its own infrastructures, including setting up emergency online meetings as *interaction mechanisms* for school leaders and teachers in the Network to share experiences of the challenges encountered and strategies that were successful in addressing them. The sharing and co-inquiry covered issues at various levels, such as school policy and routines, technology arrangements and support for teachers and students, including strategies to detect cases of hardship and stress among students during school suspension, and ways to provide socioemotional support within the school community. The Network collated the shared situated knowledge under thematic headings and set up a dedicated website for open dissemination of *reification artifacts*. Shortly after addressing the most pressing crisis management issues, the pre-pandemic monthly Network teacher professional development events resumed, but took place using both synchronous and asynchronous online *technologies.* By refocusing the Network activities on the SDL-STEM project goals via alternative channels of communications and interactions, the University partner also wanted to model how the use of technology could be designed to support online STEM learning. Each Network school was originally committed to the development of STEM curriculum units with dedicated support from a Network consultant assigned by the university team. However, schools had full autonomy in determining their innovation pathway. During the pandemic, the Network schools could re-design their own new strategies, and the mode and frequency of school-based co-planning meetings, lesson observations and open classrooms. Among the 30 schools participating in the two innovation networks supported by the same university team throughout the 1.5 years from the onset of the COVID-19 pandemic, 26 schools were able to resume the design and implementation of SDL-STEM innovations by the end of that period (Ko, et al., 2022). The selected two case study schools, X and Y, were among these 26 schools for in-depth examination of their infrastructuring work during this period.

Methodology, sampling, data sources and analysis

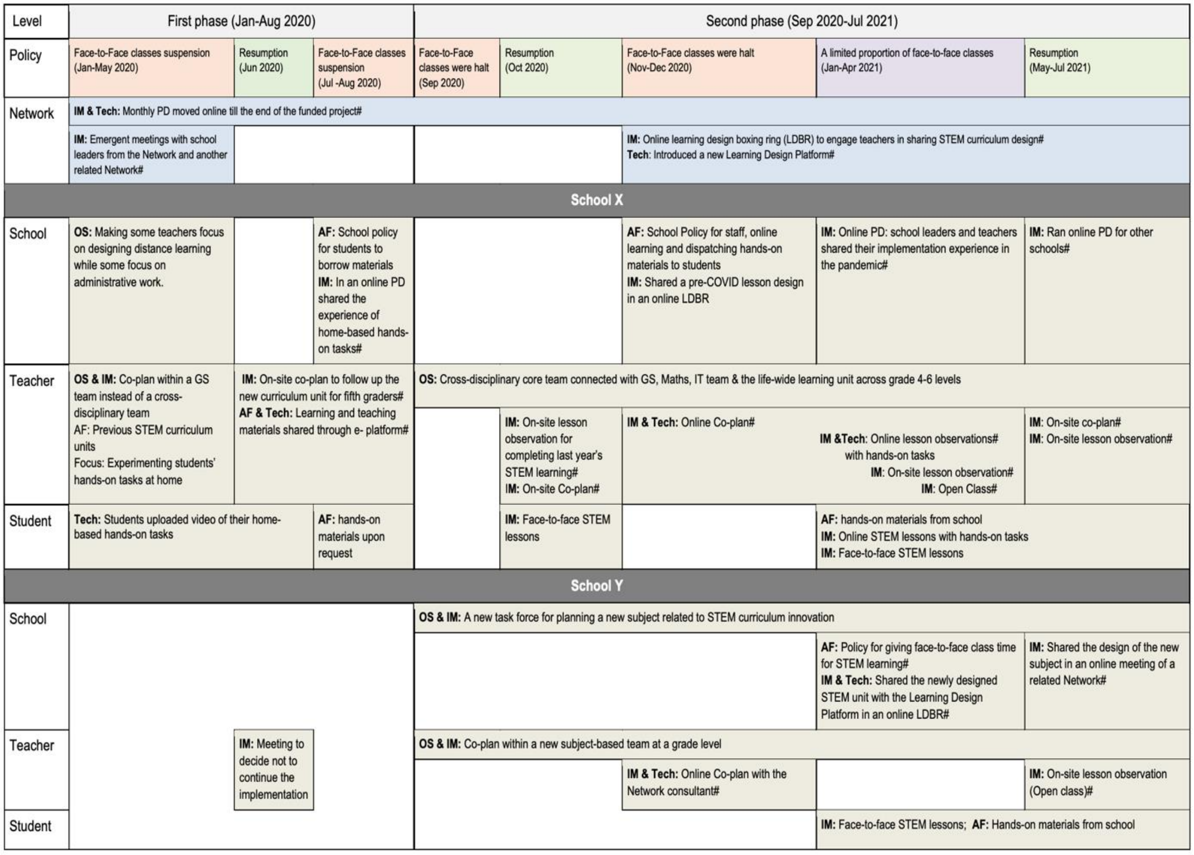
The investigation adopted a qualitative case study methodology (Yin, 2003) with comparative analysis of teacher learning in two different schools. A comparative case study method is suitable for investigating cases with common relevant characteristics or interests through comparing commonalities and differences in actions through time (Miles, et al., 2020) to find out the "predictable reasons (a theoretical replication)" (Yin, 2003, p.47). A two-case comparative analysis is a heuristic design that identifies features more responsible for the generation of specific outcomes. The two schools in this study, X and Y, were purposefully selected as they were among the successful schools in staying on track for the innovation during the crisis. Both are primary schools that had been collaborating with the university team for 3 and 4 years respectively, which include collaborations in prior funded Networks for self-directed learning before joining the current SDL-STEM innovation Network. Multiple data sources were used for examining these schools' infrastructuring work as well as their teachers' engagement in STEM curriculum innovation during the study period of 1.5 years from the pandemic outbreak. Data used in this study include transcriptions of interviews with principals and teachers held at the end of each academic year, transcriptions of teacher sharing during Network meetings, fieldnotes, audio-recordings of co-planning meetings, video-recordings of lesson observations, and transcriptions of debriefings in the two schools.

We investigated changes in infrastructures during the study period in two phases based on the academic school year as it was a common practice for schools to revise their yearly plan in preparation for a new academic year. The first phase was from the end of January to August 2020, starting from the first school suspension due to COVID-19 until the end of that school year. The second phase was from September 2020 to July 2021. We took several steps to analyze schools' efforts on infrastructuring work for teachers to have learning opportunities to face unanticipated challenges. As learning brings changes (Law, et al., 2016), we first coded the data of interviews, debriefings and teachers' sharing collected in the two phases to identify (i) the learning conditions and outcomes and (ii) challenges at different levels in each of these two phases, which allowed us to identify changes, if any. Aligning with our focus on infrastructuring, we categorized the changes under the four architectures for learning components: organizational structures, interaction mechanisms, artifacts, and technology (Law, et al., 2015). Adopting an ecological perspective, we also investigated the relationship between learning conditions and the changes effected (learning outcomes) to meet the challenges encountered at different levels. Importantly, we analyze the schools' infrastructuring strategies within the context of their modified innovation visions and goals in the face of mega-scale disruptions due to the extended periods of pandemic-induced school suspension.

Findings

Right before the pandemic hit, both schools X and Y targeted to build teacher capacity for STEM curriculum development with self-directed learning as a pedagogical approach of choice, but they had different strategies and major concerns. The principal in school X emphasized on making progress in the development of STEM education with hands-on and technology-facilitated STEM activities. Teachers from different subject departments engaged in and shared the responsibility of developing these curriculum innovations. The innovation focus of Principal Y was on building teacher capacity to scaffold inquiry learning and to foster an innovative mindset among students. In past years, different novice teachers in School Y were assigned to work with experienced teachers in the school-based project team as an innovation diffusion strategy to build teacher capacity beyond the STEM subjects. When the COVID-19 pandemic struck, both schools maintained their engagement in the scheduled Network meetings. However, both schools were unable to continue their original plan to design and implement STEM innovation curriculum units during the first phase of class suspension. On the other hand, teachers in both schools were able to innovate, develop and implement new STEM curriculum units in the second phase. School X teachers developed the capacity and confidence to implement STEM curricula with hands-on activities despite the having to teach fully online. School Y embarked on a school-based curriculum reform by spearheading the creation of a new school subject to foster students' 21st century skills throughout the six primary grades, and involving the efforts of the entire school in scaling-up the concept of curriculum integration based on their experience with STEM integration. Figure 1 provides an overview of the infrastructuring work across the two phases in schools X and Y respectively, showing only key changes in the architectures for learning components at school (leadership), teacher and student levels in relation to the SDL-STEM innovation focus in the Network. In the following part, we will answer the two research questions by first highlighting changes in the architectures for learning and challenges faced by teachers in the two schools, and then relate their infrastructuring work to teacher learning and innovation outcomes in times of uncertainties.

Figure 1
An overview of infrastructuring work in schools X and Y across the two phases; Key: 1. OS = organizational structure; IM = Interaction mechanism; AF = Reification artifact; Tech = Technology for teaching and learning; 2. cross-unit interactions between the school and other Network members are marked with #.



Level	First phase (Jan-Aug 2020)			Second phase (Sep 2020-Jul 2021)				
Policy	Face-to-Face classes suspension (Jan-May 2020)	Resumption (Jun 2020)	Face-to-Face classes suspension (Jul -Aug 2020)	Face-to-Face classes were halt (Sep 2020)	Resumption (Oct 2020)	Face-to-Face classes were halt (Nov-Dec 2020)	A limited proportion of face-to-face classes (Jan-Apr 2021)	Resumption (May-Jul 2021)
Network	**IM & Tech:** Monthly PD moved online till the end of the funded project#							
	IM: Emergent meetings with school leaders from the Network and another related Network#					**IM:** Online learning design boxing ring (LDBR) to engage teachers in sharing STEM curriculum design# **Tech**: Introduced a new Learning Design Platform#		
School X								
School	**OS:** Making some teachers focus on designing distance learning while some focus on administrative work.		**AF:** School policy for students to borrow materials **IM:** In an online PD shared the experience of home-based hands-on tasks#			**AF:** School Policy for staff, online learning and dispatching hands-on materials to students **IM:** Shared a pre-COVID lesson design in an online LDBR	**IM:** Online PD: school leaders and teachers shared their implementation experience in the pandemic#	**IM:** Ran online PD for other schools#
Teacher	**OS & IM:** Co-plan within a GS team instead of a cross-disciplinary team AF: Previous STEM curriculum units Focus: Experimenting students' hands-on tasks at home	**IM:** On-site co-plan to follow up the new curriculum unit for fifth graders# **AF & Tech:** Learning and teaching materials shared through e- platform#		**OS:** Cross-disciplinary core team connected with GS, Maths, IT team & the life-wide learning unit across grade 4-6 levels				
					IM: On-site lesson observation for completing last year's STEM learning# **IM:** On-site Co-plan#	**IM & Tech:** Online Co-plan# **IM &Tech**: Online lesson observations# with hands-on tasks **IM**: On-site lesson observation# **IM**: Open Class#		**IM**: On-site co-plan# **IM**: On-site lesson observation#
Student	**Tech:** Students uploaded video of their home-based hands-on tasks		**AF:** hands-on materials upon request		**IM:** Face-to-face STEM lessons		**AF:** hands-on materials from school **IM:** Online STEM lessons with hands-on tasks **IM:** Face-to-face STEM lessons	
School Y								
School				**OS & IM:** A new task force for planning a new subject related to STEM curriculum innovation				
							AF: Policy for giving face-to-face class time for STEM learning# **IM & Tech:** Shared the newly designed STEM unit with the Learning Design Platform in an online LDBR#	**IM:** Shared the design of the new subject in an online meeting of a related Network#
Teacher		**IM:** Meeting to decide not to continue the implementation		**OS & IM:** Co-plan within a new subject-based team at a grade level				
						IM & Tech: Online Co-plan with the Network consultant#		**IM:** On-site lesson observation (Open class)#
Student							**IM:** Face-to-face STEM lessons; **AF:** Hands-on materials from school	

Infrastructuring work in school x

In the first phase, team teachers in school X faced the challenge of designing distance learning as they had no experience in conducting online lessons. The initial infrastructuring work featured in school X was a change in organizational structures to enable some teachers in the school to focus on re-designing the learning tasks to make use of technology so that they can be conducted at a distance. The cross-subject teacher team reverted to work in subject-based teams to focus on the exploration of how to facilitate students' self-directed learning at a distance during school suspension. The second feature was the use of an existing reification artifact facilitate imagination. Instead of moving on with the development of the new curriculum unit, teachers used a previous STEM curriculum unit and imagined how that could be adapted for implementation in the home-based learning conditions. They then engaged in the experimentation of home-based hands-on learning. Some students were able to conduct home-based investigations and uploaded videos for teachers to examine. Engaging in the exploration process made teachers affirm the plausibility of home-based hands-on learning while feeling discontented about how students' engagement had been limited by the materials students had access to. Teachers' discontent in the exploration stage contributed to changes in school level infrastructures for student learning such as delivering hands-on materials to students in later implementations. The initial infrastructuring process of the School in the second phase was the revitalization of a nested organizational structure for the innovation with a cross-subject team to spur more teachers to be involved in the curriculum innovation process at three different grade levels. This was followed by a re-emphasis of the school-level goal of self-directed learning (a school-level reification) which became a common language among leaders and teachers. The third infrastructuring move was the enhancement of multidirectional cross-unit interactions for building teachers' innovation capacity. The vice-principal and curriculum leaders created more beyond-unit interactions between teachers and the University-based Network consultant to facilitate the generation of new solutions in the face of uncertainties in the resumption of face-to-face classes. The teacher team enhanced their ability to use technology to manage and negotiate meanings through reification artifacts such as lesson designs among team members and with the Network consultant. With improved competence in conducting online lessons, teachers further experimented with ways of conducting hands-on synchronous lessons. At the school-level, learning outcomes were evidenced by the generation of guidelines for online lessons and the increase in funding for home-based hands-on learning materials. These developments provided opportunities for students to demonstrate their abilities in using technology for interactive learning. The teachers' enhanced competence was reflected through their sharing during online Network events.

> "After we made preparations for a physical classroom, we would think about what can be implemented online that we can do the same, and what can be replaced with some virtual means… so we will prepare a little more, and we can solve problems in the face of different situations" (Teacher X5, project team teacher, in Jul 2021 year-end interview)

Infrastructuring work in school y

At the start, similar to school X, team teachers in school Y lacked experience in conducting online lessons during the first phase. A new STEM curriculum unit scheduled to be implemented was halted in response to the first period of stipulated school suspension. Cross-school and within-school interaction mechanisms for STEM curriculum innovation diminished in the first half year. When the face-to-face classes resumed during the first phase, teachers found difficulties in re-arranging the provision of materials to individual students when students could not work in groups due to the need for social distancing within physical classroom settings. There was also a growing tension between time for catching up with the planned teaching schedule in the subject curriculum and time for the innovation implementation. Teachers decided not to continue the implementation despite feeling disappointed by the inability to realize the designed self-directed STEM learning opportunities for their students.

In the second phase, the original project team was replaced by two parallel strands of infrastructuring. First, the school set up a subject-based team with novice and experienced project teachers to take responsibility for the development of a new SDL-STEM curriculum unit, the scope of which was confined within a single school subject for one grade level. In parallel, the school established a cross-disciplinary task force to focus on the imagination and preparation of a new school subject to foster the development of 21st century skills (such as critical thinking, communication, collaboration, and creativity) to be delivered to students at all grade levels. This initiative was embarked upon to realize the implementation of curriculum integration with self-directed learning beyond STEM subjects. The principal engaged some existing and former project team teachers with experience of curriculum integration gained through the Network project to contribute to this new initiative.

The two initiatives described above were in fact connected. The new STEM curriculum unit which was underway in the second phase constituted one component in the new subject on 21st century skills. Co-planning meetings were resumed for the design of the new STEM curriculum unit. The project coordinator was able to arrange an online co-planning meeting with the Network consultant. When there was a change in the territory-wide policy about giving schools discretion to run a limited proportion of half-day face-to-face classes, the school decided to allocate some regular face-to-face class time for the STEM curriculum unit, indicating the priority given to removing the obstacles in conducting hands-on learning activities in the innovation implementation. After that, teachers were able to implement the newly designed curriculum unit and later to conduct an open class for learning together with other Network schools. Throughout the implementation experience, teachers felt discontented with the time constraint to implement STEM education within a conventional subject in the pandemic as they understood the provision of self-directed learning opportunities in STEM required time. Unlike school X, teachers in school Y did not learn how to run online hands-on STEM lessons. However, the instructional time constraint felt by teachers when innovating STEM education in the pandemic became a support for the school's infrastructuring work of a new subject in which more lesson periods would be allocated for STEM learning. Teachers felt optimistic with the new subject and were prepared to re-design curriculum units to extend self-directed learning opportunities for students with the concept of curriculum integration for the year ahead.

Comparison between schools x and y

A comparison between schools X and Y illustrates how infrastructuring work could influence teachers' learning trajectory and hence their agility in staying on track in curriculum innovation under crisis situations. Their agility is supported by a determined intention to scale up innovation despite being in difficult situations. The infrastructuring work in the two schools were respectively driven by different educational priorities. According to the principal in School X, their innovation was driven by a focus on enhancement of self-directed learning with hands-on STEM learning through pedagogically appropriate integration with e-learning as a visible outcome or "end-product". The work in school Y was driven by a focus on curriculum integration and self-directed learning by building on their experiences in STEM innovation. To achieve their respective focal visions and goals, infrastructures were instituted to support imagination, engagement, and alignment (Wenger, 1998). School X set up a renewed organizational structure in the first phase for teachers to focus on technology-enhanced pedagogical innovations. Teachers imagined home-based hands-on learning with existing STEM lesson design and engaged in experimenting new ways for students to engage in STEM inquiry. Their design principle aligned with the goal of self-directed learning at both school and network levels. School Y set up a task force to imagine and plan for a new subject which was aligned with the overall educational goal of the original project but their ambition went beyond STEM education. Previous designed curriculum units were used to facilitate imagination. Previous and new project teachers engaged in the innovation process despite the mega-scale pandemic disruptions.

Infrastructures at different levels necessarily change through multilevel multiscale connected learning. For example, the change in organizational structure in school X at the school level facilitated the exploration of home-based hands-on learning at the teacher level in the first phase. Responses from students and teachers' discontent led to school-level funding support increase for hands-on materials in the second phase. Guidelines for online lessons at the school level facilitated learning interactions during the synchronous hands-on lessons at student and teacher levels in the second phase. While school Y teachers faced severe instructional time constraints in designing STEM curriculum units within a subject-based team during the pandemic, a new task force at the school level was in place for developing a new subject as a new infrastructure to enrich self-directed learning opportunities and curriculum integration for the development of students' 21st century skills. When learning across levels is connected, teachers' discontent could stimulate or support emerging changes in infrastructures.

Conclusion and implications

Guided by the MLMS model, we examined the infrastructuring work of two schools in terms of changes in architectures for learning at school leadership, teacher, and student levels. The differences between schools X and Y in (re)designing components of architectures for learning illustrates how the educational goals and foci underpinning infrastructuring work could affect how teachers learn and the ensuing innovation outcomes in times of crisis. Infrastructuring work in both schools are characterized by the provision of opportunities for imagination, engagement, and alignment (Wenger, 1998) for learning and achieving innovation agility. While infrastructuring cannot be prescribed, it can be guided by design principles for multilevel multiscale connected learning to achieve dynamic alignment for innovation advancement. This study was limited to the exploration of infrastructuring work in two schools with substantial experience of engaging in education innovations in the same Network. Analysis of the infrastructuring work using the MLMS framework shed light on how these two schools were able to stay on track with connected learning at multiple levels and within/across units but with different developmental foci. Further research is needed to explore the value and limitations of this framework in its application to the analysis of infrastructuring among a wider spectrum of schools with different responses to crisis situations. More research is needed to understand the agility of schools and teachers in responding to crisis situations and its relationship to infrastructuring design to enrich the literature on the scalability of education innovations.

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Critical Data Storytelling through Photography

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Abstract: Understanding why and how to support claims with data is a key challenge in scientific inquiry. We propose that arts-integrated approaches to data literacy have potential to increase engagement in data reasoning and support students in making data-based arguments. We co-designed a data storytelling unit, which aimed to engage 8th-grade students with their neighborhoods through photography and data. We asked: (1) How did students reason about data in their artist statements? (2) How did students use artistic strategies to communicate a message in their photo-essays? and (3) In which ways do data reasoning and artistic strategies co-occur in photo-essays? Based on qualitative analysis of 20 photo-essays, we found that students operationalized socio-scientific concepts through use of *variety*, highlighted differences within or between neighborhoods through *contrast*, and synthesized quantitative and qualitative data through *pattern*. Findings suggest that connecting artistic strategies and data reasoning practices generates opportunities for critical data literacy.

Introduction

The ability to ask questions, analyze and interpret data, construct evidence-based explanations, and engage in argument from evidence is essential to scientific literacy (National Research Council, 2013) and for societal engagement more broadly. Creating and interpreting data visualizations are key practices in making evidence-based claims that relate one or more variables to an outcome variable (i.e., scientific explanations). In middle school, students might construct a scatterplot to investigate whether the relationship between two variables is linear/non-linear and strong/weak; consider and interpret data represented in maps and histograms; or collect their own data. Yet students commonly struggle to support claims with evidence. They may fail to justify conclusions, consider the limitations of data, or support arguments with specific data (Hug & McNeill, 2008; Sandoval, 2003). Students may also approach "data as something to be explained but not as a necessary component of an argument" (p.41; Sandoval, 2003). More research is needed to explore how integrating data reasoning and artistic practices might support students in constructing data-based arguments.

Data storytelling is an interdisciplinary practice that supports *data literacy*, or "the ability to read, work with, analyze, and argue with data as part of a larger inquiry process" (p.84; D'Ignazio & Bhargava, 2018). Data stories integrate visual and narrative elements to engage an audience with data. Stories often elaborate on graphs, explaining what choices were made during data analysis, why a question is worth investigating, or the results of data analysis (Wilkerson et al., 2021). These visual narratives or arguments often highlight the people behind the data (e.g., the data storyteller or communities represented by the data) and aim to connect data to lived experiences (Lupi & Posavec, 2016). Data storytelling, therefore, has potential to challenge neutral, objective conceptions of data and support students in building *critical data literacy*, or using or producing data in ways that consider, highlight, or challenge inequities in social or environmental contexts (Philip, 2013; Bhargava et al., 2015; Tygel & Kirsch, 2016; Pangrazio & Selwyn, 2019; D'Ignazio & Klein, 2020). We suggest that data storytelling is particularly relevant for engaging students with data in non-math contexts and that more research is needed to investigate the role of artistic practices and materials in making sense of data.

In this study, we investigated how middle school students connected data reasoning with artistic strategies through the construction of photo-essays. Photography has been used in education to critically engage students with their community (e.g., photo-voice) as well as help students see mathematical relationships in everyday contexts (Meier et al., 2018; Rizzo et al., 2019). Yet in these studies, participants do not engage with quantitative data nor attempt to connect data reasoning to artistic strategies (i.e., principles of design, composition strategies, and elements of art). Photographs are used as a tool for elicitation rather than argumentation. To support argumentation, we build on documentary photography, which has a history of bringing attention to hidden stories and social issues by highlighting the lived experiences of people. Dorothea Lange brought public attention to the lives of poor, migrant workers during the Great Depression (e.g., *Migrant Mother, 1936*), Henri Cartier-Bresson captured “decisive moments” to elevate everyday street life, and Eugene Smith chronicled the everyday lives of individuals through a series of photos (e.g., *Country Doctor, 1948*). In more recent years, Wendy Ewald and Tony Diefell collaborated with students, who are frequently subjects of images, to represent themselves and their needs through photography (Klingensmith, 2016). However, the increasingly personal ways that data impact our everyday social interactions presents new challenges for documentary photography and data storytelling. We explore how integrating these practices might support critical perspectives about data.

Background

Data stories are syncretic texts; they create potential for new forms of action by connecting practices that are often in tension, such as everyday and formal practices or practices in art and STEM disciplines (Gutierrez & Jurow, 2016). Data storytelling activities implemented in non-math contexts can lead to sense-making, critical questions about how data are produced and used, and data wrangling (Wilkerson & Laina, 2018; Stornaiuolo, 2020; Kahn, 2020). For example, 7th grade students in a science classroom drew on their lived experiences to generate new lines of inquiry and ask critical questions about how data were produced (Wilkerson & Laina, 2018). High school students in a media arts maker space integrated data inquiry and visualization with design and storytelling to investigate how they spend their time (Stornaiuolo, 2020). Researchers found that students expanded their ideas about what counts as data (e.g., narratives, art, social interactions), seeing everyday experiences as opportunities for data collection. Students also widened their conceptions of how data can be used, for example, to know something, to learn about themselves, or learn about issues that matter to them (Stornaiuolo, 2020). A third study, which engaged youth in connecting family stories of migration to U.S. census data, found that data storytelling prompted students to engage in data wrangling (Kahn & Jiang, 2021). We build on these findings by designing opportunities to engage students in explicitly connecting data with artistic techniques and strategies used in photography.

Visual artists draw on an understanding of elements of art, principles of design, and composition strategies to construct meaning in their artworks (National Coalition for Core Arts Standards, 2014). Principles of design like variety, contrast, and pattern emerge through the organization of elements of art and use of composition strategies (J. Paul Getty Museum Education Staff, 2023a). Data storytellers who build on photography often find ways to connect quantitative data to photos that highlight everyday places, events, and routes; potential social and environmental consequences; or physical experiences and emotion (Segal, 2015; Field, 2021). These strategies mirror critical approaches to data visualization, such as those described by Data Feminism. Data Feminism is an approach to data “informed by direct experience, by a commitment to action, and by intersectional feminist thought” (p.10; D'Ignazio & Klein, 2020). The seven principles of data feminism include: (1) examine power, (2) challenge power, (3) elevate emotion and embodiment, (4) consider context, (5) challenge binaries and hierarchies, (6) embrace pluralism, and (7) make labor visible. We build on the principles of Data Feminism as a framework for critical data literacy, because they offer concrete design challenges and criteria that are relevant to visualizing data.

We designed opportunities to engage students with principles of Data Feminism by integrating data analysis into an art classroom, engaging students in telling data stories about their neighborhoods, and using photography as a tool for data collection, inquiry, and visualization. In their review of data literacy curricula, Lee and colleagues (2022) identified similar design characteristics that supported engagement with various principles of Data Feminism. Researchers also suggested designing for critical engagement by creating opportunities for students to reflect on how data are produced and measured, identify disparities within or between neighborhoods, and make arguments for change. In this study, we ask: (1) How did students reason about data in their artist statements? (2) How did students use artistic strategies to communicate a message in their photo-essays? and (3) In which ways do data reasoning and artistic strategies co-occur in photo-essays? This study offers insights into how arts-integrated data literacy units might engage students in constructing data-based arguments that use or produce data in ways that consider, highlight, or challenge inequities in social or environmental contexts.

Methods

Participants and context

In this study, we discuss findings from Year 2 of co-designing an arts-integrated data literacy unit investigating the question, “What contributes to a healthy neighborhood?” Participants included 20 eighth graders from a private middle school in a large urban area with a predominantly Latine and Black or African American population (85%). About 70% of students who attend the school are eligible for a free-or-reduced-price lunch. The initial curriculum was co-designed by two teachers, one who taught art and PE and one who taught math and ELA, during Year 1 (Amato, 2022). Teachers aimed to engage students in creating and interpreting scatterplots from community data, constructing stories inspired by data, and recognizing how art can be used for multiple purposes (e.g., to advocate for change or engage in inquiry). The second iteration, led by the art teacher, had a greater focus on artistic practices: (1) Students had three structured photography activities (vs. one photo walk), (2) lessons discussing elements of art, principles of design, and composition strategies were added, and (3) student writing was framed as an artist statement (vs. a letter) and supported with professional models and guidelines for introducing an artwork through description, reflection, and analysis (J. Paul Getty Museum Education Staff, 2023b).

Unit description

In this 13-day arts-integrated data literacy unit, which ran for 5 weeks, students were asked to create photo-essays in response to the prompt, "What contributes to a healthy neighborhood and why should people care?" Students engaged in the unit primarily in art/PE classes (8 classes total, one to two 45-minute classes/week). Individual lessons which focused on data analysis and writing were further supplemented with class time in math (3 classes) and ELA (2 classes). The unit included the following key activities:

1. **Introduction to data storytelling:** Students are introduced to the driving question and to the practice of data storytelling through the discussion of model photo-essays.
2. **Photo-walk 1:** "Tell a story about your neighborhood in three photos." This activity included in-class reflection: identifying key themes in photos, explaining how photos connect to the driving question, and constructing statistical questions to explore in their photo-essays.
3. **Analysis of neighborhood data:** (1) Create neighborhood maps that show places or routes that contribute to or symbolize a healthy neighborhood. (2) Investigate and analyze data from *data2go.nyc* (e.g., make a scatterplot, compare neighborhood statistics).
4. **Photo-walk 2:** Construct a data story that responds to the question, "What contributes to a healthy place and why should people care?" This activity included an introduction to elements of art and composition strategies, creation of a shot list (i.e., outlining a sequence of images and describing how each image connected to statistics they had investigated), and photo-captioning.
5. **Analysis of neighborhood data:** Reflect on emerging themes or trends in photo-essays and revisit *data2go.nyc* or other data source to refine data-based arguments.
6. **Photo-walk 3:** A whole-class photo walk in a well-known regional park. Students practiced composition strategies (e.g., leading lines, framing, point of view) and explored their topic in a different context. Students decided whether to integrate images into their final photo-essay.
7. **Construction of artist statements:** Students were prompted to introduce their work of art to an audience by engaging in description, reflection, and analysis of photo-essays.
8. **Presentation:** Students presented their photo-essays to peers, teachers, and researchers and finalized their work for a collective presentation in a well-known photography festival.

During the implementation, the curriculum was adapted in response to the following events: the art teacher received approval for a field trip to a well-known regional park, which shifted the order of photo-walks, centralized an investigation of greenspaces, and offered an opportunity to photograph a contrasting neighborhood. In addition, midway through the unit, the teacher was notified that her students would be able to participate in a well-known photography festival, which shifted the deadline for final photo-essays a week earlier than anticipated.

Data sources and analysis

Our data consist of 20 student photo-series, artist statements, data journals, and one 45-minute semi-structured interview with three students. We also triangulated findings with data from a one hour-long post-implementation interview with the art teacher in which we asked her to reflect on a selection of student photo-essays. We first read through students' photos and artist statements and described their main message. To answer RQ1 we used a constant comparison approach (Strauss & Corbin, 1998) to open code 20 data journals and artist statements for instances of data reasoning, ways in which students read data, read between data, or read beyond and behind data (Shaughnessy, 2007). Data reasoning codes included: describes a data point, makes a quantitative comparison, describes a bivariate relationship, and asks a statistical question. In a second pass, artist statements were then read in relation to principles of Data Feminism to characterize critical ways in which students read beyond and behind data (D'Ignazio & Klein, 2020). We then summarized data reasoning and critical data reasoning codes for each student. Table 1 shows the final set of codes for *critical data reasoning*, which are based on principles of Data Feminism.

Table 1
Critical data reasoning codebook

Critical Data Reasoning Code	Description & Student Examples
Embrace Pluralism	Makes a claim based on 2+ data types or sources. (e.g., personally-collected and public data.) Example: "Places with higher amounts of pre-schools had a higher percentage of children enrolled in the schools."
Elevate Emotion & Embodiment	Connects to lived experiences or emotion while (1) personally collecting data, or (2) reasoning about a statistic or graph. Example: "I see so many cigarettes everyday just on my walk to school. One day, I ended up counting 57 cigarettes on just one block."
Examine Power	Reasons about social or environmental implications or how data supports a claim about equity. Example: "There is a lower percent of white people who have diabetes in the Bronx area. I guess white people have access to better foods and proper medication to treat the start of diabetes."
Challenge Power	Generates new lines of data inquiry or ways to address issues of equity using data. Example: "The higher the white percent of people the more the health insurance coverage. The pattern could be shown because in most neighborhoods they are grouped by ethnicity. This could be important to show where more health insurance coverage could be put."
Rethink Binaries & Hierarchies	Reasons about how big ideas are operationalized or measured. Example: "... Life expectancy is a good way to measure the health of places because it shows how long people live in a certain neighborhood."
Consider Context	Represents details about social and environmental context to frame interpretations of data. Example: "*Downtown commercial area:* This is an area where all residents come together to shop. I love the cozy cottage, village vibe…"

To investigate how students used artistic strategies to communicate a message in their photo-essays (RQ2), two researchers independently coded photo-essays, looking at both the photo series and artist statement to identify artistic strategies related to their main message. We used a constant comparison approach to identify the following characteristics (Way, 2006; J. Paul Getty Museum Education Staff, 2023a): (1) principles of design: e.g., variety, contrast, pattern, (2) elements of art: e.g., line, color, value; and (3) composition strategies: e.g., leading lines, background/foreground. For each photo-essay, we discussed discrepancies in codes and came to a consensus. We then summarized frequencies for each principle of design and used codes for elements of art and composition strategies to help describe how design principles were constructed in students' work. Finally, to identify trends in how students connected critical claims and evidence to design principles (RQ3), we analyzed photo-essays for co-presence of critical data reasoning, data reasoning, and principles of design codes.

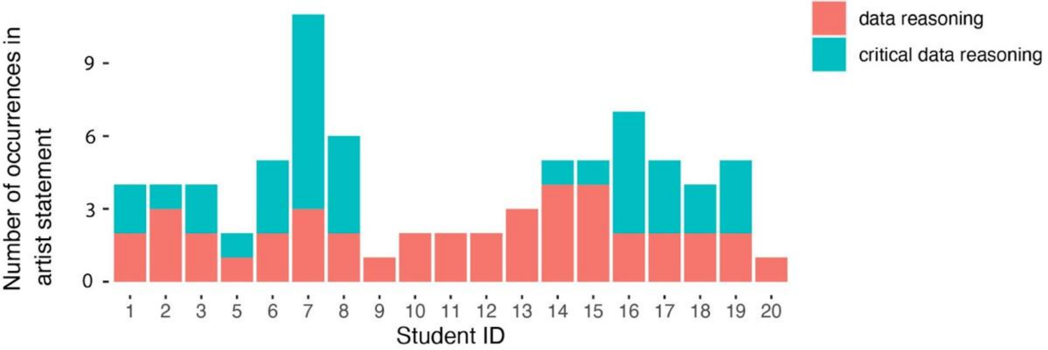
Findings

Participants constructed photo-essays that reflected on the health of their neighborhoods from various perspectives. Some students highlighted common, potentially overlooked, problems that affect their everyday life, such as litter on the streets, exposure to construction or highway traffic, access to nature, safety, poverty, access to healthy food, and unhealthy behaviors such as smoking. Others highlighted community resources using data such as neighborhood helpfulness, access to transportation, planned tree plantings, rates of recycling, and how small businesses support community members. To investigate these themes, students demonstrated both data reasoning and critical data reasoning in their artist statements and attention to principles of design in their photo series.

RQ1: Students reasoned critically about data in their artist statements

Students reasoned about data in their artist statements by asking statistical questions, citing relevant data points, describing bivariate relationships, and/or making quantitative comparisons. 13 students went further, also demonstrating critical data reasoning (see Figure 1): examining power (N=8), embracing pluralism (N=5), challenging power (N=5), elevating emotion and embodiment (N=3), and rethinking binaries and hierarchies (N=3). In their interview, three students reflected on how they not only read data but selected relevant data, considered how different variables were connected, and thought about how data "comes into play with society."

Figure 1
Number of occurrences of data reasoning and critical data reasoning in students' artist statements



RQ2: Students used variety, contrast, and pattern in their photo-essays

Students drew on principles of design to communicate a message in their photo series. There were 12 students who submitted complete photo-essays that expressed one or more principles of design. Three design principles (i.e., variety, contrast, and pattern) emerged as key strategies for connecting their main message to data. Below, we outline how the three primary principles of design emerged in students' photo-essays and offer an example of each.

Variety

Variety is the use of multiple elements of art or compositions in the photo series (N=5). One student application of variety transformed places into symbols of both community resources and expressions of beauty. The content of the series suggested that commercial areas, walkability, parks, nature, and housing contribute to a *healthy neighborhood* (e.g., see Figure 2). Whereas, the use variety connected these symbols by highlighting the peacefulness and beauty of living in a healthy neighborhood. A second application of variety, used in combination with pattern or contrast, supported a narrative arc in photo-essays (e.g., setting the scene, highlighting people, representing conflict, and symbolizing impact).

Figure 2
The Beauty Within defined a healthy neighborhood by connecting symbols of community resources to emotion.

"I wanted to depict something that represents how the resources and overall health of my neighborhood… impacts the way me and many other residents view it…In my photo series, the three most important elements that are depicted throughout the whole series are color, line, and space…"

Contrast

Contrast is a juxtaposition of visual elements or ideas (N=6). Photo-essays used value, space, color, and texture to create visual contrast. Contrast was used to visually distinguish images taken in different neighborhoods, whereas conceptual contrast (e.g., absence and presence; nature and trash) established the conflict or tension. The photo-essay *Trees*, which used conceptual contrast in conjunction with pattern reinterpreted the artist's initial observation of absence and presence by categorizing trees as the number of planned trees, newly planted trees, and grown trees (see Figure 3). Counting absences in this context helped the students predict a future increase in trees and thus neighborhood health.

Figure 3

The photo-essay Trees investigated the number of neighborhood trees from multiple perspectives by combining contrast and pattern.

"I wanted to depict something that represents how the resources and overall health of my neighborhood… impacts the way me and many other residents view it…In my photo series, the three most important elements that are depicted throughout the whole series are color, line, and space…"

Pattern

Pattern is a repetition of elements or repetition of a combination of elements (*N*=4). Photo-essays constructed patterns within a single image or across images (e.g., use of line to divide nature and the built environment). Pattern was fundamental in photo-essays that synthesized qualitative and quantitative data to construct an argument (see Figure 4). For example, in *Building the Bronx*, the artist represents construction as a norm in her community and part of everyday life by using repetition. She suggests that the everyday occurrence of construction in her neighborhood contributes to lower air quality by connecting her photo series to data on air quality.

Figure 4

Building the Bronx highlights everyday exposure to construction as a potential health problem.

"Construction isn't deemed to be important to many people, yet causes decreased air quality that is capable of damaging lungs and increased harsh sounds that contribute to noise pollution. My goal for this photo series was to shine light on these neglected endangerments…"

RQ3: Students used principles of design to express evidence-based arguments

Artist statements and photography worked together to form evidence-based arguments. Students who expressed pattern, contrast, and/or variety in their photo-essays frequently reasoned critically about data in their artist statements compared to those who did not express principles of design (83% vs. 25%). Photo-essays showed evidence of examining power across all combinations of design principles, whereas rethinking binaries did not occur in photo-essays that expressed only contrast. To support critical claims with evidence, students who used a principle of design made quantitative comparisons or described bivariate relationships more frequently than those who did not express a principle of design (75% vs. 33%). Students who did not express a principle of design were thus more likely to just cite a statistic and less likely to make data-based inferences.

Discussion

In this study we asked how integrating photography and data inquiry practices might support critical data storytelling in non-math contexts. We found that constructing photo-essays offered multiple ways for students to enter into data inquiry and that students frequently expressed principles of design in critical data stories.

Photography prompted students to shuttle between local and global perspectives

Data storytelling through photography offered students multiple entry points into data reasoning. "Stepping into the world of photography," according to the art teacher, helped students ask statistical investigative questions and explore their neighborhoods. For example, writing a statistical question that reflected observations in their photos challenged students to construct questions that were not only answerable with data but also relevant to their everyday lived experiences. Several students also reflected in their artist statements that photography helped them begin to make sense of data. They identified community issues by noticing emerging patterns in their photographs (e.g., plastic bottles in every photo) and used photos to quantify their environments (e.g., summing up the number of trees on each block). Others drew on artistic values and themes, such as beauty, to help them identify community resources. For those who had a clear investigation in mind, photography challenged them to translate quantitative findings into a story by representing potential implications for people and environments. These findings reflect prior research showing that students often shuttle between local and global perspectives to construct data stories (Wilkerson & Laina, 2018; Kahn, 2020). However, photography offered students a tool to collect and organize lived experiences as data and enabled them to draw on artistic strategies to help them construct evidence-based arguments.

Engaging students with principles of design can prompt critical data reasoning

Engaging students with elements of art, composition strategies, and principles of design generated opportunities for students to visually narrate data in different ways. The art teacher noted that her students' greatest challenge was making their photo-essays a complete story, not just highlighting a problem visually but also connecting it to data. Findings showed that those who were successful, typically drew on three principles of design: variety, contrast, and pattern. In traditional data visualization, the application of contrast might support a quantitative comparison, whereas pattern can show associations and variety can represent the distribution of a variable or identify multiple variables (Bach et al., 2018). However, students drew on photography not just as a data visualization tool but also as a secondary form of data and as a storytelling medium. Findings show that students connected artistic strategies and data reasoning practices in unique ways that were responsive to both their environments and investigative questions. For example, using contrast and pattern in *Trees* helped one student rethink how trees are counted and what counting absences might tell us about the future health of her neighborhood. In *Building the Bronx*, the student not only identified construction as a possible contributor to the lower air quality in her neighborhood but also constructed a pattern to justify her reasoning. Her photos, taken over multiple trips to school, framed construction as visible in her everyday routine and as a norm in her community. These findings reflect prior research showing how data storytelling challenges neutral, objective interpretations of data and can connect data to lived experiences (Stornaiuolo 2020; Kahn 2020). However, prioritizing engagement with artistic strategies in a data storytelling unit enabled students to draw on the tools of multiple disciplines to advocate for their neighborhoods, rethinking observed absences, highlighting overlooked variables, and representing the emotional impact of community resources.

Conclusion

Data storytelling is particularly relevant for engaging students with data in non-math contexts. However, students still need support to recognize and express principles of critical data literacy. This study suggests that prioritizing both artistic strategies and data reasoning practices in a data storytelling unit offers potential to support students in making data-based arguments and expressing critical data literacies. Findings in this study, however, are limited by a focus on a single classroom and on photographic arts. Future research might investigate how drawing on the artistic strategies characteristic of other forms of narrative-based art might support critical data storytelling.

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Using Computational Thinking as a Metacognitive Tool in the Context of Plugged Vs. Unplugged Computational Activities

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Abstract: This paper explored how K-5 teachers incorporated computational thinking (CT) to support young children's development of metacognitive knowledge and abilities. Two 4th-grade mathematics teachers' lesson videos were analyzed to understand how K-5 teachers used CT as a metacognitive tool. One teacher incorporated CT ideas and practices into her teaching without using any computational device (i.e., unplugged), whereas the other used Dash & Dot robots to engage his students in CT (i.e., plugged). Within those activities, teachers used CT to engage students in a variety of metacognitive strategies, such as attending to critical features of a problem, creating a mental model of a problem, and monitoring solution paths. Our findings provided insight into how K-5 teachers can leverage CT to enhance their students' metacognitive knowledge and abilities.

Introduction

In recent years, computational thinking and computer science (CS) education researchers have shown a growing interest in metacognition (Prather et al., 2022). Metacognition is one's awareness of own cognitive processes, and it is critical to learning per se for enabling students to control and monitor their cognitive processes (Flavell, 1976). Similarly, CT—a systematic approach to solving and formulating problems—involves processes where one must constantly reflect on one's own thinking and actions, such as finding and fixing own errors (e.g., debugging) (Yadav et al., 2016). Given these overlaps, scholars have called for investigating the connection between CT and metacognition for their students' academic benefit (Yadav et al., 2022).

Some scholars have proposed that students' metacognitive awareness can be developed by engaging them in a systematic problem-solving process during programming (Loksa et al., 2022). Others have claimed that CT through unplugged activities (i.e., without any computational device) could also help develop students' metacognitive abilities. For example, Yadav et al. (2022) suggested that CT potentially enables and overlaps with several metacognitive processes (e.g., identification of steps to solve a problem, execution of the steps serially or in parallel, and solution-monitoring); therefore, CT could be one way to teach metacognition in classrooms explicitly. In this context, our purpose was to explore how elementary teachers can leverage CT to support young children's development of metacognitive strategies. To explore that premise, we asked:

1. In what ways do elementary teachers use CT to support students' metacognition?
2. How does teachers' use of CT as an approach to engaging their students in metacognitive strategies differ between a plugged and an unplugged CT approach?

To address this desideratum, we video-recorded two 4th-grade teachers' CT-integrated mathematics lessons. One teacher used Dash and Dot robots to teach the concepts of area and perimeter, while the other teacher implemented CT ideas into the arrays lesson without using any computational device. Treating each case separately, we elicited the metacognitive strategies that teachers taught during computational problem-solving. Our purpose was to expand the list of metacognitive strategies that teachers use to bring metacognitive experiences to elementary mathematics classrooms through unplugged and plugged CT activities. Our question is relevant and timely and contributes meaningfully to ongoing and current questions about using CT as a metacognitive tool to enhance learning and instruction.

Computational thinking and metacognition

Computational thinking

In 2006, Jeanette Wing defined CT as "solving problems, designing systems, and understanding human behavior by drawing on the concepts fundamental to computer science" (p.33) and proposed that CT is not only for computer scientists but for every child. Since then, the efforts to bring CT into elementary education have only grown stronger. Built on the momentum generated by Wing's (2006) article, several educational initiatives and reforms have focused on developing children's CT knowledge and skills by integrating computing into K-12 classrooms (e.g., International Society for Technology in Education [ISTE], American Computer Science

Teachers Association [CSTA], and Next Generation Science Standards [NGSS]). Those initiatives are critical in that they reflect the growing presence of computing in K-12 education. At the same time, education scholars have also called for meaningful CT integration practices as CT has made its way through standards and K-12 curricula. To date, CT has been incorporated across disciples for a wide range of purposes, including but not limited to its use to support problem-solving skills, modeling, analyzing and representing data, and, more recently, helping students understand how computing impacts society. The most common perspective around CT integration conceives it as a problem-solving approach (Kafai et al., 2020) that includes several practices, such as decomposing problems into manageable parts (i.e., problem decomposition), using a set of steps to solve a problem (i.e., algorithmic thinking), seeing whether the solution could be transferred to similar problems (i.e., abstraction). Yadav et al. (2022) have also argued that these sub-practices overlap with several metacognitive strategies that have been shown to support students' academic outcomes.

Metacognition

Metacognition has been extensively studied for over fifty years. In 1976, Flavell pioneered the notion of metacognition and framed it as a phenomenon associated with one's awareness of own cognitive processes, such as memory and problem-solving. Flavell (1976) proposed that metacognition had two major components: metacognitive knowledge (MK) and metacognitive experiences (ME). MK refers to knowledge of one's own strengths and weaknesses when dealing with a task, while experiences emerge when MK is called on during problem-solving (Efklides, 2002). The scope of metacognition, however, is over and beyond what one declares about their own cognitive states; it extends to how one takes action in controlling one's own cognitive processes, which overall entail "thinking about the learning process, planning for learning, monitoring of comprehension or production while it is taking place, and self-evaluation of learning" (O'Malley et al., 1985, p. 560).

Computational thinking and metacognition

Similar to metacognition, CT involves processes where one must constantly reflect on own thinking and actions. A growing literature suggests that CT naturally enables and offers mechanisms to engage learners in self-reflective practices through debugging, iterations, and abstraction (Allsop, 2019). Those processes naturally engage learners in retrospective and prospective decision-making to help reach an equilibrium between their current actions and future goals. In this way, students '*debug [their] own thinking*' retrospectively while engaging in processes help them move closer to achieving their final goal (Kafai & Burke, 2016, p. 321). Considering these connections between CT and metacognition, young children, who are taught CT, have a better chance of mastering their own learning and cognitive processes, which could also benefit their long-term academic success. However, still little is known about the shape and degree of how CT overlaps with metacognition. In this paper, we aim to fill this gap by examining metacognitive strategies that in-service teachers employ during CT tasks in plugged and unplugged contexts—which can provide insight into how CT could be used as a pedagogical tool to teach metacognitive strategies explicitly.

Method

The study employed Bezemer's (2015) analytical framework for video-based multimodal analysis for social interaction to analyze 45-minute length videos collected from two classrooms. Multiple channels of communication (e.g., spoken dialogue, body-based gestures) are translated into a multimodal transcript through a set of steps—such as choosing a methodological framework, designing a transcript, and defining transcription conventions—where images and text are combined for fine-grained analysis. This approach helped us elicit metacognitive strategies (e.g., gestures) that are multimodal, going beyond teachers' discourse or dialogue only.

Context

The videos were collected as part of a research project, CT4EDU, that focused on supporting elementary teachers in integrating CT into their science and mathematics teaching. Elementary teachers incorporated CT practices in their mathematics lessons, and we video-recorded their lessons and the interactions with the students using Swivl—a robotic mount for a camera that helped record the actions of a moving teacher. We used these videos to form a preliminary understanding of how teachers use CT practices as a metacognitive tool within their instruction. We randomly selected two 4th-grade mathematics lessons from two teachers who volunteered to participate in our study. We chose mathematics as a subject because it naturally enables CT integration and the development of metacognitive skills for being at the heart of problem-solving. All data were kept confidential, and the participants were given pseudonyms, as displayed in Table 1.

Participants

Participants included two elementary teachers from two schools in the Midwestern United States, as displayed in Table 1. The teachers had participated in a professional learning experience that focused on preparing elementary teachers to integrate CT into their mathematics and science instruction. The focus of this study was CT-integrated mathematics lessons that the two teachers facilitated. The first teacher, Michael, used dash and dot robots to teach the concepts of area and perimeter, while the second teacher, Jill, taught simple arrays without using any digital computational tools.

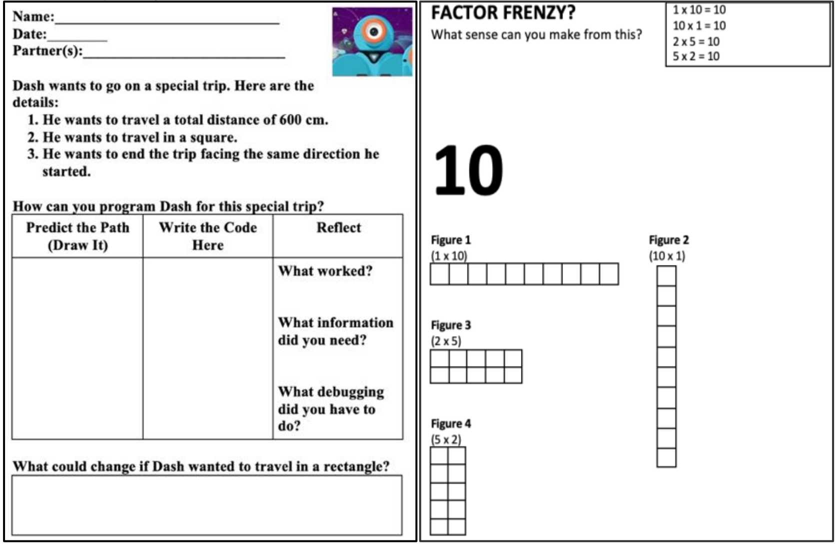
Table 1
Teacher Demographics and Recorded Lessons

Pseudonym	Gender	Grade	Class Size	Activity
Michael	Male	4	23	Dash & Dot Robot Plugged CT
Jill	Female	4	23	Factor Frenzy Unplugged CT

Research context

Dash and Dot plugged CT activity: In this activity, CT ideas and practices were used to teach basic mathematical concepts (e.g., perimeter and directions) when programming Dash robots. The major idea was to program the robot Dash to travel in a square. Therefore, our first teacher, Michael, instructed students to program the robot Dash for a special trip following the preset rules, such as traveling a total distance of 600 centimeters and ending the trip facing the same direction he started (see Figure 1, left column).

Figure 1
Dash & Dot Robot Plugged CT Activity (left) And Factor Frenzy Unplugged CT Activity (right)



Name:_________________________
Date:________
Partner(s):_______________________

Dash wants to go on a special trip. Here are the details:

1. **He wants to travel a total distance of 600 cm.**
2. **He wants to travel in a square.**
3. **He wants to end the trip facing the same direction he started.**

How can you program Dash for this special trip?

Predict the Path (Draw It)	Write the Code Here	Reflect
		What worked? What information did you need? What debugging did you have to do?

What could change if Dash wanted to travel in a rectangle?

FACTOR FRENZY?
What sense can you make from this?

1 x 10 = 10
10 x 1 = 10
2 x 5 = 10
5 x 2 = 10

10

Factor frenzy unplugged CT activity: The second teacher, Jill, used factor frenzy to teach factors in mathematics. At the same time, the activity largely drew on the use of debugging, abstraction, and decomposition to teach arrays, factors, and products. The students first used base ten blocks to write different multiplication equations for 10 in the form of arrays (see Figure 1, right column).

This activity was also scaffolded by giving a lower or higher number other than 10; an example for the number 54 might be as follows:

1. Students were reminded to begin with one row for the number 54 (i.e., 1 x 54).
2. Students then found different ways to create the factors of 54 (e.g., 2 x 27, 3 x 18, 6 x 9).
3. Students were asked to find the array's vertical and horizontal orientation (i.e., all the factor pairs).
4. Students then recorded their arrays on a construction paper, using the grid paper and correctly labeling their arrays (see Figure 2 for a sample construction paper)

Figure 2

A Sample Construction Paper

Data analysis

The video data was first transcribed verbatim and analyzed by three raters in segments according to where we identified both CT practices and metacognitive strategies. First, we identified CT practices such as *decomposing* large tasks into smaller sub-goals, using *patterns*, and thinking *algorithmically* to develop efficient solutions. Then, we explored the emergent metacognitive strategies associated with each CT practice. This approach allowed us to figure out overlapping elements of CT and metacognition. We then collated the information into overarching themes. The themes were identified through consensus building in recursive meetings with the raters (Baxter & Jack, 2008).

Results

Our video-based multimodal analysis in the context of plugged and unplugged computational activities revealed a set of strategies on how CT could help enhance young learners' metacognition in mathematics classrooms. The metacognitive processes and associated strategies used by the teachers are detailed in the following, and their connection to CT ideas, sub-skills, and practices are explained in a narrative form within the cases. Our focus was on the ways in which teachers' used CT as a metacognitive strategy rather than how the students reacted to the teachers' strategies.

Case 1

The analysis of the data from plugged computational activity (i.e., Dash & Dot) revealed three major themes of how CT could be used as metacognitive strategies: (1) developing an understanding of the critical features of a problem, (2) feeling for the constraints of the problem, and (3) monitoring solution paths.

(1) Developing an understanding of the critical features of a problem: The first metacognitive strategy that the students engaged in during CT was the critical analysis of a task. Our first teacher, Michael, first began by prompting the students to develop an understanding of the critical features of a problem (see Table 2). For example, after introducing the Dash & Dot activity, he asked his students: "What are some things that you need to think about with these preset rules, and what is important to know about Dash's trip". These questions helped students assess the problem's existing condition and better understand its critical features to attend to in the later stages of problem-solving. This is also a critical process of computational problem-solving, where students engage in abstraction as a CT practice (i.e., focusing on the most relevant and essential details of the problem).

Table 2

A Moment of Abstraction Through Developing An Understanding of The Critical Features of a Problem

Dialogue	Interaction	Transduction
Michael: So, with the people sitting next to you, I want you to turn and talk about what are some things that you need to think about with these directions [e.g., the total distance and shape of the path that robot must follow] **Michael:** … do some early thinking now. Ready, set, turn …	 [prompts the students to think about the critical features of a problem]	→ [metacognitive strategy: critical analysis of a task] Michael engages the students in **abstraction**, which involves focusing on the most relevant and essential details of the problem.

(2) Feeling for the constraints of the problem: The second metacognitive strategy that the students were taught during CT was feeling for the problem's constraints. Michael combined verbal prompts with perspective-taking to teach students how to set goals that are sensitive to problem constraints, which is a significant metacognitive activity (Paulson & Bauer, 2011). Table 3 displays how Michael first mentioned the limitations of the robot's movement. He said: "Dash can only walk forward, backward, turn right, and turn left." And then, following the verbal prompt, he visually executed those movements algorithmically as if he was the Dash robot. This interaction is significant for showcasing how algorithmic thinking and perspective-taking emerged as strategies to support students' goal-setting process—that is, a critical element of one's metacognition.

Table 3
A Moment of Algorithmic Thinking Through Verbal Prompts and Perspective-taking

Dialogue	Interaction	Transduction
Michael: Some of the groups are finding out that they made a plan that involves their robot traveling in certain directions. And then what they found out is that there are some limits that …Dash can only walk forward, backward …	 [prompts questions to feel for the constraints of a problem]	→ [metacognitive strategy: planning ahead] Michael prompts students to become cognizant about the problem constraints, executing a sequence of the robot's movements (i.e., CT practice of **algorithmic thinking**).
Michael: … turn left …	[Michael turns right, imitating the robot] 	
Michael: … or turn right … **Michael:** …So, there are really some things that you need to think about … that are a little bit different … So, if your planning involved just moving and sliding around, you might have to add in different things and try that out.	[He prompts the students to think about the critical features of a problem] 	→ [metacognitive strategy: planning ahead]

(3) Monitoring solution paths: The third metacognitive strategy that the students engaged in during CT was metacognitive monitoring. Metacognitive monitoring is "evaluating the process of learning or current state of knowledge" (Rivers et al., 2017, p. 549), and controlling that process is the ability to make changes to the original plan when it does not work as planned. Throughout the process, one asks oneself introspective questions, such as "am I following my plan? Is this strategy working?" (Martinez, 2006, p.698).

The following exchange between Michael and the students suggested that as students engaged in debugging (i.e., finding and fixing problems), they were given an opportunity to enhance their strategies associated with metacognitive monitoring and control. The following excerpt from Michael's instruction is strong evidence of how those initial strategies were later used by the students as part of their metacognitive monitoring at the end of the lesson, as appears in a set of brackets:

> What was nice is that they [i.e., small groups] kind of made a plan, and when they weren't sure [when the plan worked out well], they went back [monitored the solution], and they found some of the important information that was in these three things here [revisited the preset rules]. So, they said, well, I don't know, maybe I can do this, this, and this … [thought algorithmically &

> envisioned possible solutions]. And then when they were like, well, I'm not sure if I forgot an important part [checking task information to validate comprehension]. They went back, and they were looking at the three important rules here because the big idea is that he wants to go on a trip.

Case 2

The analysis of the data from unplugged computational activity (i.e., Factor Frenzy) revealed three major themes of how CT could be used as metacognitive strategies: (1) discovering patterns, (2) activating students' relevant background knowledge, (3) creating a mental map of a problem.

(1) Discovering a pattern: Our second teacher, Jill, first displayed the pair of numbers on a whiteboard, which gives a 10 when multiplied (aka factor pairs of 10), such as 1 x 10 = 10; 2 x 5 = 10. Like Michael's case, Jill began the lesson by encouraging the students to analyze a problem critically. She asked: "What sense can you make from this slide?" This exchange suggests that assessing the problem's initial condition is critical and common to CT and metacognition.

Jill: Take a look at the board. It says factor frenzy. *What sense can you make from this slide?*
Student: If that's factors frenzy, then the factors are like the multiplication numbers.
Jill: So, she remembers from last year. Good! That a factor is our multiplication numbers.
Jill: Tell me more. What does that mean?

(2) Activating students' relevant background knowledge: Next, Jill activated students' relevant background knowledge, which is an important metacognitive strategy (Lai, 2011). She asked, "Do you remember the name of these 10s? What were they called from last year?" (see Table 4).

In this case, activating students' relevant background knowledge went hand in hand with the CT practice of pattern recognition. Jill enabled her students to explore patterns based on the types of problems they had solved in the past. She used a variety of questions that engaged students in pattern recognition. She then used those patterns to help her students to understand the characteristics of a problem and figure out the kind of operations needed to solve a problem. As displayed in Table 4, she prompted her students to remember the nature of the problems that sum can be used: "Because remember … If we look over there [points at the CT posters in the classroom], sum goes with what kind of problems …"

Table 4
Teacher prompts

Dialogue	Interaction	Transduction
Jill: Anything else you notice? Somebody else? **Student:** … in the equation … All of them have 10s in. **Jill:** Do you remember the name of these 10s? What were they called from last year? Student: … Sum? **Jill:** Not the sum! Because remember … If we look over there [points at a poster in the classroom], sum goes with what kind of problems?	 [prompts the students to think about the givens of a problem]	→ [metacognitive strategy: activating relevant background knowledge] Jill prompts them to recall previous knowledge, using patterns to detect the inherent characteristics of a problem.

(3) Creating a mental map of a problem: The last metacognitive strategy Jill facilitated was when she mapped out "givens, a goal, and obstacles" (Davidson et al., 1994) of a problem for the students by posing several inquiry questions and suggesting strategies as appear in a set of brackets. For example, she said:

> I'm modeling (i.e., the problem) right now because you're going to be doing this. Today, you're going to be finding as many factors as you can for a number [setting a goal]. This is our target number [pointing at the givens of a problem]. And we were trying to find all the factors we could. We use the arrays to help us find the factors [cueing about reaching the goal]. And we

use the arrays to represent the equations. That's what computer scientists do. That's called abstraction [cueing about when to use what CT skill].

Being able to establish a relationship between *givens, a goal, and obstacles* of a problem is helpful in decomposing a problem and abstracting the essentials of that problem, and those are also critical skills of CT. The exchange above is, therefore, strong evidence of the connection between CT and metacognition.

Discussion

This study presented how two elementary teachers used CT to support students' metacognition in the context of plugged and unplugged CT activities as a part of their mathematics instruction. The findings suggested that CT could be used as a pedagogical tool to explicitly teach metacognitive strategies to young children in elementary mathematics classrooms. In both CT activities, with or without a computational device, our teachers brought in diverse metacognitive strategies that helped strengthen their students' metacognition during the different stages of CT; those strategies and processes are listed in Table 5.

Table 5
Metacognitive Strategies Emerged During Plugged & Unplugged Computational Activities

Name of the CT Practice (Yadav et al., 2022)	**Associated Metacognitive Strategy**	**How Our Teachers Used CT As a Metacognitive Strategy**
Abstraction: "Focusing on the most relevant and essential details of the problem that needs to be solved." (p. 409)	• Critical analysis of a task • Paying attention to important ideas • Creating a mental model of a problem	Asking students questions to develop intuition about critical features of a problem: 1. "What's going to be important?" 2. "What's important to know about this trip?"
Pattern recognition: "Finding the similarities and differences between problems." (p. 409)	• Activating students' relevant background knowledge through recognizing patterns • Understanding the inherent characteristics of a problem through those patterns	Asking students questions to encourage them to discover a pattern in the problem: 1. "What sense can you make from this?" 2. "What kind of problems does this pattern go with?"
Algorithmic thinking: "Designing a step-by-step solution to a problem." (p. 409)	• Perspective-taking to design a step-by-step solution	Asking students to think of the robot as an embodied agent, thinking of Dash as a human: 1. "Dash wants to go on a special trip. How can you program dash for his special trip?"
Decomposition: "Simplifying complex tasks by breaking them down into smaller parts." (p. 409)	• Creating a mental model of possible solutions	Designing lessons in a way that they have a built-in prediction component (e.g., "you have to predict the solution and draw the path")
Debugging: "Finding and fixing errors." (p. 409)	• Monitoring solutions	Asking questions to encourage students to think about their solution paths (e.g., "what makes you say that").

Our teachers often strengthened the metacognitive elements of the CT-integrated mathematics units by asking questions that made the students constantly think about their own decisions during the entire problem-solving process. We also observed that both teachers designed CT-integrated mathematics lessons in a way that both had a built-in prediction component, which is also crucial for metacognition. This helped learners to predict several possible solutions without executing them and select the appropriate strategies based on the expected outcome. As shown in Table 5, strategies used by our teachers are naturally a part of CT (first column) and essential to metacognitive skill development (second column).

Conclusion

This study is an initial attempt at exploring how CT can be used as an approach to support teachers to teach metacognitive strategies in elementary classrooms explicitly. Our findings hold several implications for the future of CT in elementary education. While much of the focus on CT in K-12 classrooms has been as a pathway to introduce computer science, our findings suggest that elementary teachers can use CT to teach metacognitive strategies to support disciplinary learning. Introducing those strategies might help students assess the initial conditions of a problem, devise solution paths responsive to the problem's constraints, and predict multiple solutions that could be applied as the problem conditions change (Liu & Liu, 2020). It should also be noted that one teacher used CT practices as a metacognitive tool in the context of the plugged activity, while another used CT as a metacognitive tool in the context of an unplugged activity. Future work should expand on this line of research to examine how CT can support students' learning in the core disciplines while improving their problem-solving skills.

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Designing for Justice-Oriented Critical Caring in Science Methods Courses

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Abstract: Contemporary science education centers on the desired conceptual understandings and science practices students should develop. While positioning students as knowledge constructors by valuing a sensemaking stance and leveraging heterogeneous meaning-making repertoires are important for equitable learning, the moral and ethical dimensions that undergird this emphasis have been overlooked. Here, we study our efforts to support science pre-service teachers (PSTs) in our methods courses to develop pedagogies rooted in what we call *justice-oriented critical caring.* Our design-based research approach grounds PSTs' science futures pedagogical practices in an ethic of care and in broader sociopolitical systems, particularly in three key ethical and design commitments: *discursiveness*, *relationality*, and *reflectiveness*. Our findings show how intentionally designed learning experiences for PSTs supported learners in navigating complex trajectories toward enacting transformative forms of caring.

Rationale and framing

From research agendas to policy documents and standards in the US, the conversation on what students should learn in science classroom centers around the desired conceptual understandings and science practices students develop (NRC, 2012). Within this scholarship, the moral and ideological implications undergirding this emphasis have often been overlooked. While positioning students as knowledge constructors by valuing a sensemaking stance (Russ, 2014) and fostering heterogeneity of ideas (Warren et al., 2020) is important for promoting justice in science, scholars have also called for a relational ideology of schooling where teachers support students in developing as persons who care and are cared for within oppressive systems (e.g., Antrop-González & de Jesús, 2006). Teachers are key for creating opportunities for students to learn science through engaging in science practices (Berland et al., 2016; Krist & Suárez, 2018) and fostering a culture of critical caring (Antrop-González & de Jesús, 2006). However, a relational orientation is seldom the focus of science teacher education. In this paper, we study our efforts to support science pre-service teachers (PSTs) in our methods courses to develop pedagogies rooted in what we call *justice-oriented critical caring.* Our approach centers PSTs' pedagogical practices in an ethic of care and in the context of broader sociopolitical systems. To this end, we designed science methods courses for PK-8 PSTs that foregrounded relational dynamics within the epistemic work of science: (1) examining and engaging with students' science ideas; (2) developing meaningful relationships with students rooted in solidarity and high intellectual expectations; and (3) create transformative science learning environments that build on the meaning-making resources and potentials of individual students.

Theoretical framework: An ethic of critical care

Within educational scholarship, an attention to care comes from philosophical considerations about the goals of schooling, as well as arguments about what kinds of ideological commitments should undergird teaching and learning. As originally formulated in the context of education by Nel Noddings (2013), teaching undergirded by an ethic of care is characterized by three important dimensions: (i) *Relatedness* – inextricably being present with others, knowing who they are as people and thinkers; (ii) *Receptivity* – listening intently and remaining open to others' ideas, rather than immediately judging them, as well as being attuned to the affective experiences of others, not as deterrents, but as modulators; and (iii) *Responsiveness* – attending to the meaning-making of others, with the intention of engaging with that thinking.

While this conceptualization of care attends to the roles adult teachers and students inhabit in classrooms, it does not directly account for the structural hierarchies that undergird these relationships. Critical education scholars have redefined the concept of care to explicitly illuminate and address issues of power in schools. For instance, Antrop-González and de Jesús (2006) introduced a caring framework that privileges "the cultural values and political economy of communities of color as a foundation for education" (p. 413). Specifically, the research from Antrop-González and de Jesús suggests that marginalized students benefit from relationships guided by *critical care*, where teachers offer friendship and mentorship in and out-of-the classroom, while maintaining high intellectual and academic expectations for their students. Similarly, Rivera-McCutchen (2021) calls on researchers and educators to leave behind what she calls limiting forms of care that are "characterized by pity and excuse-making made ostensibly in the service of children," and refuse to structural inequities such as racism (p. 3) –

Valenzuela (1999) characterized a similar form of care as *aesthetic care*, which privileged the grammar of schooling and denigrated youths' backgrounds. Rivera-McCutchen argues for a *radical care* that is rooted in anti-racist pedagogies, developing authentic relationships with and between children, creating and upholding high expectations for students, and creating nurturing and transformative schools. This scholarship contextualizes a notion of care, arguing that definitions of care that are not grounded in peoples' everyday perpetuate oppression.

In such versions of an ethic of care, caring is shaped by intersecting systems of privilege of oppression. Enacting care, then, also requires striving towards justice: reducing harm and promoting human flourishing via dismantling oppressive systems. Relatedly, feminist legal scholar Hudson (2006) rejects what she calls the "white, male character of justice in modern liberal societies" and describes a relational ethic of justice that comprises: (i) *Discursiveness* – bringing minoritized peoples into the discursive circle, rejecting the expectation that "claims to justice can only be acknowledged if they are voiced in the terms of the dominant group" (p. 34); (ii) *Relationality* – rights (and responsibility and culpability) are created and exercised in relation to other individuals and groups, including the recognition of connectedness between teachers and students, how each is understood in relation to social and historical context, and the interdependence upon one another; and (iii) *Reflectiveness* – considering individual claims of justice "in terms of all its subjectivities, harms, wrongs and contexts, and then measured against concepts such as oppression, freedom, dignity and equality" (p. 39), rejecting an abstract ethic of justice.

In our design, we bring into coordination these instantiations of an intersectional, justice-oriented interpretation of an ethic of care and propose a framework specific to science education that is grounded in the following ethical commitments: (1) Adopting a caring stance is a radical act in normative schooling that should *disrupt both meritocratic and technocratic* aspects of science teaching and learning; (2) Adopting a critical caring stance towards science teaching and learning must be *discursive* in nature, both because it emphasizes the need for examining and engaging with ideas, and because it pushes us to reconsider how minoritized students are often left out of the discursive circle; (3) Adopting a critical care stance towards science teaching and learning must be *relational*, accounting for authentic relationships between individuals, groups, and communities that are rooted both in solidarity and high intellectual expectations; and (4) Science educators who adopt a critical care stance must exercise *reflectiveness* around their own and their students' positionalities, particularly as they create transformative science learning environments that see the resources and potentials of individual students, rather than subsuming the unique circumstances of students under stereotypical generalities.

We are interested in how the commitments to discursiveness, relationality, and reflectiveness create opportunities for learners of all ages to engage in rich and meaningful science work. Specifically, we explore how to design learning opportunities for PSTs to develop a science pedagogy guided by justice-oriented critical caring. Here, we describe two iterations of science methods courses that aim to do so. In the context of these designed courses, we pose two research questions: (1) How do PSTs attend to relationality in science teaching and learning contexts?; and (2) How do PSTs attend to discursiveness in science teaching and learning contexts?

Designing for justice-oriented critical caring in science methods courses

This study comes from a collaboration between us – the two authors – following a design-based research approach (Cobb et al., 2003) to modify activities in the pre-service methods courses we taught at two public universities in Fall '21 and Fall '22. One course was designed for PK-5 PSTs (taught by Suárez), and the other one was for future middle school (MS) science teachers (taught by Krist); more details are provided below. Our designs aimed to attune PSTs to the ethical commitments of *discursiveness*, *relationality* and *reflectiveness*, particularly as they relate to contemporary science pedagogies. Given our own commitment to reflectivity, we defined these embodiments and how they should be implemented within the context of our individual courses.

We also note here the productive tension between the lofty ideological vision of our framework and the humbleness of design hypotheses and claims (Cobb et al., 2003). The two iterations we present are nowhere near the full implementation of our ideals. In alignment with DBR's goals and commitment to developing humble theories that are both domain-specific and are accountable to the design, we present the messy mangle of frameworks for care and justice, the tensions and challenges in learning to teach science through engaging in investigations of natural phenomena, and the bureaucratic realities of pre-service teacher education programs.

Course contexts and design features

The PK-5 methods course was taught by Suárez in a large public university in New England, USA. This course was part of undergraduate and teacher licensure programs within the institution, including both undergraduate students who planned on becoming PK-5 teachers and master students who were enrolled in the one-year teacher licensure program. Masters students also completed a full-day practicum in schools, while the undergrads did not. In Fall '21, the course enrolled 11 students: 5 undergrads and 6 grads (6 of whom consented to participate), and all identified as white women; in Fall '22, the course enrolled 7 undergrad students (6 of whom consented to participate): 5 of whom identified as white women, one as an AfroLatina, and one as an Asian woman. The course aimed to support PSTs in becoming enthusiastic, effective, and caring educators that design equitable science learning activities. Specifically, the course was guided by the following objectives: (i) Understand science as a collective process of meaning-making that leverages scientific practices (*discursiveness*); (ii) Develop a definition of "equitable science education" that attends to children's meaning-making repertoires (*discursiveness, relationality, and reflectiveness*); (iii) Develop a critical caring stance towards science teaching that humanizes students and supports their learning (*discursiveness, relationality, and reflectiveness*); and (iv) Develop strategies for eliciting students' ideas, prioritizing investigations, and developing collective explanations (*discursiveness*).

The course included three main activities where PSTs would reflect on, express, and leverage their ethical orientations as they developed an equitable science pedagogy. First, PSTs completed surveys that prompted them to reflect on their definitions of care and how they would center critical caring in their science teaching (e.g., "In the context of science investigations, what do you think "caring for students" could look like?"). These surveys were designed to promote *relationality*, as PSTs considered how to develop solidarity with and high intellectual expectations of their future students, and *reflectiveness*, encouraging them to identify how their positionalities guided their teaching and relationships with students. Secondly, three assignments asked PSTs to analyze videos from PK-5 science classrooms (e.g., "What evidence of Caring did you observe during these interactions in the classroom?") that depicted young bi-/multilingual students investigating and explaining physical phenomena. These video-based tasks required PSTs to attend to the *discursiveness* of critical caring, focusing on the substance of minoritized students' ideas and anticipating how meritocratic and technocratic ideals could hamper these ideas. These analyses also supported PSTs to consider *relationality* and *reflectiveness*, primarily through attending to the caring relationships between students and between students and teachers in those classrooms (or lack thereof). Finally, PSTs implemented a discussion-based lesson, in which PSTs described and enacted the pedagogical practices to emphasize the *relationality* and *discursiveness* aspects of critical caring towards their peers.

The Middle Grades (MG) methods course was taught by Krist in a large public university in the Midwest, USA. The MG course met the state's science subject-area endorsement requirement for students seeking a middle grades licensure; it also met the middle grades endorsement requirement for licensure in a specific high school science discipline. All students had a science placement in middle schools where they observed 1-6 hours per week. In Fall '21, the course enrolled 12 students: 11 undergrads and 1 grad (10 of whom consented to participate); and in Fall '22, the course enrolled 4 students: 3 undergrads and 1 grad (all of whom consented to participate). The course was designed to support PSTs to develop expertise on how to teach science in ways that were effective, transformative, and following a justice-oriented critical caring approach. The course had the following objectives: (i) Describe current theory and practices in teaching middle school science; (ii) Design science lessons that are consistent with current science education standards, guided by an ethic of critical care, and address the needs of middle school students; (iii) Critically analyze and reflect on the assets and inequalities at play in their placement community; and (iv) Critically analyze and reflect on one's own and others' teaching.

The course included three main activities that asked PSTs to enact and reflect upon their own ethical orientations with respect to students. Each of these activities was guided by Phillips' (2019) concept of *principled improvisation* for novice teacher learners, including asking students to both plan for and reflect upon their growth in the four key practices he identifies: (1) Learning to authentically listen to students; (2) Learning to follow students' lead in their learning; (3) Learning to facilitate students building on each others' ideas; and (4) Learning to craft critical questions that build on students' responses and move their analysis toward a deeper consideration of power and historical, social, political, and economic processes (ibid, p. 28).

The first assignment was a "get to know you" interview with students in their placement classroom about things *other* than science, such as what they liked to do for fun and what they thought about school. The goal of this assignment was to invite PSTs to engage with the students in their classroom and learn something about them that went beyond what they might see through their science learning. This assignment was quite open-ended and encouraged PSTs to ask questions that allowed middle grades students to be the "experts" teaching PSTs about themselves, their school, their families, and their community. My design hypothesis was that this orientation would promote *relationality* by beginning to re-position powered relations as more reciprocal. The second activity entailed reading responses to intentionally paired readings. I purposefully paired descriptions of pedagogical practices (e.g., eliciting and responding to student ideas) with first-person accounts from students about how they experienced schooling (e.g., what they wished their teachers knew about them during class discussions). The design hypothesis guiding these pairings is that the intentional contrasts would foster reflection around how various students might experience enactments of teacher-centered descriptions of pedagogical practices, imbuing *discursiveness* and *relationality* into practice-based teacher education. Finally, a third activity was a series of microteaching experiences that included modification, rehearsal, revision, and enactment of a lesson given to them by their placement teacher. They developed a written reflection about these processes, including a critical analysis of their final lesson as enacted using four frameworks for science and equity that we used throughout the term. These frameworks were intended to support their identification of how to "...move [students'] analysis toward deeper consideration of power and historical, social, political, and economic processes," Philip's (2019) 4th practice, which all students identified in self-evaluations as one in which they wished to improve.

Data collection and analysis

Qualitative data for this study comes from different streams, as each course had its own set of activities and assignments. For the PK-5 methods courses, data were collected from: (i) surveys; (ii) course assignments; and (iii) synchronous class activities, including analyzing videos of PK-5 classrooms and common science curricula that foregrounded investigations. For the MG methods course, course assignments were the primary data source, focusing on: (i) the get-to-know-you student interview reflection, (ii) reading response discussion posts for weeks with paired readings, and (iii) reflections and critical analysis of microteaching experiences.

We conducted thematic analysis (Braun & Clarke, 2006) from qualitative data across the iterations of our methods courses, guided by the analytic concepts of *discursiveness, relationality,* and *reflectiveness* to understand how PSTs conceptualized and enacted justice-oriented critical caring as part of their developing science teaching practices. For the PK-5 course, we analyzed two course surveys (administered in Week 2 and Week 7 of the semester) and the final video essay where PSTs analyzed how a group of 3rd bi-/multilingual students investigated how a string instrument produced sounds. For the MG methods course, we analyzed all of the assignments described above. For the purposes of this study, we focused our analyses on how PSTs attended to: (1) *relationality* in science teaching and learning contexts, particularly as it related to how PSTs attended to relationships and behaviors in the classroom and the power dynamics that shaped those interactions; and (2) *discursiveness* in science education, especially as it pertained to identifying and valuing students' varied conceptual and cultural resources and recognizing and disrupting the powered nature of participation. We coded these data separately and shared emerging findings to corroborate and refine analytical interpretations.

Findings

In this section, we discuss the main themes we identified in the data we collected from each course, particularly as they related to how PSTs attended to *relationality* and *discursiveness* in the related activities and assignments. We organized our findings according to the courses, rather than the research questions, in an attempt to highlight the complexities of developing a stance towards justice-oriented critical caring. First, we describe the group-level insights from the PSTs from Fall 2021 PK-5 science methods course, and then present the trajectories of three PSTs in the MG as they worked towards embracing justice-oriented critical caring.

Balancing politeness and meaning-making in the PK-5 science classroom

In Week 2 of the course, PSTs completed an initial care survey where they considered their own science learning experiences and generated a set of care-based features science learning environments should have. For instance, when thinking about how they would show care for their peers during the course's learning activities, PSTs emphasized the importance of listening "closely to what [peers] have to say and respect their views as individuals" and "always being respectful when others are sharing their ideas and by working collaboratively and respectfully with others." Similarly, when asked to describe how they would like others to express care towards them, PSTs described actions like "checking in to see if I'm feeling okay, checking in about confusing assignments," and "understanding that everyone makes mistakes and not to judge me based on not understanding a certain part of the classes lesson." Survey responses, which prompted PSTs to reflect on their experiences and positionalities, suggest that, at first, PSTs were attuned to how relationality shaped their interactions with peers. These reflections imply that PSTs were concerned with learning within a discursive space that would be respectful, free of judgment, and receptive – characterized by what we would call *politeness*. While this stance could be foundational for enacting justice-oriented critical caring, conspicuously absent from most of their insights is the need for relationships that would hold high intellectual expectations of each other, as well as be rooted in solidarity and comprehension. Moreover, these responses did not consider how school-based power hierarchies determine who is invited into the discursive circle (*discursiveness*) or whose ideas are valued and validated (*reflectiveness*). To move beyond this emphasis on politeness, I (Suárez) enacted learning activities for five weeks that pushed PSTs to expand their definitions of justice-oriented science education. Specifically, PSTs engaged with scholarship on students' heterogeneous meaning-making repertoires and analyzed four classroom videos, attending to: students' ideas, whose ideas were invited and engaged with, and how students and teachers enacted care towards each other.

When PSTs completed a follow-up survey in Week 7, their answers focused more on the role caring should play in science teaching and learning. When asked to reflect on how caring would shape their interactions with young students during an upcoming one-on-one science investigation, the PSTs were committed to caring " by really listening when they are discussing their answers and encourage them to explain and express their ideas," and "by not telling [students] they're wrong or that their thought processes are incorrect […] it would be key to ensure them that it is a low stakes environment." We interpret these statements as evidence of how the PSTs had reframed the construct of *relationality* towards wanting students to feel comfortable and respected and addressed elements of *discursiveness,* acknowledging that children come to science learning activities with a swath of valuable ideas that are essential for developing conceptual understanding, and wanting to develop the kinds of relationships with their students that would support their learning. At the same time, PSTs did not explicitly consider how their positionalities and/or those of their students could shape the enactment of care and their science learning (i.e., *reflectiveness*). Supported by these responses, I (Suárez) prioritized course activities where PSTs identified how the curricula explicitly connected science to children's lives and their communities' goals.

For their final assignment, PSTs in the course analyzed a video from a third classroom where a group of bi-/multilingual students problematized the mechanisms behind sound production. Students in the video explained their observations through connecting the physical features of the string instrument (e.g., length of the strings, tension on the strings) and the characteristics of the sound produced (e.g., low and high pitches), laminating multiple semiotic resources. In their essays, PSTs had to attend to the substance of students' ideas, the science practices students leveraged for investigating sound production, and how students and instructors expressed care for each other. As their responses to the surveys intimated, PSTs attention to relationality and discursiveness in the third-graders' caring reflected a wide range of themes. One prominent category in PSTs' insights pertained to how students and teachers created a discursive space driven by different forms of relationality. For instance, one PST highlighted how the teachers created a caring environment through making sure "that no other students were talking while another student was talking so they could really show respect for each other." We take this remark as evidence that some PSTs continued to focus on a form of relationality that valued *politeness*, where being respectful of their peers by not talking over them was essential for student learning. These analyses suggest that future iterations of the course ought to support PSTs in recognizing how justice-oriented critical caring must question cultural constructions of politeness and the teacher's normative expectations of behavior.

The majority of the PSTs attended to elements of *relationality*, *discursiveness*, and *reflectiveness* in their analyses, particularly as they reflected on the features of equitable science learning for bi-/multilingual students. Specifically, they focused on an exchange that involved G – a newcomer to the US who was learning English as an additional language – his peers and the teachers, where G explained how increasing the length of the string lowered the pitch of the sound produced. Independently focusing on this episode, these PSTs identified and analyzed the different forms of caring that supported G's rich meaning-making. First, PSTs identified how the other students gave G ample time to express his thinking through a combination of speech, onomatopoeia, and gestures, out of intellectual respect and not politeness. These PSTs were excited to see how G's ideas were taken up by other students as they explained the how/why of the sounds they heard. Second, PSTs focused on how the teachers enacted care and encouraged a caring learning space, highlighting the words of affirmation the teachers gave G to remind him that his thinking mattered. For instance, one PST wrote that "G seemed nervous when he was sharing his ideas, so [teachers] telling him that he did a good job affirmed that his ideas added something important to the discussion." Based on these excerpts, we argue that the PSTs' analyses of the exchange displayed their understanding of justice-oriented critical caring, articulating how students and teachers had developed strong relationships that supported their humanity and ideas (*relationality*), and leveraged the key conceptual resources G brought to the investigation (*discursiveness*). Moreover, these PSTs exercised *reflectiveness* through rejecting educational paradigms that would construe G's communication as insufficient and/or deficient, and instead highlighted the richness of his languaging and creativity for expressing a scientifically complex idea.

Science and caring in the middle grades: Navigating school norms and assumptions

We now present examinations of three students' individual trajectories of considering dimensions of caring through the course, as traced in their written course assignments that were largely about their own instructional enactments. These trajectories illustrate the range of possibilities for growth we saw in our courses, as well as offer areas for design refinement (i.e., are there ways we want to intentionally bound to support more focused growth?). The first trajectory follows "Carly" and represents her shifting from an ethic of relationality centering *politeness* to one centering *meaning-making.* The second trajectory follows "Gabby" and "Rob" who each entered with initial stances that revealed some elements of *reflectiveness* and *relationality*, yet as they brought these stances into contact with the standard pedagogies of science and cultures of schooling, tensions surfaced.

Carly's trajectory: From politeness to meaning-making

Carly typifies the students in the university's teacher education programs. She identified as a white woman from a wealthy suburb of a nearby large metro area, who was involved in her sorority. She was ambitious, working towards endorsements in math and science. During the Fall semester she TAed for a large math education course.

Carly's reflections about her "get to know you" interview focused around her surprise that a student she talked to was failing some of her classes. Carly wrote, "I can't tell if this is a common view of students, but personally when I was in middle school, I wouldn't be okay with my grades anything lower than an A." When discussing how these observations would inform her future teaching, she said, "I will try my best to have a positive attitude and energy in the classroom. I want my students to feel comfortable in the classroom and to have a connection with me. This way they will be more honest with me if they're struggling and will be more respectful in the classroom." This orientation towards respect continued to show up in Carly's reading response posts, which frequently mentioned boundaries, expectations, and reducing undesirable student behaviors.

Enacting a "microteaching" lesson where they were required to facilitate a sense-making discussion pushed Carly's comfort zone. Her co-designed lesson was more highly structured than I [the instructor] would have liked, but she insisted that her students needed the structure because she had never seen them do anything other than take lecture notes during her placement observations. I chose to respect her judgment, not knowing much about her placement classroom, and instead worked with her to select a few questions to make more open-ended and generate "back pocket questions" (Windschitl et al., 2020) to support elaboration of ideas.

Her reflections on this lesson were hesitant, but positive. She noted a high degree of student "stress" given the open-ended nature of the discussion, which they "weren't used to." Carly also reflected on how she had co-facilitated the discussion: "I think that I was good at following students' lead in their learning - if a student's response strayed from what we were looking for or brought up another topic, I wouldn't go right back to the next scripted question, but elaborated or asked further questions on where the student was leading the conversation [...] An area I could work on would be authentically listening - I think I was a little nervous as well so I could have had better responses to students' points and to have listened better than being nervous about all the possible scenarios during the discussion." In my comments back to her, I affirmed her decision to use follow-up questions and her goal of focusing on authentically listening (emphasizing *relationality*), and asked if she thought her nervousness would be diminished now that she had completed one teaching experience. Though she did not respond to my assignment comments, our next series of in-class activities involved small-group microteaching experiences. Carly was part of a small group with Rob (described in the case below), who wholeheartedly embraced the opportunity to try out a sensemaking discussion. He began by asking his "students" what they noticed about a photo of a sequoia seed vs. a sequoia forest and asking them how something so small could get so big. Although these microteaching experiences were meant to take 20 mins or less, this group discussed for about 45 minutes and then picked up the conversation again for another 10 minutes after class ended. Although Carly did not mention this particular experience in any of her artifacts, I remember noting that it was unusual for her to stay after class as she usually was one of the first ones out the door.

For her second teaching assignment, I saw resonances of the sequoia discussion experience coupled with her push to be more comfortable with "authentically listening" in her planning. Carly taught an engineering lesson in which students worked in small groups to design and test balloon rockets. In modifying this lesson, she carefully constructed how the groups would work together, including many back-and-forth emails with me, wordsmithing questions that would structure the interactions, but also be open-ended enough to facilitate conversation and not make students feel like there was "one right answer." In her final reflection, she was thrilled with how successful she felt this lesson was, noting, "Students were able to use this collaboration to identify patterns or commonalities with other groups' findings. I feel like socially, this lesson helped students come together and discuss the concepts. [...] Although they were following a set-up lesson, they had their own time to explore the things that happen with the balloon rocket and got to decide which areas/variables they wanted to explore within the rocket. Students also had a lot of discussion which had prompting questions, but was mainly student-led."

In terms of justice-oriented critical caring, there is still a long journey ahead for Carly. However, these small shifts – from "being comfortable as control," to recognizing in herself a goal to listen more divergently as well as valuing student interaction and discourse as supportive for learning – are important beginning steps, a foundation for moving towards the more ambitious ideals in our framework.

Gabby and Rob's journeys: Tensions between reflectiveness, relationality, and grammar of schooling

Gabby and Rob are two students who each came into the course with orientations to students that went beyond the discourse of politeness described above. They each encountered tensions throughout the course with various ideologies of schooling and how these conflicted with their stances towards students, though they navigated these tensions differently. At the end of the course, they collaborated on a final lesson modification that allowed them to leverage the strengths they had each developed in ways that stretched the other towards a fuller version of justice-oriented critical caring. Their two intersecting trajectories represent the complexities that students experience when enacting caring as a radical act. Here, we focus on the tensions they encountered as they navigated between an ethic of care and the structures of schooling, as they inform future design iterations.

Gabby and Rob both held multiply-minoritized identities within our teacher education program. Although neither of them directly connected their identities with their priorities to students, the orientations they held even early on reflected compassion and a sensitivity to individual's unique differences and needs. Gabby identified as a Black disabled woman who had shifted to education from engineering after growing weary of the constant (micro)aggressions she experienced. Rob identified as a white man who changed careers to become licensed as a teacher. Being an older student and a single father made him a non-traditional in our program student.

Neither Gabby nor Rob expressed ethics of care characterized by politeness. Instead, Gabby expressed an assumption of and value for heterogeneity in students' experiences, rather than "subsuming the unique circumstances of students under stereotypical generalities" – this reflects the component of *reflectiveness* in her ethic of care. For example, after conducting a "get to know you" interview with a few students during Week 2 of the course, Gabby reflected: "[T]his interview showed me I need to get to know all of them to see what they really want in science lessons. I need the whole picture, not just one case." She went on to describe how understanding that range of student desires and expectations would help her figure out how to strike a "balance" in her planning for instruction. In response to the same interview assignment, Rob expressed his surprise at how open students were in talking to him about their struggles and challenges. He wrote, "I think it's easy to forget how hard it is to be 14 [...] and especially after being online for the last two years and being thrust back into in-(person schooling. It is so important that we view our students as whole people, and give them time to adjust to new settings and new life situations. [...] I'm planning to informally check in with both of these students next week [...] to show that I was listening and care, so hopefully that at least shows them that someone is in their corner. I'm looking forward to seeing how all of these students grow as learners, and as people over the next few months." This aspect of *relationality* in his ethic of care demonstrates a commitment to forming "authentic relationships between individuals that are rooted in solidarity," at least around their experiences with COVID.

At various times throughout the semester, Gabby's and Rob's attention to reflectiveness and relationality resulted in tensions within their lesson planning and enactments, and within their observations at their placement schools. In weekly check-ins about their placements, Gabby often expressed frustration with how teachers in her placement school blamed students for not completing homework. She instead blamed boring lessons, including the school's required use of Cornell notes. When I pressed her about it, she saw the value of this structured note-taking strategy, but thought the school's policy on how students completed Cornell notes each week made them "busy work" and curtailed inquiry-oriented science. In her second microteaching assignment, Gabby used Manz's (2019) Investigations Framework to modify a flower anatomy lesson – a perfect candidate for Cornell notes! – to be a dissection activity. Students took Cornell notes as part of the "lab," but the notes were purposeful in helping students keep track of how their description of features mapped to the names and functions. She reflected on how the lesson was still more "vocab-heavy" than she would have liked, but was pleased with how engaged students were, asking a lot of questions and making connections to other plant and animal anatomical features. Notably, every student turned in their Cornell notes from the lesson, which we take as evidence of students' efforts to meet the high intellectual expectations that characterize *relationality* within a justice-oriented critical caring paradigm.

Rob similarly reflected on the implications of structures of schooling observed in his placement classroom for the kind of care-oriented teaching he hoped to enact, although his concerns throughout the course centered on how to set up class norms for discussion. For example, in a reading response post on the course's LMS about one set of paired readings, he wrote: "I still don't really have a great understanding of the norms in my placement classroom, or to what extent students even feel that there are explicit classroom norms. [...] While some engage deeply with the content, others get way off task, or will harass classmates, and I've not heard anyone reference any sort of classroom policy [...] While allowing [students] to explore [the norms] freely is critical for their emotional development, I think that setting up clear standards for science discussions is really a form of scaffolding for that practice." His commitment to students' development as whole people is clear, and his attention to collective norms as important aspects of *relationality*; however, he also describes it as "classroom policy," and mentions behavior management concerns as the ones driving his concern about norms. Unlike Gabby's articulation of trade-offs, Rob seems unaware of this tension between traditional schooling and justice-oriented critical caring. Later, this concern over classroom norms revealed a lack of trust in students to participate in small group discussions, as well as his own hesitancy to use meaning-making discussions as a regular part of his science instruction, potentially limiting opportunities for *discursiveness*. After enacting one such discussion for the first time, he wrote: "I also discovered that I 100% cannot do this every day. This lesson took a long time to put together and it took a huge amount of energy to get through! This type of lesson needs to be in my future instruction forever, but absolutely cannot be my everyday teaching style." Perhaps continuing to press on his doubts about students may be important for him to unpack this limitation, but we note that it represents an aspect of *reflectiveness* about himself – a productive move towards not operating out of an empty emotional tank.

Discussion & implications

We set out to study our efforts to support science pre-service teachers (PSTs) in our methods courses to develop pedagogies rooted in what we call *justice-oriented critical caring.* Through coordinating an intersectional, justice-oriented interpretation of an ethic of care, we proposed a framework specific to science education that is grounded in the following ethical commitments: *caring as a radical act*, *discursiveness*, *relationality*, and *reflectiveness.* Here we analyzed the activities and assignments from the pre-service methods courses we taught – one course for PK-5 PSTs and one course for future middle grades (MG) science teachers – and found evidence that our PSTs became attuned to various forms of *discursiveness*, *relationality* and *reflectiveness* in science classrooms. Specifically, PSTs in the PK-5 methods course strived to leave behind limiting forms of care that focused only on students' behaviors and, instead, embrace justice-oriented critical caring that attended to the substance of students' ideas and promoted their well-being. Moreover, the trajectories we outlined from the PSTs in the MG methods course described a much more complex process of how (future) teachers can be supported to work towards justice-oriented critical forms of care, especially when these steps are mediated by overarching structures, practices, and expectations of schooling that reinscribe oppression. Overall, our findings suggest that it is possible to design science learning experiences that reject the false dichotomy between content and ethical commitments, and doing so positions (future) science teachers to better support their students' science learning and humanities. However, our findings suggest that our PSTs encountered obstacles with reaching stable forms of *reflectiveness*, understanding how their positionality and that of their students shaped the caring relationships that supported meaning-making. For this reason, future iterations of our courses intentionally include frameworks and tools that encourage PSTs to readily engage with features of structural oppressions in science teaching and learning.

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Comparative Design-Based Research: How Afterschool Programs Impact Learners' Engagement with a Video Game Codesign

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Abstract: Community-based afterschool programs are valuable spaces for researchers to codesign technologies with direct relevance to local communities. However, afterschool programs differ in resources available, culture, and student demographics in ways that may impact the efficacy of the codesign process and outcome. We ran a series of multi-week educational game codesign workshops across five programs over twenty weeks and found notable differences, despite deploying the same protocol. Our findings characterize three types of programs: *Safe Havens, Recreation Centers,* and *Homework Helpers.* We note major differences in students' patterns of participation directly influenced by each program's culture and expectations for equitable partnerships and introduce Comparative Design-Based Research (cDBR) as a beneficial lens for codesign.

Introduction and background

Design-Based Research (DBR) is a methodology for producing generalizable knowledge about complex systems while also creating products that operate effectively within those systems (Barab, 2006). Borrowing the iterative logic of engineering design, DBR involves a cycle of building, testing, and improving prototypes in the context where they will be used. Due to the situated nature of the work, the products of DBR are influenced by the environments in which they are built. The interplay of context and creation allows DBR to not only facilitate the design of effective and engaging artifacts but also yield insights about situated environments, valuable to the Human-Computer Interaction (HCI) and Learning Science research communities.

However, a challenge remains in understanding specific constraints and unique strengths of these insights given they are derived from a highly contextualized process. When conducting DBR in settings where researchers are not members of the same social or cultural group as the intended users, participatory design methods, such as collaborative design (codesign) are often employed (Guha et al., 2013). Acknowledging that researchers' expertise does not extend to cultural and environmental norms in the settings where the products will be used, participatory design invites members of the community into the design process to provide insight into how products or programs could be designed for better cultural fit. However, it remains unclear how similar a new community would need to be for the insights to generalize, or perhaps how the design decisions could be manipulated for a differing community, given a lack of contextual information — i.e., more exact constraints, potentially limiting the findings.

Afterschool centers are a great environment to conduct adult-child DBR related to transformational games, as formal school schedules may be too rigid to allow for the unstructured play required to create highly engaging games. They cater to students' varied interests including sports, games, arts, STEM, etc. and routinely partner with external organizations to offer programs that students are highly interested in. Recently, afterschool STEM programs have been greatly promoted. Demand for such centers exponentially increased during the pandemic (Afterschool Alliance, 2022) and has remained strong even as schools have re-opened. Centers are expected to provide safe, supportive, adult-supervised environments, as well as academic, personal, social, and recreational development. Many providers are interested in expanding (or introducing) STEM program offerings, but not all STEM resources have proven successful in all environments. In fact, the multitude of virtues ascribed to afterschool centers creates an ever-growing list of expectations that partners are expected to meet, increasing pressure on providers to constantly change their programs to incorporate new, in-demand elements.

Codesign encapsulates multiple approaches, serving as a popular methodology to co-create experiences, products, and systems with users, stakeholders, and community members (Zamenopoulos & Alexiou, 2018). Codesign supports developing ideas, better designs for user and stakeholder needs, creating relationships between designers and groups of people, and quality results (Steen et al., 2011). Power sharing and shifting emerges from codesign, as stakeholders are given a pathway to provide insight and share needs (Westin & Salén, 2019). Often, codesign has been done with adult participants, however, as children utilize technology and are stakeholders in their own STEM educational experiences, it is necessary to include youth in codesign as well. Children's own insight is critical to designing effective experiences (McNally et al., 2016; Yip et al., 2013), since they are experts of their own interests. Their expertise is especially beneficial when the target goal is to create STEM educational products, such as transformational games (games developed with the intention of changing players in a specific way that transfers outside of and persists beyond the game) for diverse groups (Culyba, 2018).

Walsh et al., (2013) describe codesign as focusing on the design partners (their experience, needs for accommodations), design goal (design space, maturity of design), and design technique (cost, portability, physical interaction, and technology). However, when working with children, it is important that the techniques and framework for design fit the population and creativity is harnessed (Read et al., 2002). The needs for children from under-resourced or marginalized communities to become codesign partners may also be different and require a critical eye towards justice, diversity, and accessibility from codesigning researchers, e.g., drawing on critical race theory and intersectionality to better center diverse child codesigners (Ogbonnaya-Ogburu et al., 2020). Effectively involving diverse children in codesign can allow a range of participants to contribute valuable design insights. In particular, we aim to fill a gap in understanding how to effectively codesign with a range of children across different kinds of afterschool learning environments through a comparative approach.

In this study, we employ "comparative design-based research" (cDBR) to examine differences in barriers to implementation of STEM programs across five culturally and economically diverse afterschool centers. Our DBR program (the same program run across multiple sites) sought to create a robotics programming video game that would be engaging and practical within each cohort's environment. Each site's implementation spanned approximately 20 weeks and focused on codesigning a game that the youth in each cohort would like to – and be able to – play in their afterschool center. As expected, the codesign process produced inferences about the design of STEM games, however the cDBR approach also highlighted how different sites with communities of youth across different racial, age, and socioeconomic lines resulted in substantially different codesign experiences across populations. For the scope of this paper, we focus on the partnerships, codesign processes, and experiences to highlight methodology. Findings related to the game artifacts will be reported in a future publication.

In this paper, we argue that leveraging a cDBR approach provides insight and value to involving diverse youth in codesign work. We will demonstrate that beyond the conventional considerations that researchers take into account when designing research programs (such as racial and socioeconomic composition), additional critical factors to the conduct of participatory design-based research emerge from consideration of the internally aligned sets of goals, scheduling, and youth participation norms that follow from a program's structural character. The structural forms of different afterschool settings can be characterized by a common set of archetypal identities.

Context and method

Our program took place in a group of afterschool programs in and around a mid-sized city in the Mid-Atlantic region of the United States during the 2021-2022 academic year. Our goal was to collaboratively create video games with different afterschool sites where players program robot partners to accomplish goals together. The game was intended as an educational product, as well as a pedagogical exercise to foster students' identity as designers, increase their programming knowledge, and robotics domain knowledge.

We ran a 20-week program focusing on the codesign of game characters and narratives, block programming instruction, and game testing and iteration. In weeks 1-8, students were informed that they were partnering with our research team to create a video game where they collaborated with a robot by programming it to accomplish their in-game goals. Using different codesign instruments and activities, we explored different game narratives, co-created game characters and settings, negotiated game mechanics etc. The next 8 weeks were focused on block programming instruction to equip students with the skills needed to program their robots. This time also allowed our software development team to create a prototype version of the game. During the final 4 weeks, we iteratively tested the game with students. Students tested and critiqued prototype and beta versions of the game, often with us modifying the game elements, narratives, and mechanics between versions. Each codesign session was one hour long and consisted of snacking and icebreakers, scheduled codesign activities, and students playing diverse-genre video games from a curated selection. We obtained written consent from students' parents/guardians and our research was approved by our university's Institutional Review Board (IRB).

Each session was attended by 2-4 researchers (depending on the number of students), with one being a dedicated notetaker. One researcher (second author) was the main lead for most sessions at each site, while the others had supporting roles (taking notes, answering questions, passing out materials, etc.). Site staff members sometimes joined our sessions and assisted with the facilitation. The program was structured for 6-8 students but adjusted to accommodate much larger groups as necessary. After each session, the researchers met to discuss the data gathered and clarify any areas of confusion. These meetings were recorded and transcribed as well. All team members attended a weekly analysis meeting to review session interactions from the different network sites, design and refine planned session activities, and reflect on the types of program adjustments we needed to make to better serve each afterschool center. We recorded these analysis meetings and analyzed them as part of the data.

Table 1
Afterschool club information (collected from interviews) showing total students, age range, and demographics.

Club name	Total # students	Age range	Racial demographics description
Green Hill	30 (10 F, 20 M)	5-14	Mostly Black, some White, some Hispanic
Central Rise	12 (12 F)	11-14	Predominantly Black
Sunny Pond	19 (6 F, 13 M)	7-12	Predominantly White
Clear Bridge	15 (3 F, 12 M)	7-10	Predominantly White, some Hispanic, some multiracial
West Creek	48 (21 F, 27 M)	5-12	Diverse (including White, Black, Hispanic, Middle Eastern, multiracial)

We worked with 5 afterschool clubs (Table 1): Green Hill (former industrial low-income town with mostly Black families), Central Rise (low-income neighborhood in city center with mostly Black families), Clear Bridge (rural town with mostly White families), Sunny Pond (suburban town with mostly White families), and West Creek (diverse suburban town). Site names are pseudonyms. All programs took place in-person, except for at Sunny Pond, which was run mostly remotely due to COVID regulations with the help of a staff member onsite.

We have several sources of data: Staff interviews, observation notes, researcher reflection meetings, student surveys about technology and programming experience, and codesign data (including design artifacts, playtesting session observations, etc.). Staff interviews (N =10; 5 F, 5 M; 5 White, 3 Black, 1 South Asian, and 1 Hispanic) consisted of 8 who were dedicated to their individual centers, while 2 were administrators who served as STEM coordinators for all afterschool centers in the network. Each interview, focused on the culture of the programs, their available resources, and values, lasted one hour and was recorded for analysis. Participants were not financially compensated but were informed that participation would allow us to better cater to their students.

We conducted a thematic analysis on the different data sources (Braun & Clarke, 2012) to understand and characterize how organizational goals, resources, activity provision norms, and student participation criteria impacted the effectiveness of our codesign program and required different adaptations. We reviewed the interviews first, then session observations, and meeting notes for data that provided evidence for each identified theme. Given the focus of the interviews, preliminary themes highlighted aspects of program culture. These themes were then corroborated and iterated based on analysis of the other data sources. After this process was completed, the entire team discussed each theme extensively to clarify areas of confusion. Where necessary, the team watched session videos as a group where multiple perspectives were needed to unpack the interactions. We triangulated our findings with student-generated artifacts to ensure that all evidence was mutually supportive. Our team consisted of a range of researchers coming from computing, learning science, robotics, and game design academic backgrounds, as well as a variety of economic, racial, and cultural backgrounds (including East Asian, Black, and White, with American and African cultural backgrounds). Researchers often had multiple roles on the teams, including being facilitators, programming and building the games, and designing the games.

Findings

We identified three "program archetypes" across the five sites with characteristically different goals, schedules, and activity participation norms, which in combination had a dramatic impact on the conduct of afterschool programs (including our DBR activity, which was shaped as a STEM program). These categories are not meant to be exhaustive, or comprehensive for describing all kinds of afterschool program partners. Researchers may encounter partners who do not have any of the factors described, or more likely, partners who have characteristics that span across these archetypes. These characterizations provide insight into how different communities can be contrasted using one design program protocol. We find differences across sites by using a comparative approach.

Program archetypes: Safe havens, homework helpers, and recreation centers

Safe Havens

We categorized Green Hill and Central Rise as *Safe Havens*. We interviewed three directors from both programs (2 Black men, and 1 Black woman). These afterschool programs are located in high-poverty neighborhoods with mostly Black and Brown students attending low-performing schools. The primary purpose of these sites was to provide a safe space for children to stay after school. Unlike our other sites, all the students in these clubs qualified for financial assistance and therefore attended the program for free. They have strong partnerships with local schools – Green Hill is physically located in the local elementary school, and Central Rise has liaisons who work in the schools they serve. The Central Rise program director mentioned, *"We help with education… education by far, because not only are we on them when they get here or just when they're not here, we keep in contact with 'em. We have a liaison up at the school. Okay? Who's also checking on them, their mannerism …"*

Staff members in Safe Havens did not only serve as enrichment coordinators but also as parent and guardian figures. For example, the program director at Green Hill shared that he regularly raised funds from different organizations to ensure the students had clothes and school supplies – on several occasions he invited hair braiders and barbers to the afterschool programs to ensure students had presentable hairstyles. In both programs, members sometimes transported students in their personal vehicles, cooked meals for them, and advocated for them in schools and with their families. Taking on this parental role came easier for all three directors as they could personally identify with the students – they all shared that they grew up in similar neighborhoods, faced similar struggles, and attended afterschool programs with adults that made a difference.

In addition to providing a safe space and serving as parental figures to students, these administrators shared that exposing their students to more opportunities regardless of their interests was important to them. Central Rise had organized international trips to Ghana and Jamaica in the past to expose their students to people from other cultures, and Green Hill was constantly looking for more exposure opportunities.

> *"It's just like abilities to see things. Whether it be resources or supplies or whatever it may be … So, for me, the idea is like the exposure. I remember like going to a tennis camp… I didn't care about that tennis camp, not one bit, but now that I'm 31 years old, I can see someone playing tennis on TV, and I can appreciate that because at a young age, I was kind of exposed. I don't think that the exposure was so much about me like becoming Serena's [Williams] little homie. It wasn't about that. It was about me experiencing it … We're going on a walking trail tomorrow … these city kids have no idea what a walking trail looks like."* — Green Hill program director

Although Green Hill is part of a larger afterschool program network, they are physically located at least 30 minutes from the city center and are largely inaccessible by bus. Therefore, they do not benefit from the STEM programming and staff available to the other flagship afterschool sites located in the city. They also have very limited computing infrastructure; when we first started working with them, there were only three computers available to both students and staff. Due to limited opportunities for STEM programming, administrators welcome lasting external programs to accommodate many students with minimal infrastructure and staffing requirements.

Central Rise is in the city downtown and has better access to STEM programs and researchers from local universities, non-profit organizations, and technology companies. However, they also struggle with maintaining consistent STEM programming, as they didn't have the staff to provide instruction in house. Throughout the COVID-19 pandemic lockdown, our research was the only external program available to them. Although they had some donated computers, they were all severely outdated, and we had to provide technical support while working with them including replacing missing peripherals, operating system updates, upgrading memory, etc.

Homework Helpers

We categorized Clear Bridge and Sunny Pond as *Homework Helpers*. We interviewed three directors from both programs (one white woman, one white man, and one Indian-descent man). Clear Bridge is located in a rural town where white working-middle class families make up 95% of the population. Sunny Pond, on the other hand, is in a small town in close proximity to other afterschool programs in the network. Working class white families make up the majority of the population. Families in both clubs primarily signed up their children to get homework help from the coordinators. The program director of Clear Bridge described, *"We are homework help. That's a main one… Parents come for the after-school homework help. They like that. They like that we have structure here that we do the academic things… It's the ability because [parents] don't understand the math … So, when they get home, they're not having to worry about rushing around, getting homework done. They can actually spend time with their kids."* Focusing on academics makes *Homework Helper*s conducive to running structured programs.

> *"Students [at* Homework Helper *programs] will buy in enough to do what they're told, because someone told them to do it, whether or not they [fully] buy in … Most of the students are like, 'Okay, I will do what I'm told. I will sit here. We may not be passionate about it.' So, like when I picture [other programs in the area], we have the crazy, like, nothing goes smoothly, ever. All the kids are all over the place, but there's a lot of kids that are passionate and like excited about*

> *it… [At Sunny Pond and Clear Bridge], there's a little bit of crazy, but a lot more kids with less passion."* — Network-level STEM director

Since parents entrusted the administrators at the *Homework Helper* sites with the responsibility of overseeing all afterschool academic activities, they did not get involved in what activities their children participated in. Administrators had the responsibility of pre-selecting students who attended different programs based on their perceptions of student ability and interest. At Clear Bridge, administers gave us a list of students whom they felt were best suited for our program. While most of the selected students had prior programming experience and game design interests, several other students who could have benefited from the program were left out. On one occasion, we had the opportunity to share our program information with all students who attended the club on a particular day, and seven new students came to us informing us that they were interested in joining. Sunny Pond had a more flexible signup structure. Like Clear Bridge, the administrator pre-selected the students who they felt were best suited for our program, but they often reevaluated other students who visited the club.

Both afterschool sites had adequate technology infrastructure. Clear Bridge had a computer lab with touchscreen desktop computers. There was a general space for homework, and a makerspace with more computers and programmable robots. Sunny Pond did not have a dedicated computer lab, but they had laptops available for each student and several classroom-style spaces that were used for different programs. Both sites had an in-house STEM champion. The program director at Clear Bridge had taught several STEM programs in the past and was regularly soliciting partnerships for opportunities. Sunny Pond had a dedicated STEM programming staff member.

Recreation Centers

We categorized West Creek as a *Recreation Center* and interviewed two program directors (one Black man, and one Hispanic man) for this study. Prior to their serving as directors at West Creek, they worked as program directors at Green Hill and another local center not in this study, so they could reflect on their experiences working in the different settings. One program director mentioned, *"Your role might have to shift depending on the neighborhood and the kids that you're working with. [The other director] and I have a bunch of cartoon stuff around our office, and I think that exemplifies the vibe that we have here as kind of a, 'Hey, let's hang out buddy' type of thing ... I don't think they look at us as father figure sort of thing ... [We're] one of the, one of the homies."*

When describing the purpose of their club, the program director of West Creek explained the culture of the club centering fun and entertainment: "Kids either come here for sports, or they come here to do the fun kind of hangout things that are happening… The idea of the club is fun. … You know, like when you're in school … if they make a game out of learning, that's exciting. If you go to the club, and they make a game out of learning, and [the children may think] 'Whoa, whoa, what is this? Oh, we don't want to do this.'"

In addition to a dedicated computer lab, West Creek has a dedicated gaming room with several video game consoles, board games, and billiards for teenagers. They have an open lobby space with arcade style video games and consoles, billiards, and table tennis. They also have two dedicated gyms where multiple sports programs were conducted, an outdoor playground, an art room, and a dedicated maker space. While administrators recommended and encouraged students to join certain activities, the students have the agency to leave and join any other activities in the building at will. We observed several incidents where students joined the one activity but were informed by their friends that something cooler was happening elsewhere encouraging them to leave.

Norms around participation in codesign program

To illustrate the utility of our cDRB approach, we describe one main theme from the data, characterized by differences between archetypes touching on culture, values, resources, and demographics. In particular, we saw that the norms around and barriers to consistent participation dictated the types of data that could be collected and mediated how learners could engage with our program. Table 2 shows the attendance patterns at different clubs.

Attendance patterns at Sunny Pond and Clear Bridge were most consistent with our prior expectations for our program's participation. Most students who signed up attended most sessions as long as they were in the building. Although Sunny Pond and Clear Bridge had students attend less than 40% of all sessions on the average, the main reason for this was that these clubs were most sensitive to set of fee increases implemented by afterschool network partway through our program, as most children came from working to middle class families and did not qualify for financial assistance. There was a program wide-fee increase from $90 to $110 per week which caused some parents to pull their children from the club. For students who remained, attendance was higher. We made the fewest modifications to our original program design with *Homework Helpers*. Students attended consistently enough, provided codesign input, and were invested in the game output. There was less opportunity for identity transformation and learning gains compared to *Safe Havens*, and less diversity in game feedback compared to *Recreation Centers*, but their predictability was most beneficial for the original codesign process and product.

Table 2

*Participation information and archetype. Clear Bridge and Sunny Pond experienced a tuition hike that impacted the number of families that attended the afterschool program. *The second numbers listed for these afterschool clubs are the average for students who remained in the program despite the tuition increase.*

Club name	Archetype	Avg. % of total sessions each student completed	Avg. # of repeat students per session
Green Hill	*Safe Haven*	43%	11.45
Central Rise	*Safe Haven*	71%	7.45
Sunny Pond	*Homework Helper*	31% (*53%)	5.16
Clear Bridge	*Homework Helper*	39% (*50%)	4.8
West Creek	*Recreation center*	13%	3.95

Although they provided the most consistent student attendance, conducting research in *Safe Havens* was quite challenging. Despite having only 12 students, attendance was highly consistent at Central Rise. Most students at Green Hill attended 43% of all sessions — however, this was further reduced by months of including some students and excluding others, as we tried to maintain a maximum of 10 students in our program to avoid crowding in small spaces and support meaningful codesign interactions. Attendance was more consistent when we could provide enough research staff to accommodate all students. Staff members insisted that equitable provision of programs to their students involved mandatory participation. We tried different approaches to account for the number of students including taking half of the students on one day and coming the next day to repeat the program for the other half. That too, was not sufficient as staff members could not guarantee student attendance, so we had to cater to all students without additional time available. We also needed to spend more time teaching prerequisite skills. Students at Green Hill had mastered fewer arithmetic, reading, and STEM competencies compared to their middle- and upper-class counterparts. The mandatory participation requirement also meant that we had varied student interest in our program and had to work with students who did not want to be there. Given the low prior STEM knowledge and mandatory attendance requirements, students in *Safe Havens* showed the highest potential for STEM identity transformations and learning gains. Long term programs that make strong connections between STEM and other domains provide consistent attendance by research partners and expose students to different kinds of professionals seemed especially useful for this archetype of afterschool program.

In *Recreation Centers*, we had the most inconsistent attendance of all our programs. West Creek students attended an average of 13% of all sessions, and approximately 4 students were repeats compared to the 48 students we encountered in totality. Students in *Recreation Centers* shuffled between multiple spaces within the same time block looking for activities that seemed the most exciting. When students opted to play outside, play video games, or play sports in the gym, it was unlikely that they would stop by our program. When we had students in the room, there was high interest, but the attitude was all about play. One potential strategy to increase student participation was to communicate our program goals, milestones, and output directly to parents so they could encourage their students to attend. However, we did not have direct access to parents and lacked the consistency in output materials per child to make that strategy feasible during our time there. Given these attendance patterns, it was impossible to conduct pre- and post-testing, observe long term identity transformations, or conduct programs not centered around play or fun. Students in *Recreation Centers* provided inconsistent input in the codesign process, but their input was particularly valuable when testing new iterations of our video games. Because they did not have the same emotional ties and investments as groups who consistently informed the design of the game, their feedback was critical for understanding how each game might be understood by fresh students from other demographics.

Discussion

The outcomes of Design-Based Research are typically twofold: contextually appropriate products, and reflections on the context-product interactions that make them so. Typically, these insights are powerful and authentic but also inherently specific to a single context. In this paper, we presented findings from our effort to deploy a STEM codesign program across multiple settings. True to its DBR roots, this work produced data and analytic leverage from which to reason about the context (afterschool programs) in which the work was taking place, surfacing characteristics of afterschool programs that affect such programs. In particular, because our STEM codesign program served as a data collection instrument, we were able to identify numerous factors relevant to the conduct of design-based research in these settings. For instance, inconsistent student attendance at programs could result from several different forces – in programs with high levels of free choice, it could be the result of our activities being unappealing; in other programs attendance was constrained by level of trust; in others, it was beyond our control entirely. In other cases, the ways in which norms affected codesign participation could be quite subtle. For example, *Recreation Centers* maintained a culture of play and value of fun, making it trickier to direct youths' attention toward creation of more serious artifacts, especially when other activities like sports were offered at the same time. Vitally, it is the fact that we were able to observe the same STEM codesign offering playing out in these different ways between sites that allow us to be confident of the different mechanisms by which this occurred. Our findings corroborate prior literature characterizing types of out-of-school programs, relating to e.g., homework assistance (Cosden et al., 2001) and its benefits to learners. We extend such work by noting that programs in fact organize themselves quite substantially around core services they offer, such as homework help, creating differences across the culture of the organization, impacting many activities, including codesign.

Educational and methodological implications

Regarding implications for informal education research, by focusing on the differences between common patterns of program structure we found that codesign-critical program participation norms and routines could be highlighted using archetypes based on administrators' characterizations of programs. Comparing the alignment of administrator characterization to observed program routines across sites allowed us to see if that administrators' visions seemed to be the genesis of scheduling and attendance norms across sites, or at least that administrators were reliably aware of such alignments. While racial, socioeconomic, and broader structural factors are likely at play and cannot be separated from our findings given the nature of our specific sites, the archetypal descriptors provided micro-level insight into the site routines that determine whether a codesign session will be productive.

This work also yields methodological implications. The findings we present here are primarily triangulated from observed *differences* between *sites*. However, between-sites comparisons are not the only analytic leverage provided by cDBR. We have also seen promising results emerging from exploration of *commonalities* between the *products* resulting from codesign at each site (Higashi et al., 2022). We may thus hypothesize that, at a minimum, a cDBR approach could produce inference based on something akin to a 2x2 matrix of either *similarities* or *differences,* between *sites* or the *products* they generate – the present study, for instance, focused on *differences between sites*. Yet the matrix-cell approach ignores the inextricable link between contexts, processes, and products in DBR. Indeed, some of cDBR's greatest inferential power may come from examining combinations of these factors. We can readily imagine, for instance, a situation where certain product design features emerge across multiple different sites for different, yet independently sensible reasons. *Product similarities* despite *site differences* in design rationale would provide provocative evidence of *convergence*, supporting the existence of important invariants around DBR. Such insights remain notional now but point to a powerful potential for comparative methods in design-based research, which we will pursue in our future work.

We recommend that researchers who intend to use cDBR keep a few points in mind. A diverse range of programs will provide the greatest leverage for triangulation. Differences and therefore findings across sites may be more robust with greater diversity across multiple axes. Larger differences in site context will entail a wider array of needs across teams and communities, impacting the overall nature of the work and increasing the need for flexibility in the codesign protocol. Preparation for this may include, for example, ensuring the ability to call in extra research team members to support facilitation onsite for certain collaborations.

Limitations

There are some threats to validity. First, our evidence is drawn from a single codesign effort conducted across 5 sites in a single, geographically contiguous network of afterschool programs. Therefore, while our argument establishes an existence proof of the value of cDBR, determining the full extent and scalability of cDBR methods is left for future research. Similarly, we acknowledge that while we intentionally employed a diverse team of researchers and took an iterative process in our analyses, there are inescapable possibilities of bias when analyzing data and the inherent advantages and disadvantages of researcher-as-instrument in qualitative work. Additionally, a programming-based co-robotic game may result in prior knowledge highly influencing participation, and different insights might be uncovered for different types of products in other domains. Finally, by nature, some of our findings about suitability and responsive adaptation of DBR instruments to different contexts emerged from failure. Thus, while analyses of these breakdowns allow us to observe the failure mode, conditions under which issues occurred, and immediate causes, it is impossible to directly observe the counterfactual, i.e., what the program would have looked like had we incorporated needed adaptations in advance. We intentionally scope this work around the methods, showing the potential of this deployment of cDBR across sites. Broader results, including additional themes related to the design artifacts, including the games, will be reported in the future.

Conclusion

A cDBR approach, employing the same codesign protocol and processes in intentionally different settings, yields important insights about interactions between protocols and settings, and therefore serves to highlight particular strengths or limitations in the codesign findings. Without the comparative multi-site aspect, we would have not had a point of comparison from which to argue that interesting codesign process decisions stemmed from an interaction with systemic local conditions. While the focus of this paper has been to highlight the potential for cDBR through emphasizing differences between sites, future work will explore the *persistent* or *convergent* design findings that can also be made apparent by the approach.

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Exploring the Primacy of Cultural Strengths for Purposeful (Agri)cultural STEM Learning in a Mexican Immigrant Community

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Abstract: This study examines how the purposes and values Mexican immigrant families bring into a community garden space can serve as cultural strengths and facilitate opportunities for rich STEM learning. Taking place at a school-based community garden in the western US within the context of a long-term community-university partnership, researchers in this study engaged in qualitative ethnographic data collection with 20 gardeners and families over the course of nine months. Utilizing sociocultural perspectives, chiefly CHAT and the notion of a "third space," researchers analyzed semi-structured interviews, field notes of garden walks and community events, and self-documentation materials submitted by participants. Findings include (1) the identification of the concepts *distraer* ("to distract") and *conectar* ("to connect") as cultural strengths and the drivers of valued activity in the garden and (2) the effectiveness of these concepts in fostering families' engagement with natural phenomena and STEM practices.

Introduction

Deficit thinking in schooling is a seemingly intractable issue for students and families from non-dominant communities. Deficit thinking attributes failings to an individual's perceived abilities or cultural background and indexes the historical and structural inequities largely responsible for the opportunity gap in the United States (US) (Valencia, 2010). Whether through a students' experience in the classroom, or a family member's experience in a school meeting, students and families from non-dominant communities often confront pervasive and implicit assumptions that they lack knowledge or skills. Yet, non-dominant communities hold a wealth of knowledge (e.g., Yosso, 2005). Scholars in the learning sciences have long argued that to improve learning outcomes for students from non-dominant communities, learning environments must privilege the knowledge systems and learning practices of these learners and their families (Ishimaru, 2019). Within STEM education, learners from non-dominant communities rarely have the chance to meaningfully bring cultural strengths from their lives and communities into their learning (c.f., Bang et al., 2012; Calabrese Barton & Tan, 2019).

The inequitable outcomes learners from non-dominant communities continue to experience in STEM brings into relief the urgent need to explore how cultural strengths may intersect with STEM learning. This paper serves as an exploratory analysis of this aim, specifically the ways cultural strengths common to Mexican immigrant members of a school-based community garden mediate STEM learning opportunities. Prior work seeking to understand how culture may shape learning in Latiné communities revealed how complex coordination within families and groups during seemingly routine activity can provide a powerful learning space (Rogoff, 2014). Research has also noted the need in learning to attend to the regularity of a cultural value system within non-dominant communities where the well-being of the group or community is paramount (Severance, 2021). This shared sense of purpose and collective identity motivate joint activity wherein rich learning can occur (Rogoff, 2014). Work in "culturally responsive" (Gay, 2002) and "culturally sustaining" (Paris, 2012) design has demonstrated the validity of making cultural strengths – whether practices, values, or knowledge – of non-dominant communities central to learning. Within STEM education, researchers have demonstrated the power of making cultural strengths central for learners from non-dominant groups, including indigenous communities (e.g., Bang & Medin., 2010), Black communities (e.g., Brown, 2021), and Latiné communities (e.g., Eglash et al., 2013). More exploration of the nature of cultural strengths and their potential in STEM learning is needed, particularly those of an axiological nature which can promote particularly meaningful forms of STEM learning (Bang et al., 2016).

This study takes place within the context of a long-term community-university partnership in the western US, with university researchers and students having closely worked alongside local Mexican immigrant families for several years to support and sustain activity within a 0.5 hectare community garden. Located at a semi-rural primary school where 97% of students identify as Latiné and 100% receive free and reduced lunch (a marker of poverty) the garden is a hub of activity. Throughout the garden's existence, university and community members have sought to privilege community knowledges by design and to promote an anti-oppressive arrangement, where

Latiné immigrant families are the garden stewards and experts. A heterogeneous group of over forty Mexican Immigrant families cultivate not only their own food security, but also their own agency, identity, leadership, and knowledge, including STEM-related (agri)cultural knowledge (e.g., understanding of plants, water systems, etc.).

We are studying the garden as an activity system with a focus on codifying and understanding the cultural strengths Mexican immigrant gardeners and their families bring into the garden space and how these strengths may open up possibilities for STEM learning. Specifically, following work suggesting the centrality of shared purposes and values in STEM learning (Bang et al., 2016; Severance, 2021), we explore how the purposes and values of gardeners and their families can both motivate activity and mediate learning. Our research questions ask: (1) *How do the purposes and values of Mexican immigrant gardeners and their families shape their activity in the garden?* And (2) *How might activities motivated by shared purposes and values serve as rich opportunities to engage in STEM?*

Theoretical framework

To help analyze and explain learning phenomena encountered within the community garden, we draw on sociocultural perspectives, chiefly cultural-historical activity theory (CHAT; Engeström & Sannino, 2010) and heterogeneity or a "third space" (Gutiérrez, 2008). According to sociocultural theory, learning occurs as people engage in activity with one another through the use of cultural tools (e.g., language, symbols, systems of thinking, etc.), with learning having to occur on a social level between people or their proxies (e.g., writings, representations) before being internalized on an individual level (Vygotsky, 1978). Relatedly, learning within CHAT is defined broadly as an expansion of existing activity (i.e., something that did not exist previously; Engeström, 2001). These notions of learning and how learning occurs frame our examination of activity in the community garden. Within the community garden, we seek to understand whether and how learning as a 'co-construction of knowledge' and 'new social arrangement' of peoples "transforms and creates culture" in the garden (Engeström & Sannino, 2010, p. 4), particularly in relation to STEM (agri)cultural knowledge and practices.

CHAT also offers useful framings for understanding the organization of activity wherein learning occurs, namely what serves to drive and sustain collective activity. A bounded activity, such as the community garden, constitutes an 'activity system' (Engeström & Sannino, 2010). When members of an activity system engage in activity, their actions ideally support achieving a common object or goal. The notion of an 'object' equates to the purpose(s) that drives the individual and collective activity in a space. Engaging in goal or object-driven activity requires attending to other aspects of an activity system. CHAT posits that as individuals engage in activity with others in a community, their interactions are influenced by explicit and implicit rules. Moreover, for a community to engage in activity towards a shared object, a division of labor must occur. CHAT also theorizes the central role of cultural tools in increasing the capacity of individuals and community to engage in activity towards an object. We envision this project as a starting point to analyze the garden as an activity system. We seek to leverage the notion of an activity system to better identify and codify purposes and values that drive activity and better explain how aspects of the garden space, such as relationships among family members and the use of certain tools, shape activity.

In addition to CHAT, we draw on heterogeneous perspectives, chiefly the notion of a "third space," to better understand how horizontal arrangements of expertise, which have shown promise in promoting motivation and collective ownership over activity (Gutiérrez, 2008), can lead to potentially transformative learning opportunities. Often associated with formal education settings, achieving a "third space" requires the traditionally dominant practices of a space to come into dialogue with traditionally marginalized practices, resulting in a hybrid space offering previously unavailable access and agency to learners. Although the garden is not a carefully designed learning environment, we seek to leverage the notion of heterogeneity to examine whether and how the garden and the learning occurring in the garden may be developing and transforming "the individual, the individual's relation to the social environment and the environment itself" (Gutiérrez, 2008, p. 152). Possibilities may emerge in which the activity in the garden can confront ethnic and racial hierarchies and create new systems of relations that can provide opportunities for Latiné learners' empowerment, particularly regarding STEM learning.

Methodology

This study is a qualitative case study composed of multiple embedded cases (Creswell, 2007; Yin, 2009). Learning occurring in the context of activity in the community garden as a whole serves as the phenomenon of interest. The nature of this phenomenon results from the interaction of smaller subunits within the activity system, that is, the activity of individual gardeners and their families. In a tangible, physical way, the 0.5 hectare space of the garden reflects the parts-to-whole organization of the activity we seek to understand with the garden subdivided into 48

4.5x4.5 meter plots for which families take the lead on caring for and serve as the primary locus of their activity. The garden also has a large milpa (corn, beans, and squash) field, one large plot of pumpkin and squash varieties, a nopal garden, herb garden, and communal seating and cooking areas. All community members volunteer three hours a month to maintain communal areas under the direction of a garden manager (also a community member).

Data collection followed ethnographic qualitative approaches (Gonzáles et al., 2005), with researchers "following" the activity of gardeners and families over the course of a growing season from March to November. 8 gardeners and 12 families volunteered to serve as focal participants in this research study. The makeup of families in the community garden typically consisted of intergenerational units (e.g., children, parents, and grandparents). All participants identified as Mexican immigrants with a sizable number revealing undocumented statuses and over 70% employed as farm workers. Data for this study consisted of over 200+ WhatsApp entries from community gardeners engaging in photo and video self-documentation of their activity (approximately 3-4 times a month), 30+ semi-structured interviews, three filmed garden walks with gardeners and their families each season where we acted as observers and asked about their activity in their plots and the garden in general, and field notes from regular events and other communal activities that occurred over the course of a year in the garden (e.g., fall harvest activities and celebrations). All data underwent transcription and translation into English by researchers fluent in Spanish.

Data analysis involved periodic analytic memos (Emerson et al., 2011; Saldaña, 2009), as well as rounds of inductive and deductive coding. As we collected data over time, research meetings became facilitated reflection sessions focused on using an emic stance to derive potential insights into gardeners' and families' activity up to that point and capturing these in-process claims as analytic memos. These insights (e.g., primacy of relationships, different purposes observed) led to potential codes for use in reducing the data during coding. The coding process followed rounds of inductive ("bottom-up") and deductive ("top down") analysis (Emerson et al., 2011). To derive an initial set of codes, we drew on ideas from CHAT (e.g., object/purpose, cultural tools, rules, division of labor) and the notion of a third space for STEM learning (e.g., participant practices, STEM practices) in conjunction with insights from the aforementioned analytic memos. We revised the codebook via successive rounds of coding data. Any disagreements in coding led to group discussions to resolve the disagreement. Coding pointed to potentially revealing patterns and excerpts thought to exemplify (or contradict) those patterns. These excerpts underwent further fine-grained analysis to identify evidence supporting (or contradicting) claims related to broader patterns found.

Findings

Data collected over the course of nine months in the community garden has provided preliminary evidence for what we believe to be commonly occurring cultural strengths of an axiological nature that Mexican immigrant gardeners and families orient towards in their activity and how these strengths may offer opportunities and productive contexts for youth and their families to engage in meaningful STEM learning.

Claim: *Distraer y conectar* as axiological cultural strengths to drive activity

A consistent pattern that has emerged from data across 10 of the 12 focal families indicates the primacy of valuing connection as a cultural strength and the integral role this plays in motivating purposeful activity in the garden. We have characterized this phenomenon in the garden as what we see as the mutually constitutive concepts of *distraer* and *conectar. Distraerse*, is a reflexive Spanish verb meaning "to distract (oneself)," but is used more broadly to describe getting out of the norm of everyday life and being distracted in a positive way. Conectar means "to connect" and in the garden, we have seen activity focused on connection while seeking distraction, including "to connect" with family, with the land, with their foodways, and with their community more broadly.

Gardeners have talked about *distrayendo* (being distracted) and *conectando* (connecting) in primarily two ways while explaining the purpose and rationale for their activity in the garden. For many, going to the garden provides a change of scenery from day-to-day work and family activities and allows them to disconnect from various aspects of daily life, and to *conectar* (to connect) to themselves, each other, plants, and the land. One gardener, Marta, who decided to participate in the garden to "desocupando un poco mi mente" or *empty my mind a little* but also reinvest in her relationship with her sister, exemplifies this emphasis. Marta reflects, "ella era más como figura mamá y exigía y yo pues obedecia pero últimamente se ha convertido como ese lazo de hermandad que hemos formado." *She was more like a mother figure and she ordered and then I obeyed but lately she has become like that bond of sisterhood that has formed.* Being together in the garden, distracted from the typical dynamics that guided their relationships, Marta and her sister found a way to connect and remediate their relationship.

Gardeners also talked about the importance of the garden as a means to *distraer* and *conectar* for their children, to distract them from the TV and spend time outdoors in the garden and also promote building deeper relationships with their parents and connections to nature and long held (agri)cultural knowledge associated with prior generations and family origins. Fully 20 out of 42 of all families demonstrated this emphasis over time. Enrique and his children serve as a prime example of families who sought out distracting activities that could also provide opportunities for intergenerational relationship building and connecting through growing plants. During his interview, Enrique's explanation for his family's activity points to the cultural strengths of *distraer y conectar*:

Researcher:	¿Cuáles son las razones por las que le gusta participar en el jardín aquí en Calabasas?	What are the reasons you like to participate in the garden here in Calabasas?
Enrique:	Una de las razones más grandes es que ellos vienen a distraerse, mis hijos. Y cómo se los dije, él es al que le interesan más las plantas y se siente a gusto estar aquí. Y cada vez que venimos siempre vemos algo nuevo. A veces ellos se ponen a agarrar los insectos. Entonces mi mayor razón es que ellos puedan disfrutar un momento de estar a gusto, y también que aprendan cómo es que se producen las frutas y las verduras. Hay muchas cosas que aprendo de él. El luego me dice "las frutas crecen de está manera" o "podemos plantarla así y van a estar mejor." El me sorprende porque sabe muchas cosas de las plantas. Y yo veo que ellos están contentos y alegres. Y cuando vienen y cortan las fresas o ven que está creciendo lo que ellos plantaron, la emoción en ellos es muy grande. Entonces la mayor razón por la que yo estoy aquí son mis hijos.	One of the biggest reasons is because they come to get distracted, my children. And as I told you, he is more interested in plants and he feels comfortable being here. And every time we come we always see something new. Sometimes they [my kids] start to catch the insects. So my main reason is that they can enjoy a moment of being comfortable, and also that they learn how fruits and vegetables are produced. There are many things I learn from him. He tells me "the fruits grow this way" or "we can plant them like this and they will be better." He surprises me because he knows many things about plants. And I see that they are happy and joyful. And when they come and harvest the strawberries or see that what they planted is growing, they get very excited. So the biggest reason I'm here is my children.

Enrique describes how when his children "get distracted" in the garden it provides them valued opportunities to connect in multiple ways. He notes that his son can "[feel] comfortable being there" and how his children "start to catch insects," denoting desires to connect to the land and to nature. Enrique also reveals – albeit implicitly – the value he places on connecting with his children through their garden activity. His description of how "every time *we* come *we* always see something new" (emphasis added) suggests a perception of activity in the garden as an opportunity to share experiences with one another. Not only are his children learning "how fruits and vegetables are produced," but Enrique notes the "many things [he] learn[s]" from his son, a relationship dynamic he enjoys for its novel dynamic ("He surprises me") and the enjoyment he sees it promotes in his children. The cultural strengths of *distraer y conectar* mediate an impressive array of activity for this family.

Claim: Meaningful STEM learning through cultural strengths distrayendo y conectando

While the cultural strengths of *distraer y conectar* drive broad activity valued by families, we also see evidence that these strengths in the context of the garden promote rich opportunities for STEM learning. Mexican immigrants and the broader Latiné community have long experienced inequitable opportunities for STEM learning in the US. And yet within the garden we routinely observed families essentially doing STEM through a "third space" wherein they productively integrated the cultural strengths of valuing connection and relationships into their engagement in STEM practices – the ways in which scientists figure out phenomena and solve problems (NRC, 2012). Our data provides some insights into the mechanism by which *distrayendo y conectando* may promote opportunities for STEM learning that families see as purposeful and meaningful. Across all families, the intergenerational nature of the activity (e.g., with children, parents, grandparents) provides a rich foundational relationship that when taken to the space of the community garden provides the *a gusto* or "comfort" we observed with Enrique's children earlier – there is a sense of belonging (Calabrese Barton & Tan, 2019) – that helps mediate a willingness to explore nature and solve problems in the garden.

How families engage in STEM practices in the garden within the context of *distraer y conectar* has taken many forms. Consistently, however, families' engagement in STEM practices always centers on local phenomena and problems within the garden. Within science education, major instructional models (see Krajcik & Blumenfeld, 2006) and science education reform efforts (e.g., *A Framework for K-12 Science Learning*; see NRC, 2012) all seek to have students engage in figuring out phenomena and problems over time, seeing this framing as an effective way to position students as scientists using science and engineering practices. Families in the garden, however, have created a more natural and perhaps more meaningful setting for learners to deeply engage with phenomenon buoyed by the cultural strengths of *distraer y conectar*. For example, for two families observed, the gardeners shared that their children started to love watching, observing and caring for the plants, so much so that in each case, the parents mentioned their children are now conducting plant experiments, exploring whether they can grow mango and peach seeds and other seeds they find in their food at home with the hope of transplanting these seeds into the garden.

In the following excerpt, we revisit Enrique and his children from earlier. Here, he again explicates on the purposes and values he sees as driving his family's activity in the garden. But notably he connects these cultural strengths to more recognizable and traditional notions of engaging in STEM:

Researcher:	¿Y porque crees que es importante que tus hijos sepan cómo crece la comida?	And for you why is it important that your children know how food grows?
Enrique:	Porque así ellos también aprenden a valorar la Tierra, nuestro planeta, y los recursos que tenemos. Y nosotros cómo padres podemos tener una conexión diferente con ellos. No nada más es tenerlos en la escuela o la casa. Muchas veces nosotros cómo padres no nos damos cuenta de que, aunque a lo mejor lleguemos cansados del trabajo, pero tener esos espacios y salir a convivir con ellos nos da una perspectiva muy diferente y creo que nos desestresamos al verlos que ellos andan corriendo y contentos. Es importante que ellos vean las cosas crecer porque valoran los recursos que tenemos y nos ayuda a desestresarnos al estar aquí. Y también para que vean que no es tan fácil el cosechar y cultivar. Nos encontramos con muchos obstáculos, cómo ahorita hay una parte donde no hemos podido hacer crecer los cucumbers. Entonces ellos me preguntas "por que se secan?" y "por qué no crecen?"	Because that way they also learn to value the Earth, our planet, and the resources we have. And we as parents can have a different connection with them. It's not just having them at school or home. Many times we as parents do not realize that, although we may arrive tired from work, having those spaces and going out to be with them gives us a very different perspective and I think we let ourselves de-stress when we see them running and happy. It's important that they see things grow because they value the resources we have and it helps us to de-stress being here. And also so that they see that harvesting and cultivating is not easy. We find ourselves with many obstacles, for example right now there is a part where we have not been able to grow cucumbers. So they ask me "why do they dry up?" and "why don't they grow?"

Enrique makes clear how he values the learning his children experience around how food grows as this activity not only enables them to connect with and "value the Earth, our planet, and the resources we have" but he sees it as important to his relationship with them as a parent. Specifically, he sees the activity as an opportunity for a "different connection with them." It is within this context that Enrique notes how the garden space seems to provide a "different perspective," one where his children are free to run around but also to ask questions about phenomena and related problems: "So they ask me, 'why do [the cucumbers] dry up?' and 'why don't they grow?' *Asking questions and defining problems* constitutes a central science and engineering practice (NRC, 2012), which serves to focus STEM activity on a tangible phenomenon or problem. We see Enrique's family's experience of engaging phenomena within the context of pursuing *distraer y conectar* as a new learning arrangement (i.e., "third space") that privileges the values of a community historically marginalized in STEM alongside deep engagement in widely recognized STEM practices like *asking questions and defining problems* or *analyzing and interpreting data*.

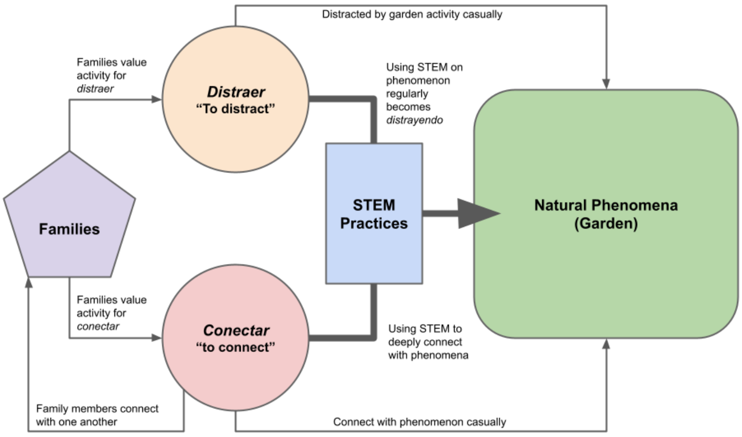
Families in the garden engaged in *distraer y conectar* over extended periods and opportunities for children and their families to connect to the phenomena of the garden and solve problems continued accordingly.

Families' prolonged engagement with phenomena echoes principles in science education (NRC, 2012; Krajcik & Blumenfeld, 2006), and sometimes became a primary focal activity in the garden. With Enrique and his sons Diego and Ronaldo, for example, the engagement with phenomena became synonymous with *distraer y conectar*. Enrique began to encourage and facilitate his son's exploration of natural phenomena in and out of the garden, even so much as providing his son Diego with resources to do "research" on plant growth. Here, during a self-documentation session, Enrique asks his son Diego to provide an explanation of their activity that day while in the garden:

Enrique: So what are you doing?
Diego: Planting the watermelon.
Enrique: Uh huh.
Diego: And each one, each time you plant one it always starts as a first little watermelon plant and it'll grow up to a bigger one and it'll have a flower and that flower will have a small little round thingy inside it and it'll grow and grow and grow bigger and bigger until it turns into a full-size watermelon.
Ronaldo: It'll grow bigger, bigger, bigger!
Diego: And ultimately if you find seeds in there you can replant them. And make sure you have great soil.
Enrique: Okay so this is the process in the plants to the watermelon. Correct?
Diego: Si. It's the lifecycle of the watermelon.
Enrique: Okay thank you.

Enrique's simple prompt belies the research and thinking his son has engaged in recently around the phenomenon of plant growth, specifically the development of fruit. Enrique expects his question to elicit an explanation – an act that very much resembles the science and engineering practices of *constructing an explanation* and *communicating information* (NRC, 2012). His utterance of "Uh huh" seems to act as a sort of science "talk move" (Michaels & O'Connor, 2012), similar to "say more" which is intended to draw deeper explanations of thinking from learners. Diego's extensive description of the phenomenon of plant growth and fruit development reflects *conectar,* with Diego connecting to nature (valued by Enrique), but also mediates a connection for younger Ronaldo with plant growth (in echoing "It'll grow bigger, bigger, bigger!). Similar to the previous vignette, we also see the family members connecting with one another in notable ways in the context of phenomena. Ronaldo interjects with his own mini-explanation to become part of the activity between Diego and Enrique. Enrique's prompts are purposeful, he is enjoying documenting their activity ("thank you"). Diego embraces his given role in this intergenerational activity, even correcting his father in providing a more accurate scientific term of "lifecycle" in wrapping up his explanation.

Figure 1
How cultural strengths distraer y conectar support (agri)cultural STEM learning in the community garden



Discussion and conclusion

This study examined how the purposes and values Mexican immigrant families bring into a community garden space can serve as cultural strengths and facilitate opportunities for rich STEM learning. Specifically, this study offers the mutually constitutive concepts of *distraer y conectar* as cultural strengths for learning. In the context of the abundant phenomena of the garden, pursuing *distraer y conectar* can lead children and families to explore the natural world through recognizable STEM practices while striving to *distraer*, to distract or disconnect from the everyday dynamics of life and to *conectar* or to connect with themselves, each other, and the land (see Figure 1). Broadly, this work follows previous STEM education research examining the axiological aspects of science learning (see Bang et al., 2016), and similarly finds that cultural values and purposes can serve as robust cultural strengths for STEM learning. Having a space to enact axiological cultural strengths can prove consequential, allowing for new activity, new relations to nature and each other, and a new relationship to STEM for youth and families, particularly those from historically marginalized populations in the US.

Relatedly, this study provides evidence for the transformative potential of allowing youth and families space to pursue and act on axiological cultural strengths like *distraer y conectar*. As gardeners purposefully engage in the garden to disconnect from the mundane routines of everyday life and to connect with themselves, each other, and the land, they place themselves in a different space both physically and otherwise. In line with the notion of "re-mediation" (Gutiérrez, et al. 2009), this study showed how the relationships people have with their external world can shift or transform into new relations and connections, changing themselves in the process. This study provides examples of how STEM learning can support such transformations. We offered evidence for how Diego's very being seemed to shift when in the phenomenon-rich space of the garden: he is happy in the garden, running around chasing bugs, exploring how the environment has changed and supported by his father in using STEM practices to deepen his explorations. As Enrique commented, Diego feels *a gusto* or at ease and comfortable in the garden. He feels a sense of belonging in this space, notable in that many students from Latiné and other marginalized communities do not feel welcome when engaging in science (Calabrese Barton & Tan, 2019). In a real sense, this study offers evidence for not only how STEM learning in the garden led to new understandings of STEM knowledge and phenomena, but people coming to new understandings of themselves and others.

Additionally, this study offers needed insights into how to achieve a heterogeneity of expertise or a "third space" (Gutiérrez, 2008) for STEM learning and its transformative potential. Beyond seeking a hybridization of dominant and non-dominant practices in learning (e.g., Gutiérrez et al., 1995), this study shows the potential of seeking to infuse values and purposes of marginalized groups with dominant practices (e.g., STEM practices). In this study, we saw evidence that the new arrangement – a valuing of *distraer y conectar* and exploration of the natural world via STEM practices – leads to new forms of value-laden STEM activity. The implications of this are potentially significant. It opens avenues for community members to both continue in valued cultural practices but simultaneously pursue explorations of phenomena in the natural world, solve relevant problems, and become essentially "culturally-sustaining" (Paris, 2012) STEM practitioners. Given time, this value-affirming activity may take root among families in the community garden, and children explaining phenomena and developing solutions to problems in the context *distraer y conectar* or other cultural strengths could become a regularity.

This study also contributes to research documenting knowledge and practices from non-dominant communities and provides unique ethnographic insights for understanding how shared community spaces like gardens function as rich sites for learning, including STEM learning. Learning in CHAT can be broadly understood as an expansion of existing activity (Engeström, 2001). This study provides evidence for how the garden is a new social arrangement where even the "experts" in the space who arrive with (agri)cultural knowledges are learning with others as they adapt to the climate and soil conditions, suggesting gardeners are "co-constructing knowledge together" (Engeström & Sannino, 2010). We continue to explore the full complexity of learning in the garden, but what is emerging in the data is how relationship building is embedded in the purposes of *distrayendo y conectando*. The importance of "learning with purpose" (Severance, 2021) in STEM and other settings in ways that attends to community and relationships has become increasingly clear. This study adds further evidence to these perspectives.

More research is urgently needed to understand how cultural strengths can support meaningful learning in STEM, particularly those of an axiological nature (Bang et al., 2016). Numerous important questions remain about how to properly engage learners' cultural strengths (e.g., *What counts as a cultural strength for learning? Under what settings and circumstances can cultural strengths be effective for learning?*) New insights that emerge from future work may provide the principles needed to support design work in other settings beyond community garden spaces (e.g., schools, museums, libraries). The implications are potentially vast in terms of addressing longstanding, seemingly intractable inequities in STEM learning and moving towards providing all learners, but particularly learners from non-dominant communities, opportunities to use and embrace cultural strengths in purposeful activity.

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How Does Feedback Formulation Pattern Differ Between More-Improvement and No-Improvement Student Groups? An Exploratory Study

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Abstract: Accumulating studies suggest including multiple feedback components such as evaluation and suggestion within one feedback unit is beneficial, yet how various feedback components are formulated and their learning effect remain understudied. This study examined the formulation pattern of different feedback components in the feedback given and received by groups with different levels of learning improvement. In social studies classrooms in Singapore, fourteen groups of secondary schoolers (n=61, female=61) participated in giving peer feedback during collaborative argumentation activities. Collaborative argumentation and feedback components of each group were collected and analyzed. The result reported that more-improvement groups tended to give and receive feedback that included an evaluation or position component before giving suggestions. No-improvement groups were more likely to give and receive feedback that started with a supportive standpoint of the reviewed content before opposing standpoints. The findings provide insights for the implementation of effective peer feedback in authentic classroom settings.

Introduction

Peer feedback is defined as a learner-centered educational activity in which students assess the quality of their peers' essays and provide feedback (Wu & Schunn, 2020) with the intention "to improve and accelerate learning" (Sadler, 1998, p. 77). From the socio-constructivist and socio-cognitive learning perspectives, peer feedback activities provide students the opportunity to close the gap between current and desired performance via discussion with peers, logical reasoning, and in-depth reflections (Noroozi et al., 2020; Sadler, 1998). Researchers conceptualized peer feedback as a communicative event based on the interpersonal communication model (Johnson & Johnson, 1991) that stressed the equal importance of feedback giving (producing feedback), feedback receiving (decoding the feedback), delivery of feedback (communication channel) and learning context (instruction and activity design) (Winstone et al., 2017). Despite the growing body of research highlighting the learning benefits of a feedback giver and receiver (e.g., Su & Huang, 2022), the delivery of peer feedback was less discussed. Delivery of feedback refers to how feedback is presented to receivers such as through feedback layout manipulation, level of detail, and presentation medium (Winstone et al., 2017). A failure in feedback delivery may result in not only feedback providers giving surface-level feedback but also feedback receivers facing difficulties in understanding the feedback, distrusting their peers as well as having negative emotions towards their peers (Carless, 2019). Such challenges were often identified in real-world K-12 classrooms, where students had limited time to construct and decode peer feedback (Winstone et al., 2017). Existing scholar surrounding the delivery of feedback message usually focuses on categorizing different feedback components in feedback content (e.g., Kusumaningrum et al., 2019). The different feedback components (Strijbos et al., 2010) commonly address the nature or purpose of the feedback content, which usually includes the evaluation of the work (identification of both strengths and weaknesses), seeking clarifications, and giving suggestions for improvements. For example, Hattie and Timperley's (2007) meta-analysis argued about three major components to be included in quality feedback: Where am I going?, How am I going?, and Where to next? (Hattie & Timperley, 2007). Another commonly applied model is Perkins (2003)'s ladder of feedback, consisting of clarity, value, question, and suggestion as the key content types. The recent studies by Wu et al., (2020, 2022) also discussed the different feedback components including identifying problems, providing solutions, and indicating the location of the problem and/or solution.

The different feedback components were found to mediate the impact of feedback on student learning in different ways. For instance, a positive evaluation that identifies strengths could boost the confidence of the feedback receivers and a negative evaluation that highlights learning gaps could discourage receivers (e.g., Eva et al., 2012). Suggestion for improvement was found to be an essential component for constructive feedback or feed-forward as it encourages critical and reflective thinking processes of the feedback receivers (e.g., Wu et al., 2022). In the context of collaborative argumentation activities in social studies classrooms, the types of standpoints students take on controversial topics and statements become feedback components such as supportive, opposing, or neutral positions (Jensen et al., 2021). To support more effective application of different feedback components, various scaffoldings were developed such as sentence openers or question prompts, scripts, and feedback exemplars (e.g., Peters et al., 2018; Latifi et al., 2021). These scaffolds often support different feedback components that evaluate the strength and weakness of work and give suggestions and solutions. Empirical studies have indicated the benefits of providing scaffolds to enable learners to give and receive constructive feedback in Computer Supported Collaborative Learning (CSCL) contexts (Winstone et al., 2017).

As accumulating studies suggest multiple feedback components within one feedback unit, researchers in recent years call for attention to the interplay of multiple components within one feedback (e.g., De Sixte et al., 2020), arguing the importance of a balanced proportion and meaningful formulation of different feedback components (e.g., Wu & Schunn, 2020). Instead of involving too complex and non-structured information that becomes overwhelming for the feedback receiver, feedback components are expected to be formulated with a stepwise presentation (Armengol-Asparó et al., 2022). Therefore, the sequence of feedback components becomes a key consideration of feedback formulation. Existing empirical studies surrounding the sequence of feedback components discussed the different ways students give positive evaluations such as simple praise versus mitigating praise (Patchan et al., 2016). Mitigating praise describes the formulation of positive evaluations given right before criticism, and existing studies reported mixed results in terms of its impact on students' learning (Patchan et al., 2016). The positive impact is that mitigating praise could soften the tone of negative evaluation but it might undermine the severity of the problem, resulting in recipients being less likely to act upon feedback (Wu & Schunn, 2022). In terms of giving feedback in the form of suggestions, researchers suggested providing elaboration on the problems before proposing suggestions was more beneficial than merely providing suggestions (Patchan et al., 2016).

The limited empirical evidence indicates that apart from what feedback components are given and received, further exploration of how feedback components are formulated and their role in learners' learning outcomes can add value to the existing understanding of effective peer feedback practices. An effective approach to identify good practices of peer feedback engagement is comparing the learning process of student groups with different learning performances or improvements (e.g., Noroozi et al., 2016). This study, therefore, will zoom into the groups with more improvement and no improvement in group learning before and after peer feedback activity.

Informed by the interpersonal communication model of peer feedback (Johnson & Johnson, 1991), this study aims to address the scarcity of study in the feedback delivery aspect to provide insights into supporting peer feedback practices in authentic classrooms. Thus, this study seeks to gain insights into formulation patterns of feedback components employed by student groups of different levels of learning improvements in a tech-rich social studies classroom. Fine-grained analysis of feedback content will be employed to reveal the sequential pattern of different feedback components within one feedback unit and a key research question will be explored: What was the formulation pattern of different feedback components in feedback given and received by more-improvement and no-improvement groups?

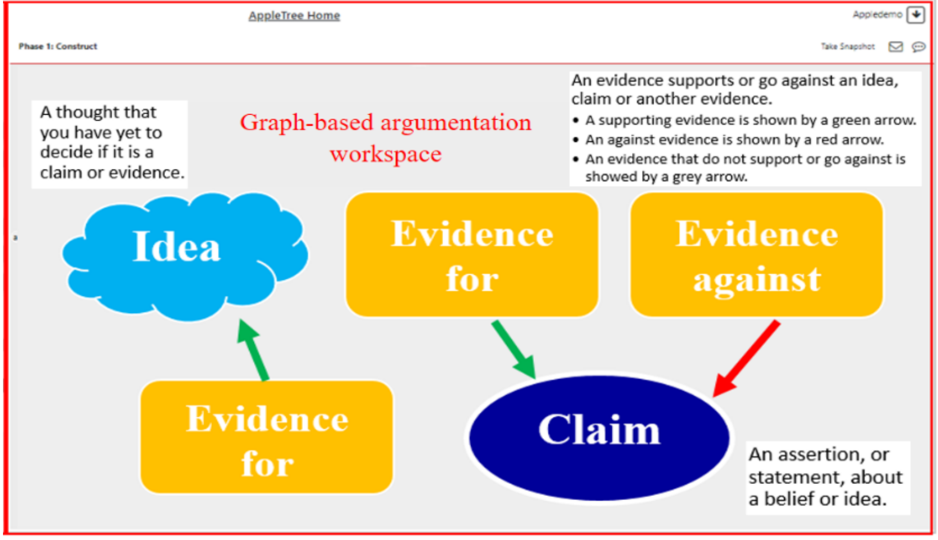
Method

Mixed-method analysis approach was employed to examine the peer feedback process and both qualitative and quantitative data analysis techniques were adopted to analyze the collected data.

Participant

A total of fourteen groups of students (n=61, female=61, average age=10) from two classes of a Singapore secondary school participated in the study and completed a series of collaborative argumentation activities on the AppleTree platform (appletree. sg), see Figure 1. This platform allows students to co-construct argumentation graphs in a shared workspace with claim bubbles, evidence bubbles, and structuring arrows. During peer feedback activity, the platform allows students to enter another group's workspace and leave comments. All participating students were familiar with their teacher and their group members before the commencement of this study.

Figure 1
AppleTree Platform Interface



A thought that you have yet to decide if it is a claim or evidence.

An evidence supports or go against an idea, claim or another evidence.

- A supporting evidence is shown by a green arrow.
- An against evidence is shown by a red arrow.
- An evidence that do not support or go against is showed by a grey arrow.

An assertion, or statement, about a belief or idea.

Procedure

Teachers and researchers co-designed 3 collaborative argumentation activities on controversial social issues of a similar level of difficulty. The collaborative argumentation activities were conducted in three classroom lessons (1-hour each) across three weeks. Each activity consisted of three phases: within-group ideation (20 mins), between-groups peer feedback (10 mins), and within-group refinement (20 mins), leaving 10 minutes for logistics and instructions. During within-group ideation (phase 1), each group co-constructed their group argumentation on the AppleTree platform. After ideation, the teachers briefly explained how to give constructive peer feedback by identifying strengths, identifying areas for improvement, seeking clarifications, and making suggestions. After the teacher's explanation, each group was invited to another group's AppleTree space to provide feedback on their group argumentation (phase 2). After providing peer feedback, they returned to their group workspace on the AppleTree platform and refined their group argumentation (phase 3). The group formation and teachers were consistent throughout the three argumentation activities.

Data collection

All groups' argumentation diagrams in both ideation (phase 1) and refinement phases (phase 3) across three weeks were exported from the AppleTree platform for further analysis. Similarly, all feedback given by groups (phase 2) was obtained from the AppleTree platform with every feedback tagged with the timestamp of feedback created, the creator's group identification, the receiver's group identification as well as feedback content details.

Coding of collaborative argumentation quality

To identify more-improvement and no-improvement groups, qualitative content analysis was conducted to code the collaborative argumentation quality before and after peer feedback activity. Each group's argumentations in the ideation phase and refinement phase were coded to identify their improvement in the collaboration outcome before and after peer feedback. The coding scheme of argumentation was adapted from Stapleton & Wu (2015) including four dimensions: clarity, multiple perspectives, selection of evidence, and elaboration and depth. Each dimension was coded on a scale of zero to three and the final quality score was the sum value of four dimensions for each group's argumentation. A total of 72 argumentation graphs were coded by two trained coders and inter-rater reliability was satisfying (Cronbach's alpha =0.844).

Based on the coding results of each group's collaborative argumentation quality, Hake's gain was calculated to identify each group's level of improvement before and after peer feedback in different argumentation activities. In this way, groups with Hake's gain higher than 15% were identified as more-improvement groups and groups with zero hake's gain were identified as no-improvement groups.

Coding of feedback components

To identify the formulation of feedback components in each feedback unit, we conducted content analysis guided by the segmentation procedure suggested by Strijbos et al., (2006) which stressed that "sentences or parts of compound sentences are more likely to contain a single concept, expression or statement" (Strijbos et al., 2006, p. 37). We used the syntactical unit or sentence level as the unit of analysis and every feedback unit was coded as a sequence of components. The coding scheme of the feedback component was adapted from the ladder model of feedback (Perkins, 2003), shown in Table 1, which was chosen for its good fit with the analysis of peer feedback activity conducted in the collaborative knowledge improvement context (Tan & Chen, 2022). Contextualized in collaborative argumentation activity in social studies classrooms, the components supportive position, opposing position, and neutral position were added to represent the content that focused on conveying assessors' standpoints on the argument topic. (Zhu & Carless, 2018). Positive, negative, and neutral evaluation components were also distinguished considering their different learning effects (De Sixte et al., 2020). A total of 316 feedback given and received by more-improvement groups and no-improvement groups were coded, 195 of which contained more than one feedback component and were coded as a component sequence. Here is an example of feedback that was coded as "Positive Evaluation (PE) with Clarification (C) and Positive Evaluation (PE) components": "It is good in the sense that the quote states clearly the obvious difference and that it really supports the claim (PE). But how many of the different races that they surveyed and is the number of people they surveyed the same for the different races? (C) A good source is chosen and it's a clear explanation (PE)." Two trained coders coded all feedback data independently and the inter-coder reliability was high (Cohen's Kappa= .891).

Table 1
Coding Scheme of Feedback Component

Component	Code	Description	Example feedback
Supportive position	SP	Statement indicating agreement or supportive standpoints on the argument	I agree with that you mentioned this because income really can't determine the number of problems people face.
Opposing position	OP	Statement indicating disagreement or opposing standpoints on the argument	I wouldn't agree that the government overlooks certain groups of people. This is because of the different financial aid and schemes given to different people of different economic statuses.
Neutral position	NP	Statement indicating neutral views on the argument	I personally feel like the application of the various schemes are extremely stringent and requires a lot of tedious tasks in order to get help from the government.
Positive evaluation	PE	Statement that identifies strengths	This is an excellent example to support this claim.
Negative evaluation	NE	Statement that identifies weakness	Your evidence is not appropriate to support your point.
Neutral evaluation	NEE	Neutral evaluation	This evidence is not linked back to your claim.
Clarity	C	Statement seeking clarifications or further explanations	How does Chinese giving up on their practices and privileges support and link to the fact that the efforts are not effective?
Suggestion	S	Statement that gives suggestions for improvement	Maybe you can elaborate on why people who are struggling refuse to get help.

Data analysis

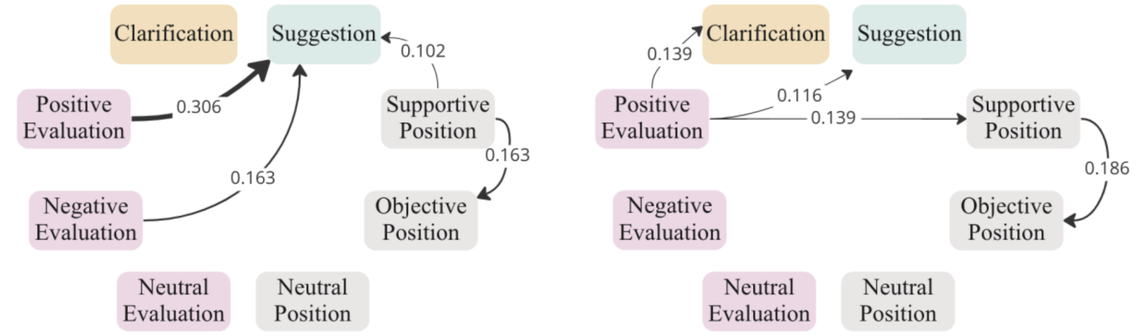
Mixed-method analysis approach was employed to examine the feedback formulation patterns in groups of more-improvement and no-improvement in collaborative argumentation quality. Based on the qualitative content analysis results of the peer feedback component, frequent sequence mining (Zaki, 2001) was implemented to reveal the sequential pattern among different components within one feedback. It is a powerful technique that was often used to reveal sequential patterns in CSCL context (e.g., Chen et al., 2017). The R package arulesSequence was adopted to the coded feedback components, which involved the SPADE algorithm, a well-known algorithm for sequential pattern identification (Zaki, 2001). To comply with the package's terminology, each feedback was treated as one component sequence and every component was treated as an event, such as the "suggestion (S) of positive evaluation (PE)". A total of 195 pieces of feedback given and received by both no-improvement and more-improvement groups were formatted and processed. The threshold of support value was set to 0.1 to identify the most frequent sequences in the output, meaning that only frequent sequences appearing for 10% or more in all feedbacks were considered. This value was chosen for its appropriateness considering the feedback dataset volume in this study.

Results

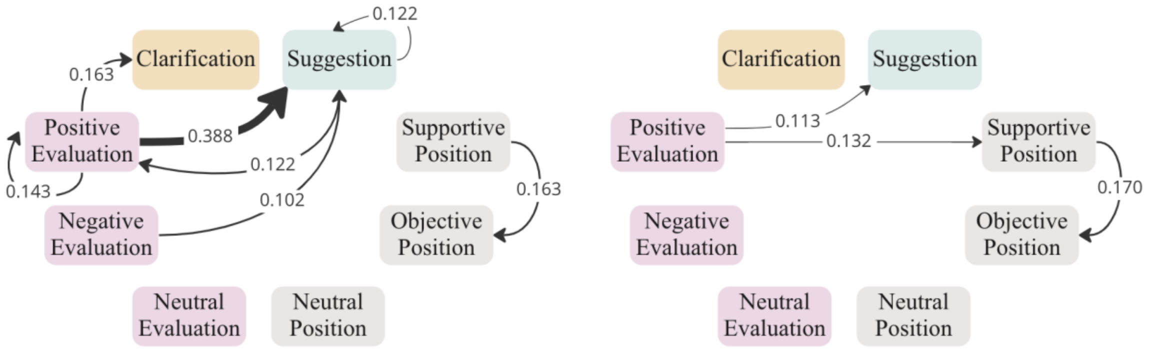
The frequent sequence mining output was reported in Figure 2. Each identified frequent sequence between two feedback components was represented with a weighted arrow line and its support value was attached. For example, the arrow line starting from positive evaluation pointing to suggestion indicates the frequent sequence of positive evaluation followed by suggestion within one feedback unit. The sequence with higher support value was presented with a thicker line, indicating its higher possibility to be identified in feedback provided and received by more-improvement groups and no-improvement groups.

Figure 2

Frequent Sequences Among Different Feedback Components in Feedback Given and Received by More-improvement Groups and No-improvement Groups



(a) Feedback given by more-improvement groups (b) Feedback given by no-improvement groups



(c) Feedback received by more-improvement groups (d) Feedback received by no-improvement groups

As feedback givers, more-improvement groups and no-improvement groups presented different feedback formulation patterns, see Figure 2 (a) and (b). More-improvement groups most frequently provided positive evaluation before suggestions for improvements, shown in Figure 2 (a). There was also a high chance that suggestions followed a negative evaluation. In comparison, non-improvement groups focused on sharing their standpoints instead of giving suggestions, reflected in the most frequent sequence of supportive position before an opposing position which stated the areas being agreed upon before articulating disagreements, see Figure 2 (b). Besides, non-improvement groups often gave a positive evaluation before a supportive position, identifying strengths and then sharing their agreements on the argumentation content. Another two sequences often applied are the clarification following a positive evaluation and suggestion. As feedback receivers, there were more diverse sequences identified for more-improvement groups than no-improvement groups, see Figure 2 (c) and (d). Most often, more-improvement groups received feedback that started with a positive evaluation and ended with a suggestion, shown in Figure 2 (c). Besides, they were also likely to receive feedback that include a supportive position before an opposing position. Some feedback sought clarification after positive evaluation. Interestingly, there was a frequent sequence that was positive evaluation followed by another positive evaluation, indicating the feedback continuously identifying strengths of the reviewed content. Another two sequences that were only spotted in more-improvement groups was the suggestion followed by a positive evaluation and suggestion after another suggestion. In the feedback received by non-improvement groups, shown in Figure 2 (d), the most frequent sequence was the supportive position and the opposing position. Other frequent sequences received by non-improvement groups were the positive evaluation followed by a supportive position or a suggestion.

To summarize, some key similarities, as well as differences in feedback formulation patterns, can be identified in the feedback given and received by the more-improvement and no-improvement groups. For both groups as feedback givers, students tended to put a positive evaluation or supportive position before introducing other components, especially before they gave suggestions or conveyed an opposing position. One noticeable difference was that the more-improvement groups focused more on giving suggestions along with giving evaluations and sharing positions, while non-improvement groups paid more effort into expressing their standpoints along with giving evaluations or seeking clarifications. Only more-improvement groups tended to point out weaknesses before providing suggestions. When receiving feedback, both groups shared the frequent sequence of supportive position followed by opposing position and the sequence of positive evaluation followed by suggestion. In addition, the feedback received by more-improvement groups showed a variation of sequences surrounding two components: positive evaluation and suggestion, reflected in the frequent sequences of suggestion followed by positive evaluation, a consecutive positive evaluation as well as consecutive suggestion. In comparison, the feedback received by no-improvement groups presented the highest frequency in the sequences supportive position before the opposing position. Besides, neutral evaluation and neutral position components were not identified in any frequent sequence.

Discussion and conclusion

As accumulating studies comparing the learning benefits for feedback providers and receivers (e.g., Wu et al., 2022), this study probed further on the feedback formulation patterns and their roles in mediating student groups' learning improvement before and after peer feedback. The results expand the existing understanding of the interpersonal communication model of peer feedback (Winstone et al., 2017), especially the *feedback delivery* aspect with a nuanced analysis of the sequential pattern of different feedback components. The finding reports that the key difference in the feedback formulation given by more-improvement and non-improvement groups lies in the ways suggestions and positions are formulated with other feedback components. More-improvement groups focused on identifying strengths or weaknesses before providing suggestions for the other groups' work. Non-improvement groups in comparison, were more likely to focus on expressing their supportive position before an opposing position, articulating the argumentation content they agreed with and disagree with. The different feedback formulation patterns between the two groups can be explained by the theoretical underpinning of cognitive and metacognitive natures of feedback when cognitive feedback focuses on the content of the work under review by summarizing, specifying, and explaining practices and metacognitive feedback is more evaluative or reflective, challenging the work being assessed (Lu & Law, 2012). From this viewpoint, the more-improvement groups may benefit from giving evaluative and reflective feedback practice when constructing suggestions for improvement along with evaluations. In comparison, the non-improvement groups may be limited to cognitive activities such as summarizing, specifying, and explaining practices as they focused more on sharing their standpoints about the argumentation content. This finding brings implications for future instructions for peer feedback activity in social studies classrooms when student learners should be encouraged to think via evaluative and reflective thinking instead of reasoning with the argument topic itself.

The finding also highlights the difference in feedback formulation between more-improvement and non-improvement groups as feedback receivers, when the more-improvement groups received feedback combined with positive evaluation and suggestions in various ways and the sequence of positive evaluation followed by suggestion stood out with the highest frequency. Different from the recommended warmly toned and elaborated suggestions in peer feedback (De sixte et al., 2021), two noteworthy sequences in feedback received by more-improvement groups were the negative evaluation before suggestion and the consecutive suggestions. Non-improvement groups received feedback that shared the feedback givers' standpoints surrounding the argumentation topic and the most frequent sequence consisted of a supportive position and an opposing position. This finding indicates that the feedback containing the givers' standpoints surrounding the argumentation topic seemed to be less effective for recipients than those seeking clarifications or offering suggestions for improvements, in the social studies classroom context. The beneficial effect of suggestion as a feedback component was also identified in previous empirical studies (e.g., Tan & Chen, 2022) as it helps recipients correct errors and offer strategies to tackle potential problems, making the feedback *feed-forward* (Wisniewski et al., 2020). Apart from suggestions, the sequence of positive evaluation followed by seeking clarification draw our attention to the feedback received by more-improvement groups. It is likely that the feedback seeking clarification has a higher level of *specificity* that made it easier for student groups to identify the missing explanations and therefore, benefit from the practice of *acting upon* feedback (Boud., 2015). Interestingly, the seeking clarification seemed to mainly benefit feedback recipients instead of feedback givers in this study.

A few shared frequent sequences across all groups deserve further discussion under the research body of *mitigating praise* and the *affective language used* in peer feedback studies (Wu & Schunn, 2022). Previous studies of mitigating praise stressed the use of positive evaluation before giving a negative evaluation (e.g., Wu & Schunn, 2020), while this study highlights the variations of mitigating praise when a positive evaluation was often provided before suggestions instead of a negative evaluation. Another variation of mitigating language use is the frequent sequence supportive position before the opposing position across all groups, indicating that in the social studies learning context, students tended to use not only *mitigating praise* but also *mitigating position* when expressing alternative standpoints surrounding the argumentation topic. In addition, although mitigating praise refers to the strategy of putting positive evaluation *before* criticism or suggestions, this study detected the sequence of positive evaluation *after* giving suggestions. Therefore, building on the existing studies that argued about the negative and positive effects of affective language use (Patchan et al., 2016; Wu & Schunn, 2020), this study suggests that apart from identifying *whether* an affective language is used, a close examination of *how* the affective language is used may contribute to a comprehensive understanding of its application and roles in peer feedback activities.

This study has its limitations. First, all participants were female secondary schoolers, which makes the finding less generalizable for male students. Besides, the existing analysis of frequent sequences of feedback components only indicates the overall formulation patterns without specifying the role of each sequence on students' learning improvement. Future studies are expected to realize a more fine-grained understanding of whether and how alternative feedback formulations may play a role in students' learning. Building on the existing studies reporting the benefits of peer feedback activity in the collaborative learning context, this study provided a close examination of the peer feedback formulation from the lens of the interpersonal communication model of peer feedback. The empirical evidence of feedback formation patterns in more-improvement groups and no-improvement groups shed light on the future effective implementation of peer feedback activities in real-world classrooms.

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Developing Productive Discourse for Knowledge Building: A Blended Approach Based on Learning Analytics

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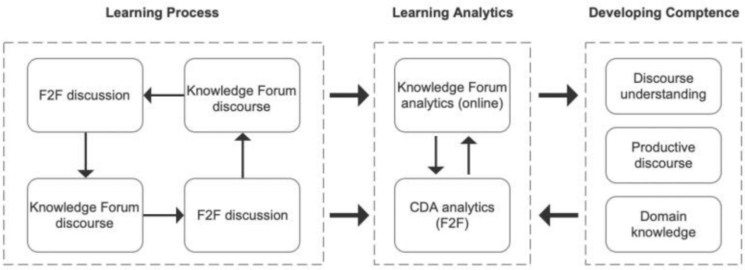
Abstract: This study investigates how secondary school students developed discourse understanding and engaged in productive discourse through a learning analytics-supported blended approach in a knowledge building environment. The study involved 15 10th-grade students studying visual arts in a Hong Kong secondary school. Students worked on collective inquiry in Art and Design through online Knowledge Forum® and classroom discussion. A key design involved the integration of online and classroom discussions through meta-discourse with the support of learning analytics. Results indicated that the students promoted discourse understanding and engaged in productive online discourse progressively. Qualitative analysis of classroom discourse and artifacts revealed students developed discourse understanding, relating to noticing of quantity and quality of discussion. The implications for the analytics-supported design to help students engage in productive discourse for knowledge building are discussed.

Introduction

Productive discourse is a dialogue that acts as a medium for helping students develop the learning processes, improve ideas, and create new knowledge (Mercer et al., 2019; Scardamalia & Bereiter, 2014). Helping students to develop productive discourse has been the focal point of research in learning sciences. However, Initiate-response-feedback (IRF), as a traditional structure that provides less opportunity for students to take responsibility and build on each other's ideas, is still the dominant discourse pattern in many classrooms (McNeill & Pimentel, 2010). Therefore, there has been a growing interest in investigating productive discourse and researchers have developed various concepts into discourse (e.g., academically productive talk, dialogic space, dialogic teaching; Alexander, 2017; Resnick et al., 2010; Wegerif, 2006). As an educational model, knowledge building focuses on the development of productive discourse and students adding value to community advances, supported by Knowledge Forum®, a multi-media discussion platform (Scardamalia & Bereiter, 2014). Knowledge Forum provides a communal space for knowledge development to support sustained productive discourse. Engaging in productive discourse is essential to knowledge building for community knowledge advancement. Previous research in knowledge building has been conducted to support students' engagement in creative processes, in particular developing productive discourse (see review, Chen & Hong, 2016). To engage students in knowledge building, classroom and online discourse are intertwined. Knowledge Building Talk (KB Talk) is commonplace as students reflect and talk about their Knowledge Forum work via classroom discussion. Research in the knowledge building field has primarily focused on using learning analytics to visualize online Knowledge Forum discourse that help students engage in a collective reflection process to improve ideas (Resendes et al., 2015; Yang et al., 2020), but limited study aligns students' reflection with online and classroom discussion analytics for knowledge building and how to integrate classroom discussion analytics into knowledge building circle is not well examined.

There has been intensive research on learning analytics to integrate big data and analytics to understand challenges in the educational area (Knight & Shum, 2017). In the context of knowledge building environment, increasing attention has been paid to the study of implementing learning analytics for supporting student collective reflection of progressive discourse (Chen & Zhang, 2016; Resendes et al., 2015). Since knowledge building emphasizes epistemic agency and collective responsibility, learning analytics need to move beyond providing feedback to teachers and be augmented with meta-talk for students to reflect on their own work to advance knowledge building process. As learning analytics use increases, it opens possibilities for visualizing the collaborative knowledge building discourse process and supporting the reflection from multiple layers, including individual and community levels. Although previous studies have considered the benefits of visualizing online Knowledge Forum discussions via learning analytics, few have looked closely at visualizing classroom KB talk. Another theme of the present study relates to students' understanding of the nature of discourse. Research in science education has examined students' understanding of the nature of science, but less research attention has been given to students' understanding of the nature of discourse. Students are not only expected to engage in productive discourse but also to understand the nature of discourse. Some preliminary evidence show that students' understanding of discourse could be fostered using reflective inquiry (Lei & Chan 2018). This study examines further how an analytics-supported knowledge building environment could help students to develop productive discourse because an analytics-supported approach may help students develop a deeper understanding of the nature of discourse, thus bringing about productive discourse. We proposed a framework integrating two modes of discussions analytics for developing knowledge building competencies (Figure 1). Guided by the framework, we designed a learning analytics-supported blended (LAB) approach that involved students integrating their online and face-to-face classroom discussions analytics for developing discourse understanding, productive discourse, and domain knowledge.

Figure 1
A design framework of analytics-supported discourse development for knowledge building.



A learning analytics tool - the Classroom Discourse Analyzer (CDA; Chen et al., 2020, 2022) - was implemented. CDA was originally developed to visualize classroom discourse for supporting teachers' reflection and analysis of classroom discourse (Chen et al., 2020). In this study, we provided the CDA to students for them to reflect on their KB talk in the classroom. Figure 2 shows an interface of the CDA visualizing various discourse moves, with corresponding videos and classroom discourse transcripts.

Figure 2
An example of the CDA interface (top left: classroom video; bottom left: discourse moves coding; right side: classroom discourse transcripts. Notes: Bubble size represents the number of words in a turn; the number on the right side of each line indicates the frequency of occurrences of the specific type of dialogue (identified in the list on the left side of each line); the corresponding percentage indicates the ratio to the total number of coded turns).

The purpose of the present study was to investigate how the designed approach was implemented to examine and help students develop discourse understanding and engage in productive discourse. Specifically, three research questions were addressed: (1) What characterizes students' understanding of discourse, and how do they change with the LAB approach? (2) How do students engage in productive Knowledge Forum discourse over time? And (3) How does the LAB approach scaffold students' discourse understanding and productive discourse?

Methods

Research context and participants

Fifteen Grade 10 students (aged 14 to 15; $n_{\text{female}} = 8$, $n_{\text{male}} = 7$), studying visual arts in a Hong Kong secondary school participated in the study. They studied the topic of Art and Design for three months. The teacher had employed knowledge building teaching for approximately 10 years.

Pedagogical design

The key design of the pedagogical cycle is to engage students in collective knowledge building through online and classroom meta-discourse processes in a designed LAB approach (Figure 3). In a regular knowledge building environment, students propose problems and build theories supported by Knowledge Forum. In this study, we enriched the design by emphasizing a blended approach by integrating online and classroom discourse, afforded by learning analytics. Primarily, students inquired on Knowledge Forum, augmented by classroom meta-discourse and learning analytics supported meta-discourse as reflecting on how their online and face-to-face discussions are developed. Students engaged in classroom meta-discourse and group work supported by analytics from Knowledge Forum and the CDA. Specifically, students were provided with the visualization of the ideas-building network (Figure 4a) and the CDA-generated discourse patterns (Figure 4b) with discussion content from the online Knowledge Forum and classroom discussion.

Figure 3
Pedagogical cycle of the LAB approach.

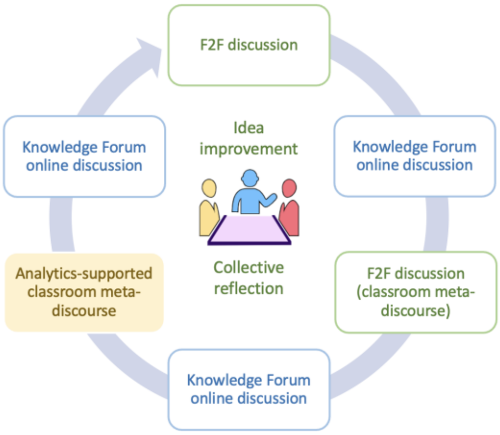
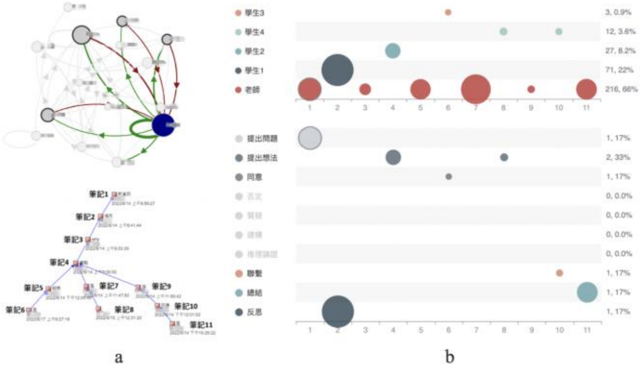


Figure 4
Visual learning analytics of online Knowledge Forum and classroom discussions. Visualization of Knowledge Forum discussion



a b

Notes. Top left: ideas-building network [different bubble represents different students; bubble size represents the number of notes contributed]; bottom left: discussion thread [each icon represents a note]). Visualization of classroom discussion (Notes. top right:

classification by speakers; bottom right: classification by types of discourse moves; bubble size represents the number of words in a turn

Data sources and analysis

Data were collected regarding students' (a) discourse understanding, using pre- and post-tests with open-ended questions; (b) domain knowledge of art and design, using pre- and post-tests with open-ended questions; (c) Knowledge Forum engagement using Knowledge Building Discourse Explorer (KBDeX) (Oshima et al., 2012) and content analysis through a theory- and data-driven coding scheme (Chuy et al., 2011; see Table 1); and (d) classroom discussion, interview, and artifacts.

Table 1

Coding scheme for analyzing discourse moves in Knowledge Forum inquiry.

Codes	Sub-codes	Description	Examples
Questioning	Explanation-seeking (C1)	Questions on seeking open-ended responses with the explanation.	How to design an artifact with the theme of traveling?
	Sustained inquiry (C2)	Asking further questions based on previous notes or ideas and making the discussion deeper.	How will you design an artifact that expresses the theme of traveling and technology with the purpose of helping people solve problems?
Theorizing	Proposing an explanation (T1)	Proposing an explanation that explains certain phenomena for the first time.	There are some steps in designing an artifact.
	Supporting an explanation (T2)	Supporting an already existing explanation proposed by another student and providing a justification.	It could be or not, but we can revise the steps during the progress of the design.
Community	Connection (C1)	Reference to their own or others' notes or quote extra sources to advance understanding.	We need to determine the theme for designing an artifact🟥("themes" S036) ...we also need to determine the purpose of this artifact.
	Synthesizing notes (C2)	Refer back to what has been discussed and ask a new question for monitoring the inquiry process and advancing the discussion or generating an explanation or evaluation to appraise their own or others' notes.	We discussed the idea of the purpose of design… 🟥 ("purpose" S015) and the purpose could be depended on the needs of the people 🟥("life" S011) What we need to inquire further is how to understand people's needs?

Results

RQ1. What characterizes students' understanding of discourse, and how do they change with the LAB approach?

The first research question examined the role of design and processes on students' understanding of the nature of discourse. We examined students' open-ended questions and interviews. Students' responses were analyzed to characterize their different levels of discourse understanding, aligned with knowledge building perspectives. We coded students' responses in the open-ended questionnaire into three levels. Students' views varied from knowledge-sharing to knowledge-construction and knowledge-building (van Aalst, 2009). At level 1, students are concerned with behavioral aspects of discussion or simple sharing, and at level 2, they referred to different views. However, at level 3, they viewed the role of community in knowledge construction. A significant change was obtained from pre- to post-test, $t(14) = 6.500$, $p < .001$. Students' responses on domain knowledge were coded using a three-point scale, ranging from simple to more complex and deeper layers. Significant pre- to post-test change was obtained, $t(14) = 4.785$, $p < .001$. The results suggested that students improved discourse understanding and domain knowledge after instruction. Qualitative analysis of student open-ended questions and interviews revealed interrelated themes about how students understand the nature of discourse. Table 2 shows the nine main themes representing students' understanding.

Table 2

Students' understanding of the nature of discourse captured in the open-ended questions and interviews.

	Themes	**Examples**
Theme 1	Share ideas (Goals).	"The goal of discourse is to express and exchange ideas."
Theme 2	Achieve correct answers, and solve problems (Goals).	"The goal of discourse is to get correct and fruitful answers." "The goal of discourse is to solve problems."
Theme 3	Advance community knowledge, create new knowledge (Goals).	"We combine diverse ideas and deepen the discussion to create new knowledge."
Theme 4	Active participation (Constituents).	"Many students participate in the discussion and express ideas."

Theme 5	Diverse topics and ideas (Constituents).	"Include different types of questions and diverse ideas."
Theme 6	Take collective responsibility and work as a community (Constituents).	"I think a good discourse needs collaborative work."
Theme 7	Build on others' ideas with examples and evidence, ask further questions (Strategies).	"Illustrate our ideas with examples and build-on others' ideas." "Ask further questions to extend and deepen the discussion."
Theme 8	Search relevant materials, and challenge each other for improving ideas (Strategies).	"Search materials and discuss them with others." "Refer back to the previous discussion and challenge others' ideas."
Theme 9	Reflect and synthesize ideas (Strategies).	"We need to synthesize ideas progressively." "Reflect on what we have discussed."

As shown in Table 2, themes 1-3 characterize student conceptions of the goal of discourse, including sharing ideas, solving problems, and advancing community knowledge. Students commented that discourse should "Combine diverse ideas and deepen the discussion to create new knowledge." So the students need to express their opinions and bring together the core ideas to deepen the discussion and advance collective knowledge. Themes 4-6 show student understanding of the constituents of productive discourse. Students regard active participation (theme 4), diverse ideas (theme 5), and collaborative work (theme 6) as essential constituents. As a student commented, "A good discourse needs collaborative work." Students should take collective responsibility to add value to their community. Themes 7-9 show students' ideas of the strategies for developing productive discourse. Students positioned that provide evidence and ask further questions as effective strategies for improving discourse (theme 7). To improve ideas, students further recognized the need to challenge others' ideas (theme 8) and reflect on the progress of the discussion (theme 9).

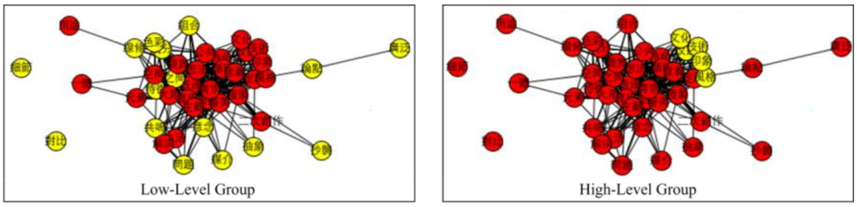
RQ2. How do students engage in productive Knowledge Forum discourse over time?

Differences in collective Knowledge Building inquiry

KBDeX analysis was conducted to understand how discourse understanding was related to students' collective knowledge building inquiry based on keywords usage and coherence (Oshima et al., 2012). First, students were divided into high- and low-level groups based on their post-test discourse understanding. Comparing the number of keywords used in the two groups (Figure 5, 30 versus 41 keywords used, respectively) suggested students with a higher extent of discourse understanding engaged more productively in knowledge building inquiry by using more keywords.

Figure 5

Visualization of keywords usage between low- and high-level discourse understanding groups in KF discourse.



Note. Yellow and Red Balls: words that were used by the whole community. Red ball: words that were used by the selected groups.

Changes in depth of productive Knowledge Forum discourse

Further to network analysis, content analysis was conducted to examine how students inquired in Knowledge Forum. Students' Knowledge Forum discussions were coded (see Table 1). The Knowledge Forum notes were analyzed into three phases, aligned with the time period based on the work of meta-discourse and visualization analytics-supported meta-discourse, to understand how students engaged in productive discourse progressively. In Phase 1, with the log data reflection (e.g., number of notes created, number of notes read), high- and low-level discourse understanding groups engaged in Knowledge Forum discourse moves, including sustained inquiry and proposing an explanation; In Phase 2, with the classroom meta-discourse, the high-level group conducted Knowledge Forum discourse moves, including sustained inquiry, proposing an explanation, supporting an explanation, and connection; while low-level group mostly engaged in surface discourse moves (explanation-seeking questions and proposing an explanation); In Phase 3, with the visual analytics-supported meta-discourse, the low-level group started to conduct higher-level discourse moves (e.g., supporting an explanation and connection) and the high-level group started to engage in more meta-discourse moves, including connection and rise-above. In sum, both low- and high-level discourse understanding groups showed engagement in progressive discourse over time. The findings suggested the role of the designed environment in supporting students' development of productive discourse.

Correlation and regression analysis

Correlation analysis was conducted to examine the relationships among different variables (Table 3). A common index of high-level discourse moves was created by combining high-level Questioning (sustained inquiry), high-level Theorizing (supporting an explanation), and Community (connection and synthesizing). Correlation analyses show that students with a deeper discourse understanding were more likely to engage in high-level discourse moves ($r = .645$) and had higher domain knowledge ($r = .553$).

Table 3
Correlation among domain knowledge, discourse understanding, and high-level Knowledge Forum discourse.

	1	2
1 Post-domain knowledge	-	
2 Post-discourse understanding	.553*	-
3 High-level Knowledge Forum discourse moves	.586*	.645**

Notes. **p* < .05; ***p* < .01.

Hierarchical regression was conducted to examine how prior domain knowledge, high-level KF discourse moves, and post-test discourse understanding predicted students' post-test domain knowledge (Table 4). Prior domain knowledge explained 46.9% of the variance, adding discourse moves explained an additional 11.8% variance, and adding post-test discourse understanding explained a further 4.3% variance, suggesting that high-level discourse moves and understanding contributed to students' post-test domain knowledge, over and above prior domain knowledge.

Table 4
Hierarchical regression on post-test domain knowledge.

	R	R^2	R^2 Change	F Change
Pre-domain knowledge	.685	.469	.469	11.471**
High-level Knowledge Forum discourse moves	.766	.587	.118	3.422**
Post-discourse understanding	.793	.629	.043	1.261*

Notes. **p* < .05; ***p* < .01.

RQ3. How does the LAB approach scaffold students' discourse understanding and productive discourse?

The following two examples illustrate students' reflection on their Knowledge Forum and classroom discussions with the help of visual analytics. Through qualitative analysis of the video recordings of classroom discussions, interviews and artifacts, these examples provided additional support illuminating how the visual analytics support meta-discourse. The examples are elaborated below.

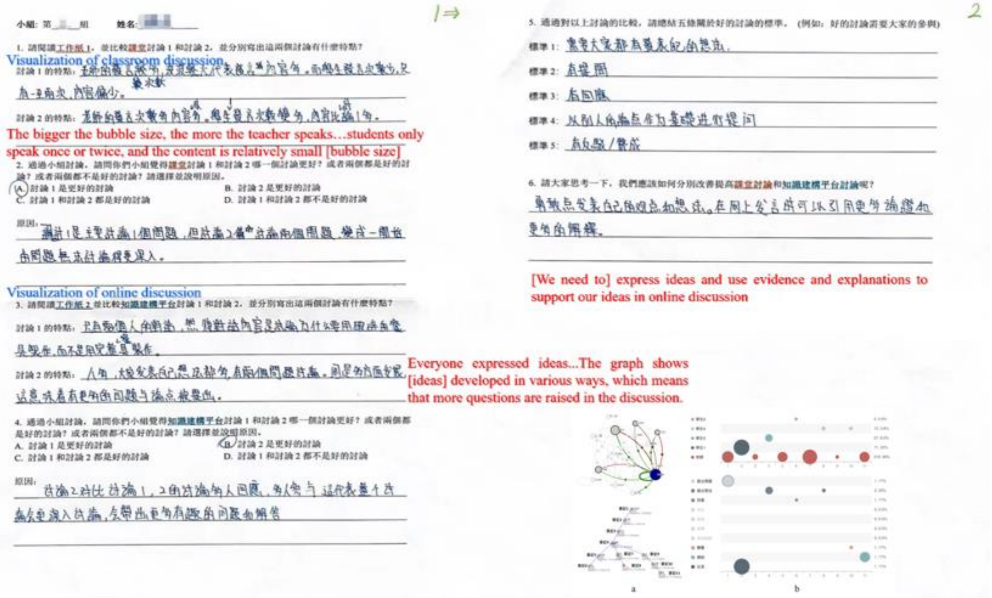
Facilitating students' noticing of participation and engagement in discussion

Guided by the LAB approach, students used the visualizations from the CDA and Knowledge Forum to help them notice their participation and engagement in both classroom and online discussions (Figure 6). Students were aided to notice the amount and content of their classroom discussion. For example, students emphasized the importance of the length of the talk and the discussion content, "We can see the length of the talk based on the size of these bubbles. However, if the content is not good, it would not be a good discussion." "The bigger the bubble, the more explanation classmates provide." Moreover, when students continued their discussion in Knowledge Forum, they realized that "[We need to] express ideas and use evidence and explanations to support our ideas in online discussion." Taken together, supported by the LAB approach, students started to enrich their views on noticing the participation and engagement in the discussion.

1. Teacher (T): What did you notice from the visualization, video, and transcript?
2. S1: Discussion.
3. T: What do you think when you read these bubbles?

4. S2: We can see who has spoken [through the bubble] and what they have said [through the transcript]. **We can see the length of the talk based on the size of these bubbles**. However, **if the content is not good, it would not be a good discussion**.
5. T: Good point. Can anyone add more?
6. S3: The more lines, the more classmates speak. **The bigger the bubble, the more explanation classmates provide**. It will make the discussion become richer.
7. T: Anyone?
8. S4: **The teacher has many big bubbles and talks a lot in the discussion. Only three or four student lines here. It would be good if more classmates can join.**

Figure 6
Prompt sheet with the visualizations from the CDA and Knowledge Forum.



1⇒

小組：第[redacted]組 姓名：[redacted]

1. 請閱讀工作紙1，並比較課堂討論1和討論2，並分別寫出這兩個討論有什麼特點？

Visualization of classroom discussion

討論1的特點：

討論2的特點：

The bigger the bubble size, the more the teacher speaks…students only speak once or twice, and the content is relatively small [bubble size]

2. 通過小組討論，請問你們小組覺得課堂討論1和討論2哪一個討論更好？或者兩個都是好的討論？或者兩個都不是好的討論？請選擇並說明原因。
[✓ A. 討論1是更好的討論]
B. 討論2是更好的討論
C. 討論1和討論2都是好的討論
D. 討論1和討論2都不是好的討論

原因：

Visualization of online discussion

3. 請閱讀工作紙2並比較知識建構平台討論1和討論2，並分別寫出這兩個討論有什麼特點？

討論1的特點：

討論2的特點：

Everyone expressed ideas...The graph shows [ideas] developed in various ways, which means that more questions are raised in the discussion.

4. 通過小組討論，請問你們小組覺得知識建構平台討論1和討論2哪一個討論更好？或者兩個都是好的討論？或者兩個都不是好的討論？請選擇並說明原因。
A. 討論1是更好的討論
[✓ B. 討論2是更好的討論]
C. 討論1和討論2都是好的討論
D. 討論1和討論2都不是好的討論

原因：

2

5. 通過對以上討論的比較，請總結五條關於好的討論的標準。（例如：好的討論需要大家的參與）
標準1：需要大家都有發表自己的想法.
標準2：有提問
標準3：有回應
標準4：以别人的論点作为基礎进行提问
標準5：有反駁/贊成

6. 請大家思考一下，我們應該如何分別改善提高課堂討論和知識建構平台討論呢？
勇敢点发表自己的观点和想法。在网上发言時可以引用更多論據和更多的解釋。

[We need to] express ideas and use evidence and explanations to support our ideas in online discussion

Increasing students' awareness and supporting reflection

Students also understand more about the use of discourse moves to enhance their awareness of the nature of discourse after the implementation of the LAB approach. Supported by the visualization of discourse types, S20 noticed the lack of higher-level moves in their discussion, "We do not have 'challenge', 'reasoning', 'connection', 'synthesis', and 'reflection' (the student points out the visualized bubble of classroom discussion). We need to have these discourse types, in particular the 'reflection'." Primarily, using discourse moves, particularly the higher-level moves, which are necessary for supporting idea development in progressive knowledge building discourse, is challenging for students and this approach could help students deepen discourse understanding and use different moves.

> "We need to join the discussion, ask questions, respond to others' questions, challenge each other, synthesize ideas, and reflect on the discussion. We also need to have evidence to support our ideas...Only three students joined the discussion. Also, **we only have the types of discourse** on one 'ask questions', seven 'propose ideas', one 'agree', and one 'build-on' in our discussion. We do not have 'challenge', 'reasoning', 'connection', 'synthesis', and 'reflection' (the student points out the visualized bubble of classroom discussion). **We need to have these discourse types, in particular the 'reflection'**."

Conclusion and implications

This study investigated the designs of a LAB approach to help students develop discourse understanding and engage in productive discourse for knowledge building. With a growing number of studies using analytics information to support teaching and learning processes, learning analytics becomes an essential approach to help students engage in productive learning (Lang et al., 2017). This study integrated two modes of discourse (online and classroom discussions) supported by learning analytics to address the issue of idea segmentation in knowledge building community. Results of the study using open-ended questions and interviews indicate that students promoted their understanding of discourse after the LAB approach. Content analysis of online discussions shows that students develop productive discourse over time. Analysis of classroom discussions and artifacts showed how learning analytics can support the noticing of participation and engagement in the discussion. This study contributes to the literature on knowledge building highlighting the role of an analytics-supported blended approach, with learner-generated information provided to participants for them to reflect on their ongoing work for promoting discourse understanding and developing productive discourse. The integration of online and classroom discussion through meta-discourse processes with learning analytics provides different possibilities. Many studies show the important role of learning analytics and this study also shows how the approach supports the development of discourse understanding. The significance of the study lies not only in its innovative combination of visual learning analytics to support both online and classroom learning practices, but more importantly, in its extension of the literature by examining how a LAB approach can be used to enhance the productivity of student discourse in a knowledge building environment, which carries implications for visual learning analytics related teaching and learning. Future research with more time would be undertaken to include multiple rounds of pedagogical cycles with visual analytics-supported reflections for knowledge building.

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Promoting Students' Self-Regulated Learning Choices with Diagrams in Intelligent Tutoring Software

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Abstract: Although students' self-regulated learning has been studied extensively, past research has not investigated students' fine-grained, self-regulated choice-making processes during learning with visual representations and strategies to support such processes. We conducted design and experimental studies with 148 students to develop and evaluate an intervention package for supporting students' self-regulated choice-making in using diagrammatic scaffolding in algebra tutoring software. A classroom experiment showed that students with the intervention learned greater conceptual and procedural knowledge in algebra than students in the control condition whose choices were not supported. Also, students with the intervention chose to use diagrams less frequently overall but showed distinctive use patterns that changed over time, indicating a form of self-regulated diagram use. This study demonstrates the importance of understanding and supporting choice behaviors that change over time during learning, going beyond simply measuring the frequency of choice behaviors and encouraging students to engage in these behaviors more frequently.

Introduction

In modern society, where we have access to abundant information and countless resources, learners need to proactively and strategically choose to use available resources so that they can handle tasks effectively and efficiently (Schwartz & Arena, 2013). Thus, one goal of education is to foster learners who can make strategic choices in using resources (Chin et al., 2019; Cutumisu et al., 2019).

One important choice for learners to make involves whether and how to use visual representations during learning activities. Visual representations are often used as instructional scaffold that can facilitate learners' sense-making processes during learning and problem solving. From a cognitive perspective, visual representations can help learning by, for example, reducing cognitive effort and making relevant information salient (Ainsworth, 2006). However, to use visual representations effectively, learners must (come to) understand when it is appropriate to proactively use visual representations, so that they can navigate problem solving effectively and efficiently (e.g., over-use of visual scaffolding might not help learning very much) (Schwonke et al., 2013). Acquiring such understanding is critical since learners will not always be presented with visual information in everyday problem-solving situations. Instead, they need to proactively choose to (or not to) use/create visual information to aid their problem solving when it is appropriate. Therefore, to use visual representations strategically, learners need to make self-regulated choices. In doing so, they need to judge if the use of visual scaffolding would help their problem solving or not, and make a choice accordingly. Such self-regulated choice behaviors could presumably lead to enhanced domain-level learning (Long & Aleven, 2016; Roll et al., 2011).

Despite the importance of understanding learner choices with visual representations, past research has rarely allowed for, and measured, these choices. Studies have mostly focused on learning *with* visual representations and student learning when students are *given* visual representations (e.g., Rau et al., 2015). A few studies investigated learners' spontaneous use of visual representations in problem solving (e.g., Uesaka et al., 2010). These studies found that, when the use of a visual representation is introduced as an option during problem solving, students generally tend not to choose to use it. Prompts can help learners use visual information more frequently (Wu et al., 2020), but these past studies use aggregated data in measuring choices (e.g., calculating the sum of choice behaviors) or post-hoc self-report data, making it unclear what specific choice behaviors students engaged in and how their choice patterns *changed over time* during their learning, a critical aspect of self-regulated learning (Greene et al., 2021; Roscoe et al., 2013). As learners develop skills and knowledge during learning, it is reasonable to expect that their use of certain strategies may change over time (Greene et al., 2021).

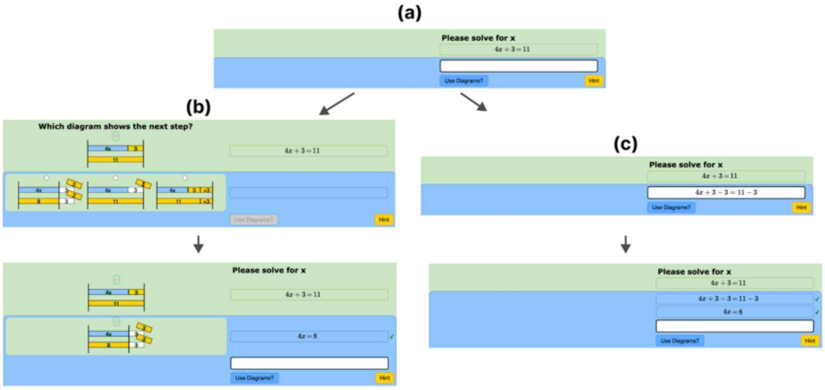
This paper reports on a design study and an experimental study we conducted with a total of 148 middle-school students in the U.S. to generate new scientific knowledge regarding learner's self-regulated choice behaviors during learning with visual representations, how these behaviors change over time, and how they might be supported with technology. We employed a user-centered design approach with eight students to create an intervention package for supporting students in self-regulated diagram use. This design phase was followed by an experimental study with 140 middle-school students in actual school classrooms in the U.S. that tests the learning that results from this intervention, when added to an intelligent tutoring system for algebra problem solving.

The diagram choice tutor

To investigate and appropriately measure students' choices in using visual representations, we designed and developed the *Diagram Choice Tutor*, an Intelligent Tutoring System for middle-school algebra in which students can choose, for each problem-solving step, whether or not to use a visual representation (called "tape diagrams," Murata, 2008) to help with their problem solving. As shown in Figure 1, when students opt to use diagrams, they need to select from three diagrams that depict what to do in the next step, one optimal diagram and two suboptimal or incorrect ones. This anticipative form of interactive visual scaffolding has been shown to support learning and problem-solving performance by having learners *self-explain* their problem-solving steps in a visual form, before they do these steps in the standard format (in this case, symbolic equations) (Nagashima et al., 2021).

The Diagram Choice Tutor presents an appropriate learning environment for learners to exercise self-regulated choice behaviors. Chin et al. (2019) argue that an ideal choice-based learning environment presents learners with options they would not select naturally (e.g., seeking negative feedback, Cutumisu et al., 2015). In the Diagram Choice Tutor, students (aged around 10-15) may naturally avoid using diagrams because doing so would require additional problem-solving steps, and tape diagrams introduce a new representation that students may not be familiar with (Murata, 2008). However, engaging with diagrammatic scaffolding during algebra learning has been shown beneficial for student learning, even with the expected cognitive effort required (Nagashima et al., 2021). Our Diagram Choice Tutor is also instrumented to collect students' learning process data to help overcome the lack of understanding regarding how students make choices.

Figure 1
In the Diagram Choice Tutor, (a) students start with an interface that shows a symbolic problem. They can choose to request a diagrammatic scaffold or not. (b) If they choose to use the scaffold for the given step, they then need to select, from three options, the diagram that shows the correct and optimal next step. After selecting the correct diagram option (e.g., the one on the left in the figure), students are prompted to do the step symbolically by referring to the diagrammatic scaffold that they have. (c) Students can also choose not to use diagrams to solve the step. This process repeats (i.e., students have the choice for every problem-solving step).



(a) Please solve for x

$4x+3=11$

(b) Which diagram shows the next step?

$4x+3=11$

Please solve for x

$4x+3=11$

$4x=8$

(c) Please solve for x

$4x+3=11$

$4x+3-3=11-3$

Please solve for x

$4x+3=11$

$4x+3-3=11-3$

$4x=8$

Designing support for self-regulated diagram use

Idea generation with students

Promoting self-regulated choices in the Diagram Choice Tutor presents a challenging design problem. It is difficult to define a criterion for when students should use diagrams (i.e., for when diagrams are most helpful for learning), as opposed to, for example, simply promoting more frequent use of diagrams. Drawing on the literature on help seeking in Intelligent Tutoring Systems, one might surmise that self-regulated learners would ideally neither over-use nor under-use the visual scaffolding but rather use it *when needed* (i.e., when the use might be most beneficial, Aleven et al., 2016). Although more frequent use of visual scaffolding means that students would get more exposure to the advantages that the visual representation has on learning (e.g., it might promote conceptual learning) (Uesaka et al., 2010), in the context of our tutor, students could overly rely on using the visual scaffolding in solving equations. Such over-use of diagrams in our tutor may lead to the acquisition of rather superficial “diagram-to-symbols translation knowledge” (i.e., copying what is shown in a diagram into the symbolic problem-solving step in the tutor, Nagashima et al., 2022, p. 1752). Because, in our Diagram Choice Tutor, tape diagrams as instructional scaffolding supplement the canonical representation (i.e., algebraic equations in symbolic notation), such superficial knowledge may not help learners when solving more advanced equation problems (for which tape diagrams are no longer useful, e.g., equations with negative numbers). On the other hand, self-regulated learners may use the visual scaffold to understand how to solve equations that they are not familiar with, but as they practice more, they might choose to practice their problem-solving/procedural skills without relying on the visual aid too much (Aleven et al., 2016). During this learning process, they may actively engage in key iterative stages of self-regulation (Zimmerman & Campillo, 2003), which are comprised of: self-assessment (“Can I solve this problem without help?”), self-monitoring (“Am I doing well with/without diagrams?”), and self-reflection activities (“How well did I do with/without diagrams?”).

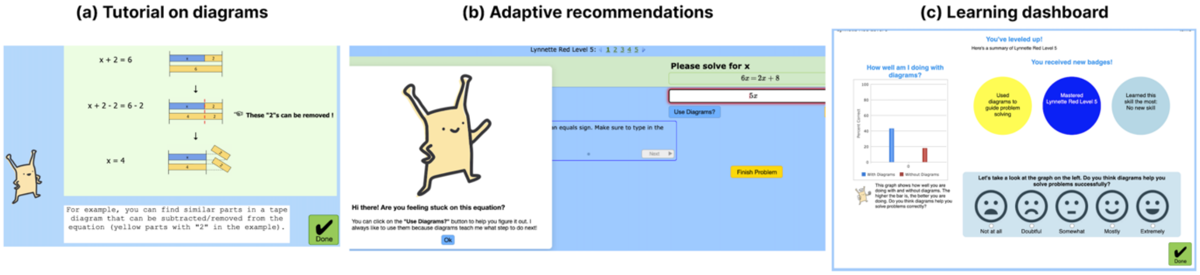
To approach this design challenge, we conducted one-on-one virtual idea-generation sessions with eight school students in the U.S. (one 4th grade, one 5th grade, one 6th grade, four 7th grade, and one 8th grade). In each session, the students first practiced a few problems with the Diagram Choice Tutor. Then, sharing a virtual whiteboard, the researcher and the student generated ideas in response to several prompting questions on self-regulated use of diagrams in the tutor (e.g., “What would be some features that would help you think carefully about whether or not to use diagrams for solving equations?”). A total of approximately eight hours of video recordings from the sessions were analyzed by three researchers using the Affinity Diagramming method. Affinity Diagramming is a standard technique used in the field of Human-Computer Interaction to analyze qualitative data to produce shared themes through multi-step synthesizing of codes and themes (Lucero, 2015). This process produced 117 codes, which we grouped into 13 themes. Then, of the 13 themes, those that share similar ideas were grouped together, resulting in five high-level ideas for promoting self-regulated diagram use in the tutor. Due to the page limit, we present just a short statement of four of the five main ideas that directly informed the design of our intervention: (Idea 1) *Tell me that diagrams are there to help, they are not there for no reason* (i.e., students want to understand how diagrams can be useful), (Idea 2) *I want to be prompted to consider using diagrams when they can be useful* (i.e., students want to know and be reminded when diagrams can be useful), (Idea 3) *Show me how diagrams are helping or not helping me* (i.e., students want to know if diagrams help their own problem solving and learning), and (Idea 4) *A diagram badge can help me think about using diagrams* (i.e., students want motivational features such as a badge for using diagrams).

Designing an intervention package for supporting self-regulated diagram use

Based on the four ideas generated by students, we (researchers) designed an intervention *package*, which consists of (a) an interactive tutorial that teaches students how diagrams can be useful (to address Idea 1), (b) an adaptive recommendation pop-up screen that prompts students to think about whether or not to use diagrams when they seem to have trouble solving problems (to address Idea 2), and (c) a student-facing learning analytics dashboard that shows how well students have been performing with and without using diagrams through visualization and badges (to address Ideas 3 and 4). See Figure 2 for more information.

Figure 2

(a) An interactive tutorial that explains how to use diagrams and research evidence on the benefits of diagrams on problem solving. (b) Adaptive recommendations, prompting students to think about diagram use, appear after any three consecutive problem-solving mistakes, after pausing for more than 90 seconds, and on the first problem in each problem set/level (more on problem levels described later). (c) A personalized learning dashboard that presents a graph showing the student’s problem-solving performance (i.e., percent correct) when they used diagrams (in blue) and when they did not use diagrams (in red) in the most recent problem level. Students are asked to answer a 5-scale “smiley” question on how they feel about the usefulness of diagrams. The dashboard also provides badges for students, based on their problem-solving performance and the use of diagrams.



(a) Tutorial on diagrams

For example, you can find similar parts in a tape diagram that can be subtracted/removed from the equation (yellow parts with "2" in the example).

(b) Adaptive recommendations

Lynnette Red Level 5: 1 2 3 4 5

Please solve for x

$6x = 2x + 8$

$5x$

Hi there! Are you feeling stuck on this equation?

You can click on the **"Use Diagrams?"** button to help you figure it out. I always like to use them because diagrams teach me what step to do next!

(c) Learning dashboard

You've leveled up!

Here's a summary of Lynnette Red Level 5

This graph shows how well you are doing with and without diagrams. The higher the bar is, the better you are doing. Do you think diagrams help you solve problems correctly?

Let's take a look at the graph on the left. Do you think diagrams help you solve problems successfully?

We designed these multiple intervention components and combined them as an intervention *package* to support the different stages of self-regulation mentioned earlier, rather than aiming to design one intervention. This decision was made because students expressed various needs and ideas for using diagrams during the idea-generation sessions. It is also suggested in the literature on self-regulated learning (Oppezzo & Schwartz, 2013). Specifically, (a) the tutorial is meant to help students think whether diagrams are useful for them (*self-assessment*), (b) the adaptive recommendations are to help students during the *self-monitoring*, and (c) the dashboard is designed to help students *self-reflect* on their choice behaviors of using or not using diagrams.

Method: Classroom study

We then conducted a controlled classroom experiment to test 1) whether the intervention package helps students gain better domain-level knowledge and skills in algebra and 2) whether and how the intervention package helps students demonstrate self-regulated use of diagrams. We compared two conditions in which students practiced algebra problem solving with the Diagram Choice Tutor (i.e., students in both conditions had control over whether to use diagrams for each problem-solving). The conditions differed in whether students had access to the intervention components (Supported Choice condition) or not (Unsupported Choice condition).

Participants

A total of 179 students participated in the study in their in-person classroom (38 5th graders, 37 6th graders, 86 7th graders, and 18 8th graders). Participants came from 11 classes in two schools in the U.S., taught by two teachers. Students in each class were randomly assigned to either the Supported Choice condition (n = 87) or the Unsupported Choice condition (n = 92). The participating teachers noted that their students' experience with tape diagrams was minimal (e.g., their instruction had never focused on tape diagrams).

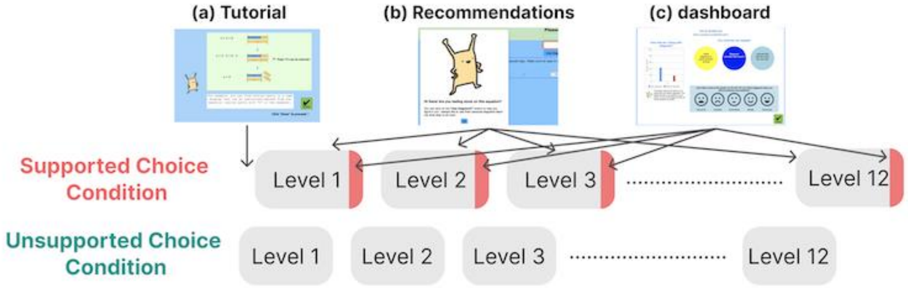
Materials

All students in both conditions in the study used the Diagram Choice Tutor (Figure 1) to practice equation solving during the study. Students in both conditions were assigned the same sets of problems (Table 1). Students in the Supported Choice condition additionally had access to the self-regulated learning (SRL) intervention components (Figure 2) embedded in the tutor. In both conditions, students had control over when to use diagrams. The only difference was whether or not students had the additional SRL components to support their choice making. Figure 3 illustrates how we integrated the intervention components into the Diagram Choice Tutor.

Table 1
Types of equation problems assigned in the tutor (in both conditions)

Problem level	Problem type	Problem level	Problem type
1	x + a = b	7	ax + b = cx + d
2	ax + b = c	8	ax + b = c (bonus content)
3	ax + b = c	9	ax = bx + c (bonus content)
4	ax = bx + c	10	ax + b = cx + d (bonus content)
5	ax = bx + c	11	ax = bx + c (bonus content)
6	ax + b = cx + d	12	ax + b = cx + d (bonus content)

Figure 3
Students in both conditions had the same practice problems from Level 1 to Level 12. Students in the Supported Choice condition additionally engaged with (a) the tutorial on diagrams before Level 1, and at the end of each Level, they were shown (c) the learning dashboard. (b) The adaptive recommendations were available from Level 1 to Level 12. Students in the Unsupported Choice condition solved algebra problems from Level 1 to Level 12 with no SRL intervention. Students in both conditions spent the same total time in the study.



We developed a web-based pretest and posttest on conceptual knowledge and procedural knowledge in early algebra based on items in the literature (e.g., Booth et al., 2013). Each test had 16 multiple-choice conceptual knowledge items and five open-ended procedural knowledge items. Two isomorphic versions of the test were developed and assigned in a counter-balanced way across pretest and posttest.

Procedure

The study was conducted during the schools' regular class periods across five consecutive days. Researchers joined the class through a video conferencing system to facilitate the study sessions. Students in both conditions first completed the web-based pretest. Then, they watched a brief video illustrating how to use the tutor. From the second day up to (and including) the fourth day, students solved algebra problems using the Diagram Choice Tutor. Students in both conditions spent the same total time in the study sessions; students in the Unsupported Choice condition spent the time exclusively on equation solving, while those in the Supported Choice condition spent it on equation solving *and* the SRL intervention components combined (Figure 3). On the final day, students completed the web-based posttest. After the posttest, all students were given access to both versions of the tutor so that they could experience the software that had been used in both conditions.

Results

Of the 179 students, 168 students completed all parts of the study. We excluded students who scored 100% on the pretest and those who did not complete more than 50% of the test items on the pretest and/or posttest, decided before testing treatment effects (Supported Choice condition: $n = 4$, Unsupported Choice condition: $n = 4$, Chan et al., 2022). Further, after a discussion with the participating teachers on students' exposure to equation solving prior to the study, all students from two advanced classes were excluded from the sample (Supported Choice: $n = 11$, Unsupported Choice: $n = 9$; these students were originally included in the study as the teachers wanted them to experience a research study, which they said they would not experience in the regular course of schoolwork). The final sample consisted of 140 students (Supported Choice: $n = 69$, Unsupported Choice: $n = 71$). No statistically significant difference was observed between the conditions in the dropout/exclusion rate, $\chi 2$ (1, N = 179) = .05, $p = .92$.

How did the intervention influence students' learning outcomes?

Table 2 shows students' mean pretest and posttest scores on conceptual knowledge and procedural knowledge in algebra. It also shows the average total number of algebra problems students solved in the tutor within the same time given to both conditions. To examine if the intervention package enhanced students' conceptual and procedural learning, we ran two separate linear regressions with condition as an independent variable, and conceptual and procedural knowledge as a dependent variable, respectively. In both models, students' pretest score (on conceptual and procedural knowledge, respectively) was added as a covariate to control for students' prior knowledge before the study. We found that students in the Supported Choice condition learned greater conceptual ($\beta = .95$, $t(137) = 2.52$, $p = .01$) and procedural knowledge ($\beta = .53$, $t(137) = 2.08$, $p = .04$) than those in the Unsupported Choice condition.

We also compared, between the conditions, the number of problems solved. We used a linear regression model with the same independent variable, and combined pretest score (conceptual and procedural) as a covariate, but with the average number of problems solved as the dependent variable. The model showed no statistically significant difference on the average number of problems solved in the tutor, $\beta = .67$, $t(137) = .32$, $p = .75$.

Table 2
Students' pretest and posttest scores (standard deviations in parentheses), and the number of problems solved

Condition	Conceptual Knowledge (*max* = 16)		Procedural knowledge (*max* = 5)		Number of problems solved
	pretest	posttest	pretest	posttest	
Supported	9.78 (2.72)	10.48 (2.49)	1.74 (1.74)	2.88 (2.03)	32.64 (13.52)
Unsupported	9.28 (2.22)	9.28 (2.15)	1.73 (1.74)	2.35 (1.88)	31.25 (13.10)

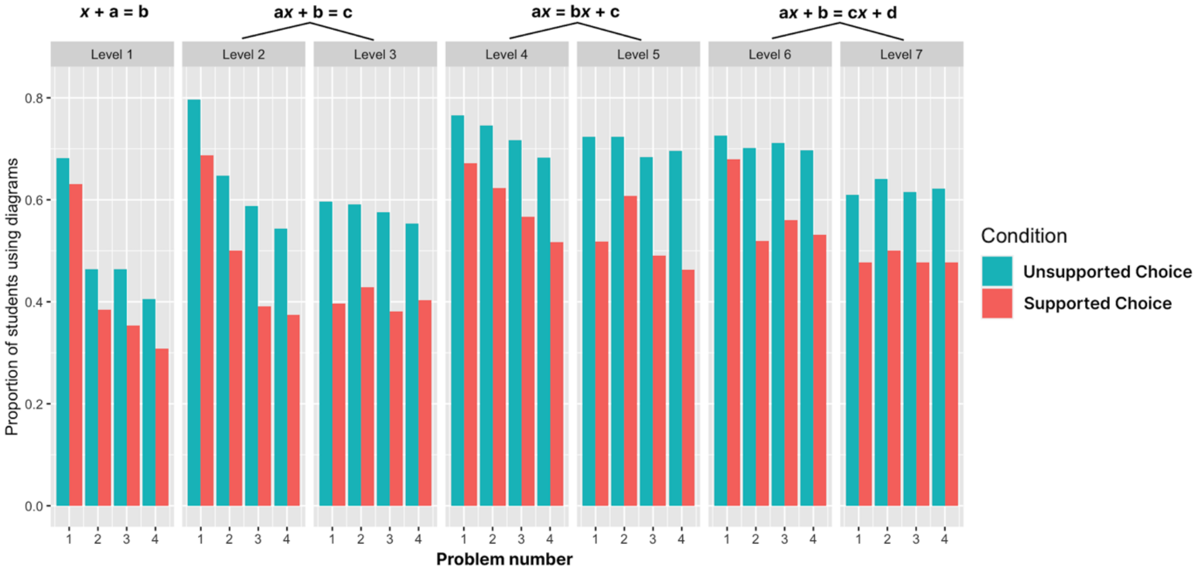
How did the intervention influence students' self-regulated diagram use?

To investigate students' diagram use across the two conditions, we examined tutor log data on the frequency of diagram use (i.e., how many times students requested to use diagrams). On average, students in the Supported Choice condition chose to use diagrams 0.12 times (*SD* = .10) per problem-solving step while those in the Unsupported Choice condition used diagrams 0.16 times (*SD* = .12). A two-sample t-test with the condition as an independent variable showed that students in the Supported Choice condition, on average, chose to use diagrams less frequently, $t(135.3) = 2.03$, $p = .04$.

To further investigate how students' choice behaviors *changed over time*, we then looked at the frequency of diagram use for each problem in the tutor. Figure 4 shows the proportions of students who chose to use diagrams at least once on each problem in the tutor, grouped by problem level. The graph reveals several notable patterns in their choice behaviors. First, many students in both conditions chose to use diagrams when they saw a new problem type (the first problem in Levels 1, 2, 4, and 6). Second, for the first problem in Levels 3, 5, and 7, in which students saw the same type of problems that they practiced in the previous level, students in the Supported Choice condition show a relatively low level of diagram use whereas at these levels students in the Unsupported Choice condition used diagrams at the rate that is not very different from their diagram use in the previous levels (Levels 2, 4, and 6, respectively). Finally, students in the Supported Choice condition show significant drops in their use of diagrams from the first to the second problem in Levels 1, 2, 4, and 6. This pattern indicates that many of the students in the Supported Choice condition chose not to use diagrams when they solved the same type of problem for the second time. This trend is also observed in the Unsupported Choice condition but is not as pronounced as it is in the Supported Choice condition (e.g., most notably in Level 6).

Figure 4

Proportions of students who chose to use diagrams at least once on each problem across problem levels. Only Levels 1-7 are shown, as Levels 8-12 were bonus problems with the same content introduced in Levels 1-7.



Discussion and conclusion

Prior work on choice behaviors in using visual representations does not offer insights into students' *choice behaviors that change over time* during learning processes despite its importance in understanding self-regulated learning processes. In our study, we first worked with middle-school students to design several intervention components to support self-regulation during learning with diagrams in the Diagram Choice Tutor. These components included a tutorial on benefits of using diagrams, adaptive recommendations that encourage students to think about using diagrams or not, and a personalized learning dashboard showing the student's recent problem-solving performance with and without diagrams. We then conducted a classroom experiment to evaluate the effectiveness of the intervention. We found that students who received the intervention learned greater conceptual and procedural knowledge, even though they chose to use diagrams less frequently overall than those without the intervention. How could less diagram use lead to greater learning in our study?

A closer look at students' changing choice behaviors in the tutor log data allowed us to understand what one form of self-regulated use of diagrams might look like. Specifically, the data suggested that students in the Supported Choice condition used diagrams more frequently when they saw a new problem type (at the outset, many students were not familiar with the problem types used in the study, according to participating teachers) but chose to use them less frequently when they kept seeing the same type of problem in the tutor. On the other hand, this pattern was not observed for students in the Unsupported Choice condition, where students made choices without the help of the intervention. These insights suggest that students whose choices were supported used diagrams when the use of diagrams may have been most helpful for learning, neither over-using nor under-using them. We conjecture that students in the Supported Choice condition, by engaging with the intervention components, were able to monitor and reflect on their own use of diagrams and were able to choose to use diagrams when they thought doing so would be helpful. For instance, it is possible that students, when seeing the graph on the dashboard, were able to deeply reflect on how useful it is to use diagrams in each problem level and on whether or not to use diagrams on the next level. Such informed choice-making practices may have contributed to the greater conceptual and procedural learning that was observed for the students in the Supported Choice condition. They focused their practice on learning how to solve new types of problems with diagrams (which may have led to conceptual learning) and then chose to practice problems without relying on the visual aid too much (which may have led to procedural learning). These insights would not have been gained only with aggregated data points but were possible with the temporally fine-grained log data collected with the technology. Such learning processes might also have contributed to faster, more efficient problem solving. Despite several additional activities (e.g., the tutorial and dashboard) that students in the Supported Choice condition had to complete (Figure 3), no difference was found on the average total number of problems completed in the tutor between the conditions.

Due to the design of the experiment, it is not possible to tease apart the effects of individual intervention components on student learning and diagram use. However, we argue that the design of the intervention as a *package* was aligned with and promoted different stages of self-regulation, as opposed to designing and testing a single intervention element. This decision was informed both by idea generation sessions with school students and a theoretical view on self-regulation. Still, we acknowledge that these speculations cannot be fully validated using the data from the current study and that other interpretations are possible. Also, the changing choice behaviors we observed in the tutor were not validated with statistical significance testing. Finally, self-regulated use of diagrams can take other forms than that addressed in the current study, depending on the context and domain of diagram use (e.g., self-constructing diagrams, Uesaka & Manalo, 2006; Uesaka et al., 2010).

The current study makes several contributions to the field of the learning sciences. First, the study contributes novel insights into how students' choice behaviors change over time, when students can choose to use or not use diagrams in the context of problem-solving practice in an intelligent system. Aggregated measures of choice behaviors (e.g., mean frequency of diagram use) do not afford the same insight. This insight is key to understanding and supporting self-regulated choice behaviors that lead to greater domain learning. The study also illustrates, by investigating students' choice behaviors, what effective use of diagrams during learning might look like. Further, we demonstrate that an intervention informed by ideas generated by students supports not only an effective self-regulated behavior but also greater domain learning, which is not typically achieved by interventions designed to support self-regulated learning with technology (but see Long & Aleven, 2016).

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Teachers' Learning to Support Students During Science Inquiry: Managing Student Uncertainty in a Debugging Context

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Abstract: This paper analyzes two teachers' participation in professional learning (PL) activities designed to help them learn to support students when they face uncertainty during a computationally-rich science inquiry unit and their subsequent enactments of the unit. In this unit, students assemble a physical computing system (PCS) coupled with sensors to program and display streams of environmental data. Students inevitably encountered moments when they were "stuck" and required teacher help. The PL activities consisted of teachers taking on "student-hat/teacher-hat" roles attempting to solve buggy PCSs followed by a discussion. Analyses using a lens on teaching as improvisation illustrated how PL activities helped teachers develop an understanding of the PCS, confidence in enacting the unit, and pedagogical strategies for making in-the-moment decisions to support students facing uncertainties. Analyses also revealed teachers' approaches for managing students' uncertainty level and the improvisation it required: one more constraining and one more expansive.

Introduction

Science education standards in the U.S. highlight several practices that are intended to reflect the work of modern scientists and engineers (NGSS Lead States, 2013). In particular, the Next Generation Science Standards (NGSS) foreground "uncertainty" as a key driver in students' developing scientific knowledge and making sense of the world. Manz and Suarez (2018) argue that "uncertainty is endemic to science" (p. 772) as "scientific practices are largely concerned with managing uncertainty and drawing conclusions in light of it" (Manz & Suárez, 2018, p. 772). For students, these moments of uncertainty arise as they engage in science inquiry when there are often "nonobvious decisions about what to do" (Manz & Suarez, 2018, p. 772). The science standards thus speak to the importance of having teachers help students grapple with uncertainty in inquiry-driven instruction as they orchestrate student learning. For many science teachers, enacting pedagogical practices that effectively support students in managing uncertainty for productive learning remains a challenge.

Moreover, just as modern science inquiry is increasingly driven by computation, so too is science classroom inquiry. Traditional classroom science instruments are being replaced with physical computing systems (PCS), like the BBC micro:bit. A PCS can be programmed and coupled with sensors to gather, process, and display streams of environmental data. By creating these systems, students engage in computational thinking practices that can have deep synergies with their disciplinary science learning.

In the context of these computing-rich inquiry activities, uncertainty often arises during moments when students' artifacts do not function as they intended, such as displaying the wrong unit of measurement (F° vs. C°). When students are unable to make their artifacts work as intended and unable to progress until they have received some kind of help, they are considered "stuck" (Huadong & Brennan, 2019). These moments of being "stuck" add additional layers of complexity for teachers as they must attend to the students' immediate concerns, help them fix their errors, while also support them in increasing their problem-solving strategies and persevering in the face of difficulties. This can be a challenging orchestration task as science teachers also often lack the necessary computing knowledge to troubleshoot and debug such systems (Tsan et al., 2022).

While prior work has examined student troubleshooting of physical computing (e.g., DesPortes & DiSalvo, 2019) and debugging programs in STEM and science contexts (e.g., DeLiema et al., 2022), much less has examined how teachers learn to support students engaged in these processes (Tsan et al., 2022). Even less has examined how teachers support students working with PCSs and engage with uncertainty as they troubleshoot bugs in the hardware (e.g., a faulty wire connection), debug the software (e.g., an incorrect conditional statement), or resolve issues across their interactions (DesPortes & DiSalvo, 2019).

To address this gap, we previously analyzed the in-situ strategies as teachers enacted a science inquiry instructional unit using a sensor-equipped PCS. We examined how teachers supported their students when they assembled their PCS. This analysis led to the design of professional learning (PL) activities focused on helping teachers learn to support students during troubleshooting and debugging (Hennessy Elliot et al., 2022). We implemented these activities as part of a four-day summer professional learning (PL) workshop with middle and high school science teachers. In this PL activity, teachers took turns in the role of a student who is stuck with a buggy system (produced with bugs previously encountered in classroom implementations of the unit) as well as the role of a supporting teacher. Participants in the PL then reflected on their experiences in this activity. The goal of the activities was to help teachers better understand their students' challenges during debugging and develop strategies to help students navigate moments of uncertainty during classroom enactments.

In this paper, we present an analysis of two teachers' participation in this PL. We examine their problem solving during the PL debugging activity, their reflections on this activity, and how their experiences shaped subsequent classroom enactments of the instructional unit. Our research was guided by the question: In what ways did the PL activities help teachers learn about managing their students' uncertainty as they engaged in debugging during a computationally-rich science inquiry unit?

Literature review

As teachers increasingly integrate programming into science classrooms, research has only begun to examine how teachers, often new to programming themselves, support their students during moments of debugging (e.g., DeLiema et al., 2022; Tsan et al., 2022). This perspective is particularly important as teachers' interactions with students are core to how students develop debugging skills and address gaps in understanding (Blikstein & Moghadam, 2019; McCauley et al., 2008). To address this gap in the research, we previously analyzed the in-situ strategies teachers used during a computationally-rich science inquiry unit to support their students when they became stuck while wiring and programming their PCS (Hennessy Elliott et al., 2023). We found that teachers do not necessarily have to be programming experts to effectively support students in debugging their physical computing systems. This work also highlights that debugging moments are highly unique and contextual and therefore require varied approaches on the part of the teacher.

To best prepare teachers for these moments of uncertainty, recent research has explored how professional learning workshops might be designed to help teachers support their students' debugging. For example, DeLiema et al., 2022 demonstrate the effectiveness of having teachers practice debugging instruction in mock classrooms and reflect on video of classroom debugging practices. Similarly, Tsan et al. (2022) describe a debugging model where teachers used a mnemonic device to assist in debugging and reflected on how they would help their students. However, they found that this strategy led to teachers mostly focused on helping students fixing the bug rather than understanding the cause of the bug.

Because learning the skills of debugging is essential to computer science (McCauley et al., 2008), PL opportunities should provide scaffolding for teachers to support students in developing debugging strategies. Strategies can help students when they run into other similar bugs in the future and can help students "handle unforeseen, novel impasses" (DeLiema et al., 2022, p. 7). Debugging can serve as rich learning opportunities as they naturally spark discussions about the learning process that help students develop critical thinking strategies and important thinking processes (Fields et al., 2021). Such thinking strategies and processes are important for teachers to support students as they encounter uncertainty in science and STEM (Manz & Suarez, 2018).

Several researchers have argued that disciplinary learning in science must go beyond a focus on scientific knowledge and practices to include epistemic affect, or learning how to feel like a scientist (e.g., Jaber & Hammer, 2016). Feeling like a scientist involves encountering and learning to grapple with the kinds of uncertainties central to the discipline (Jordan & McDaniel, 2014; Manz & Suarez, 2018). Scientists describe feeling uncertainty not only when modeling and explaining phenomena, but also when working with various tools, measurements, and determining how to analyze their data (Manz & Suarez, 2018). Further, scientists increasingly use computational tools and design processes in their inquiry and must therefore be able to debug the tools they use. Therefore, students engaging in authentic science practices that use computation to produce data should be equipped to debug and redesign tools by drawing upon technical and scientific knowledge (Hardy et al., 2020) when they encounter moments of uncertainty.

In the context of this paper, the scientific tool students used for scientific inquiry was a PCS, which offers an alternative set of introductory activities to engage students in computing (Kafai et al., 2014). PCSs are relatively user-friendly and affordable (Anastopoulou et al., 2012; Blikstein & Moghadam, 2019), but they are a challenge for debugging as bugs can occur in any part of the system: the software (or program), hardware, or the interactions between the two (DesPortes & DiSalvo, 2019).

The process of debugging PCSs used in science classrooms, similar to data collection and analysis, therefore involves encountering moments of uncertainty as students come to decision points where they do not know exactly what to do with the system. Debugging physical computing systems to use in science classrooms is a step in the process of becoming data producers (Hardy et al., 2020) that offers students – and their teachers –

pedagogical experiences with wrestling with uncertainty that they all can build on when making sense of real-world data.

Conceptual framework: Teaching debugging as improvisational

In this paper, we conceptualize teaching as "disciplined improvisation" (Sawyer, 2004), involving a strategic balance of structure and open-endedness. In exploring the integration of physical computing in science classrooms, conceptualizing the improvisation that teachers undertake is particularly important in developing teachers' ability to support student sensemaking exploring the uncertainty of questions without a single answer (Jurow & McFadden, 2011) and position science – and in turn computing – as a practice rather than a set of facts. Through experience and professional learning, teachers develop a shared repertoire of methods and strategies they draw on supporting students wrestling with uncertainty; yet their work requires being flexible enough to react to the changes, shifts, or needs of each moment.

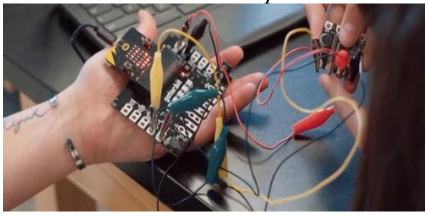
This framing affords a conceptual lens on what decisions teachers make in-the-moment to support students as they debug their PCSs and what strategies and/or structures they draw on – possibly developed in professional learning activities – to make those decisions. Improvisation, whether in art or in teaching, does not mean that "anything goes" (Sawyer, 2004); rather, improvisation has its own structures and methods (DeZutter, 2011; Halverson, 2021). Considering teaching as improvisational offers a window into how effective teaching involves authentically listening to students and facilitating students to build on each other's ideas (Phillip, 2019). Phillip (2019) describes further that when done well, teaching as improvisation involves, as a classroom community, crafting critical questions that examine issues of power in relation to historical, social, political and economic processes. Science teachers, as Jurow and McFadden (2011) argue, must make moves to set the stage by providing "slots" for students to participate in disciplinary practices using student contributions to extend the classroom community's scientific thinking.

Instructional unit and professional learning activities

This study is part of a larger multi-year, multi-site design-based implementation research project that is co-designing NGSS-aligned instructional units and PL activities that use the PCS in service of science inquiry (Biddy et al., 2021). The instructional unit in this paper introduces secondary school students to physical computing as a tool to support sensor-driven inquiry in science and STEM classes. The instructional unit uses a storyline approach (Reiser et al., 2021), where the lesson is grounded in students' generating questions about particular phenomena, planning and conducting investigations to address their questions, and creating models to explain findings.

In the storyline unit, students explore the phenomenon of the PCS that collects data streams such as classroom sound levels, local environmental conditions, or soil moisture levels in classroom plants. During this unit, students investigate the capabilities of the technology by wiring and programming physical data displays that respond differently based on data stream values (see Figure 1). The data displays incorporate a micro:bit which is wired to various sensors and programmed with MakeCode, a block-based programming language.

Figure 1
One student's PCS set up with one sensor (sound sensor)



Before implementing the storyline, participating teachers attended PL sessions which provided training on wiring and programming the PCS to explore scientific phenomena. The focus of this study is on the PL activities designed to help teachers support their students during moments of uncertainty while debugging. The PL activities were designed to provide teachers experience debugging both from the student and teacher perspectives (called student-hat/teacher-hat) (Biddy et al., 2021). During the activity, teachers were organized into groups of three, with two acting as a pair of students debugging a PCS and the third playing the role of the teacher. Each group was given a buggy PCS, planted with commonly occurring bugs that students encountered in previous implementations of the unit. The teacher pair, playing the role of students, collaboratively debugged the provided PCS, trying to find and fix the various hardware and software bugs that had been planted. The person in the teacher role gave the "students" a few minutes to work on the bug prior to entering into the conversation and facilitating the debugging process. After the activity, the PL facilitators engaged teachers in a reflective discussion about the activity, focusing on strategies teachers found helpful for supporting students during moments of uncertainty.

Methods and study context

This study took place in a rural-serving district in the western United States. Teachers participated in a four-day PL workshop designed to help them learn about computationally-rich storylines using the PCS. Two teachers were selected for further analysis because we had complete records of their PL activities and classroom enactments. These two teachers are representative of the other teachers in the project in that they were middle and high school science teachers who took part in the four day workshop and enacted the instructional unit in their classroom during the fall of 2022. The teachers, Eric and Trevor, were in their first year participating with the project and neither had prior programming experience. Eric was a third-year high school science and physics teacher and Trevor was a fourth-year middle school science teacher.

The data sources included video recordings and transcripts from the professional learning workshop's debugging activity (41 minutes) and reflective discussion (12 minutes); video recordings of debugging moments, transcripts, and field notes from Eric and Trevor's enactments of the storyline; and email correspondences. We focus our analysis on two lessons (lesson 2 and 4) where students collaboratively program and wire the PCS. We consider a debugging moment to involve the moment the teacher approaches the student(s) working on their PCS until the teacher walks away. Reviewing Eric and Trevor's classroom video, we located five debugging moments for Eric and four for Trevor. Debugging moments lasted between 49 seconds to six and a half minutes.

To answer our research question, we conducted a thematic analysis (Braun & Clarke, 2006) of teachers' discussions during the PL activities as well as their strategies during classroom enactments. We developed inductive process codes (Miles et al., 2014) to surface the strategies teachers used for debugging during the PL activity, discussion, and classroom enactments. We conducted second level descriptive coding of these strategies tracing the situations where teachers did not have a consensus or obvious strategy. To compare the strategies teachers took up, which ones they adapted, and new strategies that arose in the moment, we created a checklist matrix (Miles et al., 2014). Finally, we distilled themes based on our analysis.

Findings

In this section, we describe the themes we distilled through analyzing the debugging PL activity, the reflective discussion afterwards, and Trevor and Eric's later classroom enactments of the storyline unit. These themes drive our findings section: 1) developing strategies and understandings that promoted confidence and 2) setting the stage for managing how their students engaged with uncertainty.

Developing strategies and understandings that promoted confidence

The debugging PL activity helped teachers gain knowledge about the hardware and software and develop debugging strategies that assisted them in making decisions to support their students. While in "student-hat", teachers practiced different debugging strategies – e.g., reading the code aloud, checking the wiring, and using the available instructional resources like a wiring diagram – examining their effectiveness from a student perspective. By working in the role of a student, teachers developed knowledge about the hardware and software interactions, interrogating the relationship between the environment, the sensors, and their program. They collaboratively made sense of how the hardware and software worked together, a task that is often difficult for novices in working across the physical system and programming simultaneously (DesPortes & DiSalvo, 2019).

Teachers did more observing than talking when in the role of the teacher (teacher-hat) during the PL, often positioning themselves behind the "students" so they could look over their shoulder and examine the code. During the reflective discussion, Trevor described that his trepidation to step in stemmed from: "when I saw those two, … [I felt that] I was already watching the professionals and they were already figuring out stuff that I wouldn't have thought."

When in teacher-hat mode, we only coded two strategies to support "students'" debugging during the activity: asking questions and giving directions. Both Trevor and Eric used initial questions to get a sense of what the "students" were working on when they first walked up (e.g., "so what are you guys working on here?") and questions about hardware (e.g., "What else controls how much if you get power or not?"). While these strategies are helpful, they only touch the surface of possible moves that teachers can do to support students in engaging with uncertainty. Despite observing only surface level engagement in these practices. Participating in this activity led to Eric and Trevor in discussing a multitude of deeper strategies during the reflective discussion.

The PL reflective discussion proved to be a rich activity to help teachers in building a repertoire to draw upon during the enactment of the unit. Our analysis of classroom debugging moments revealed that the teachers used seven of the eight strategies that were mentioned during the reflective discussion and two of the strategies used during the PL activity (see Table 1). Eric left the PL experience with a clear checklist he imagined he would use in his classroom, saying: “It's literally wire. It's power supply, wires, switches, code…That's the checklist and that's the order I want it.” In contrast, Trevor only mentioned strategies for troubleshooting hardware. He mentioned wanting to know the wiring so well that he could walk up to students and quickly assess if there was an issue with the wiring. This strategy was evident during his later classroom enactments as he focused on asking students questions to make sure their hardware was working correctly.

Table 1
Teacher strategies derived from PL and classroom enactments

Strategy	PL Activity	PL Reflection	Classroom Enactments
Asking questions	√	√	√
Articulating the problem		√	
Articulating the goal		√	√
Reading code aloud			√
Talking to other students		√	
Pointing students to resources		√	√
Switching hardware		√	√
Allowing students to figure it out		√	
Giving directions	√		√
Checking switches or lights		√	√

Through participating in the PL activities, teachers also devised strategies to support students in learning the process of debugging, rather than focusing on simply fixing the bug. They imagined asking students questions to get them to explain or talk through their code, pointing students to tutorials or other instructional resources, and asking students to check with other students or compare their code.

During the classroom enactments, both Trevor and Eric regularly asked questions of their students as their main support strategy, building on the foundational practice they developed during the PL. However, the questions Eric asked of his students were more disciplinary-specific than the questions he asked during the PL. Most of the questions he asked during the PL were questions that could be asked in most instructional contexts to assess what students were working on (e.g., “what are you trying to do?” or “what is your goal?”). In contrast, Eric’s most frequent question during enactments was “how are you going to display your data?” This question became a regular strategy for Eric in determining students’ goals while also getting them to explain how they intended their system to work.

The PL reflective discussion revealed a tension among teachers about how to best support students when assembling and using the PCS. In the discussion, the teachers considered when it is appropriate to step in and when it is better to let students struggle, moving back and forth between thinking from the student’s perspective (e.g., “I'm the kind of student that doesn't want someone to just tell me the answer. I want to work on it long enough that I get the chance to find it myself before”) to the teacher’s perspective (e.g., “Like you're a bad teacher if you don't walk around and hover so you can check and say, How's it going…if they're not ready… you move on”). Discussing this tension, Trevor reflected that students are often appreciative when teachers step in, yet not all teachers participating in the discussion agreed with this assertion.

In the reflective discussion, Trevor and Eric recognized that many debugging moments would require them to enter a situation where they would not necessarily know where students were in the process of debugging. They noted that they would want to quickly determine how to support students while also quickly assessing where students were getting stuck. They concluded that asking questions such as “what are you trying to do?” would support both their students and themselves in deciding how best to proceed.

Setting the stage for students’ engagement with uncertainty

In this section, we describe debugging moments excerpted from the two teachers’ enactments, illuminating how they both drew upon the repertoire developed during PL and moved beyond these strategies, improvising to best support their students. In addition, we share the ways both teachers structured lessons 2 and 4 as part of their grounding for engaging with students working with the PCS. By setting the stage for the kind and amount of improvisation necessary to support their students, Eric and Trevor expanded or contracted the amount of uncertainty available for students. Eric’s use of strategies and structure of lessons 2 and 4, compared to Trevor’s, resulted in a more expansive approach and required a broader improvisational repertoire that he had to call on in-the-moment when supporting students.

For example, there were several times when Eric approached students who were stuck where he followed a similar checklist he had devised during the PL activity. In an email written after implementing the storyline, Eric wrote “that debugging activity we did [in PL] was a life saver because now I know all the mistakes they make and how to fix them” (email correspondence, September 2022). While using his checklist and asking questions were helpful in the initial stages of approaching students who were stuck, Eric improvised when these initial questions did not get to the root of the problem and when neither he nor his students could locate the bug. In one instance, after reading the code aloud (the last step in his mental debugging checklist), he checked which tutorial students were using, suggested students pull up a new tutorial to compare their code to the code in the tutorial, read the tutorial code aloud, moved back and forth between the students’ code and the example code, and changed a variable in the code all the while narrating to his students what he was doing and his hypothesis about what might be causing the bug.

While in this instance these strategies ultimately did not help Eric and his students resolve the bug, he approached the experience positively by saying to his students: “I don’t know if I’ve ever seen this before, this is fun!” At the end of the debugging experience, Eric proposed a hypothesis about what might be causing the issue, explaining the details to his students and expressing that while the sensor was still not returning a value they expected, the reason might be that they did not have enough variability in moisture level and that they could try measuring in a new environment. Eric’s approach here involved improvising new approaches while also modeling how not knowing the answer or direction can be an enjoyable act. At the end of the moment, Eric also allowed his students to remain in uncertainty as they came to no obvious way to debug their system. Instead, he proposed a new strategy of trying to try out the PCS in another environment. Overall, Eric’s approach, as indicated in his facilitation of lessons 2 and 4, expanded possible stuck points students could encounter thereby creating more room for them to encounter and deal with uncertainty.

Trevor also drew upon many resources from the PL, including asking questions of students; however, his questions were often in the form of more answerable “yes or no” questions, such as “did you hit download again?” and “you’ve wired it correctly?” Trevor started his interactions with students with these types of questions, geared towards troubleshooting the hardware and its connection to the program. When these did not help resolve the issue, Trevor would then examine the code. When there, he most often directed students about what to do by pointing to different blocks on the screen and directing students what to do. For example, leaning into the screen to decipher the code, Trevor explained to two students where to move a different block in their code: “Pull that one back out. [points at screen and moves finger to match verbal directions]. And then take this right here and put it, is there a circle in it? Or just put it right here and move this up here into the show...” Overall, this directive approach was more focused on the product of getting a working PCS rather than the process of developing debugging skills.

Trevor’s approach to setting the stage of the unit limited the possible stuck points students might confront. He structured lessons so that his students were always at the same place, providing all directions aloud to the whole class in a step-by-step fashion, and asking students to stop after they finished each step in order to wait until all students were ready to move on. In addition, Trevor chose to modify lesson four (where students designed PCSs using multiple sensors). Instead, he asked students to write in their science journals about what they could create with their PCS. Through these actions, Trevor constrained students’ opportunity for engaging in uncertainty, which also minimized the amount of improvisation needed to support students in debugging moments. In this way, Trevor’s range of improvisational moves were more constrained than Eric’s.

Conclusion and implications

This paper examines two teachers’ participation in professional learning (PL) activities designed to help them learn to support students when they face uncertainty during a computationally-rich science storyline. It also examines how this participation shaped their subsequent classroom enactments. Findings revealed that the PL activities helped the teachers understand the PCS from their students’ perspectives and develop a repertoire of strategies to support students. Eric and Trevor’s classroom enactments also revealed divergent approaches to facilitating the storyline unit that enabled students to engage in and wrestle with varied levels of uncertainty.

In terms of classroom enactments, the two teachers set the stage to allow for distinct levels of student uncertainty. This meant differences in the kind and amount of improvisation needed to support their students. One teacher, Eric, created opportunities for students to encounter uncertainty by how he taught the storyline and approached students when they were debugging their PCS. In this way, giving students more opportunity to encounter and persevere through uncertainty with the PCS, Eric faced more instructional decisions to be made in-the-moment and therefore presented a more complex setting for improvisation.

In contrast, Trevor appeared to constrain opportunities for his students to encounter uncertainty – thus limiting his need to improvise while teaching. During the storyline unit, Trevor had his students all work at the same pace and provided instruction that applied to many students at once. This reduced students’ chances to encounter uncertainty on their own. This more structured approach also meant that the bugs students encountered were often routine and easily "fixed" without them necessarily learning more about the PCS and related science. While this approach constrained students from experiencing uncertainty, it may have provided Trevor an amount of comfort as he learned to integrate a new science unit and physical computing systems into his classroom. Of course, a variety of external factors may have influenced these differences in enactments, for example, class size, students' age, time, or comfort with the science and technology. In addition, rather than simply asking why some teachers' practices changed more than others after PL, it is important to recognize that teacher learning coevolves with classroom practice over time (e.g., Kazemi & Hubbard, 2008).

Trevor's approach also aligns with findings from recent studies of teachers enacting inquiry science instruction, where although teachers seek to empower student inquiry, they may only take up student answers or ideas they had previously anticipated (Miller et al., 2018). This approach can minimize students' agency (Miller et al., 2018) and lead students to strive toward a single, correct solution. Moreover, when students do not have a chance to wrestle with uncertainty, they miss out on important opportunities to develop their own strategies to work through this feeling, potentially even finding pleasure in uncertainty or inconsistencies, as many scientists describe their work (Jaber & Hammer, 2016).

Findings for this work help inform future designs of professional learning where teaching for uncertainty is foregrounded. First, our work contributes to research on the benefits of providing both "student-hat/teacher-hat" experiences in PL by giving teachers the chance to engage in the discipline, experience uncertainty from both perspectives, and empathize with their students (Lowell & McNeill, 2020). We found that the approach was an effective tool to introduce teachers to unfamiliar computing concepts (Goode et al., 2014) and help them develop strategies to support their own students in debugging. Second, we found that while in "teacher-hat," the teachers mostly observed what the "students" were doing rather than offering support. While teachers may have felt their own uncertainty about how to support students during debugging (Yadav et al., 2016), the experience sparked a rich discussion and helped teachers develop new strategies and confidence.

Finally, the design of the PL activities was intended to support teachers in developing their own flexible approaches that could be adapted to a variety of debugging and uncertainty contexts. We considered alternate PL designs that would provide teachers with pre-planned debugging scripts and checklists. However, we feared that providing such guidance would turn the focus of the activity on simply fixing bugs rather than supporting teachers in developing a more expansive set of pedagogical strategies. Whether teachers actively participated while in teacher-hat or merely observed, our PL activities appeared to engage teachers in theorizing about the nature of uncertainty in the science classroom.

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Missing Command as a Debugging and Problem Solving Task for Elementary Students

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Abstract: Problem solving and debugging skills are important computational thinking practices that even young students can and should experience. We investigated 28 first graders' and 27 third graders' efforts to determine commands missing in three programs, where the missing command occurred at either the beginning, middle, or end of the program. Students attempted to find the missing command before and after an intervention where they learned how to program using a tangible programming game. Students often chose commands that resulted in bugs due to having the character move too much or too little and in the wrong direction. When the first command was missing, students often tried a pattern matching debugging strategy. When the middle command was missing, they wanted to reprogram the end. When the last command was missing, they traced the code but struggled. Implications include helping students trace their code when making sense of a new program.

Introduction

Since Wing (2006) brought attention to the wide-spread importance of computational thinking, there has been a marked increase in attention on practices that support computational thinking, especially in relation to programming, in schools. Computational thinking involves problem solving skills (Pérez, 2018), including decomposing problems, creating and reasoning about algorithms, and debugging (Anderson, 2016; Angeli et al., 2016; Grover & Pea, 2013). Especially at the early elementary level, the bulk of explorations around students' programming has focused on their learning to program using tangible and digital tools, often focusing on which commands are easy or more difficult to learn (e.g., Elkin et al., 2016). Some of these reports have also provided initial insights into how young students debug (e.g., Bofferding et al., 2022; Sipitakiat & Nusen, 2012). Related to debugging, when students play together to make programs, they must also make sense of their peer's code and what pieces they might need to add. We build on prior work on problem solving and debugging skills by presenting results of a study where first and third graders had to determine the missing command in a series of programs before and after an intervention in which they played in pairs to program using tangible coding blocks, Coding Awbie. Coding Awbie is meant for students in early elementary school. Our results highlight sequence (i.e., location of missing commands in programs) and conceptual factors (e.g., understanding of functions of the commands) that can play a role in young students' creation and debugging of programs.

Tangible programming

Tangible programming applications generally have a few forms. The first form of application involves directly programming a robot by pushing buttons on a controller to make the robot turn or move forward or backward (e.g., Code and Go Robot Mouse, Code-a-pillar, Botley the Coding Robot). A drawback of these applications is that debugging is difficult because students do not have a record of the commands they used unless they keep track of them elsewhere. A second form of application has students put together a series of blocks, each of which is a command, to program a robot (e.g., KIBO, Elkin et al., 2016). Students can trace back through their code (i.e., the blocks) to make sense of any unexpected results or bugs. The third form of application involves students putting together a series of blocks, but the blocks control a character in a game on a tablet or iPad (e.g., Coding Awbie; see Bofferding et al., 2022). The benefit of controlling a character on the screen is that students are motivated to play the game, and it allows for resetting the game and debugging the tangible blocks while also being a closer approximation to fully online block-based programming applications like ScratchJr.

Incomplete worked examples and debugging framework

As identified by Dahn and DeLiema (2020), debugging can be an emotional process and could involve changing one's goal to work around a bug or rereading the code. One type of task that can help students make sense of programs and reveal their current understanding of the steps of the code is having them work with incomplete worked examples (Hanna, 2015). One potential benefit of debugging or fixing someone else's code, is that students are not invested emotionally in the code and the goal of the program as with their own programs (i.e., when their own program does not work). In a programming context, incomplete worked examples indicate the goal of a program and provide some of the code. Students must then fill in the missing step (or steps) to complete the code for the program, much like they would when working with faded worked examples (e.g., Skudder & Luxton-Reilly, 2014). When provided with an incomplete program, students need to understand what the program is supposed to do, what the individual commands will do, and what needs to be fixed or added (Fitzgerald et al., 2008). However, students might introduce new bugs during the process of determining a program's missing code. Within Coding Awbie, bugs tend to involve students using the incorrect movement or having a different interpretation of what the movement does, having the character move in the wrong direction, having the character move the wrong number of spaces, or a combination of these.

Typically, students have more difficulty finding a bug than fixing it (Fitzgerald et al., 2008). In an incomplete worked example, we consider the missing code as the bug that is already identified. Therefore, the location of the missing code or type of missing code might influence the difficulty of correctly fixing it. When working with this existing code, students need to leverage several of the computational thinking practices, focused on problem solving, in order to interpret the code and add to it or modify it as necessary. Murphy et al. (2008) laid out a series of strategies that novice programmers use when debugging code that are relevant for both making sense of the code and fixing it (see also Bofferding et al., 2022; see Table 1).

Table 1
Debugging Strategies (Bofferding et al., 2022; Murphy et al., 2008)

Debugging Strategy	Description
Tinkering	This strategy applies to situations where students can change the code and see the results of their changes. When tinkering, students randomly make changes.
Reprogramming	This strategy involves starting over and rewriting the program.
Understanding the Code	This strategy involves trying to figure out what the program is doing by reasoning about the code and the situation.
Tracing the Code	This strategy involves starting at the beginning of the program and walking through each line step-by-step and following along with the result at each step.
Pattern Matching	This strategy involves a realization of what needs to be done, almost intuitively. Students might just notice something missing. For example, students might subitize the distance they wanted Awbie to move.

There has been little work investigating young students' efforts to make sense of incomplete worked examples, particularly before second grade and for developing programming and computational skills (see Bofferding et al., 2022 for one example). Therefore, we build on these prior works around incomplete worked examples and debugging to explore the following research questions:

1. How do first- and third-grade students debug the programs and determine the missing command in a program?
2. How does the location of incomplete commands impact students' problem solving and the type of bugs students make over time?

Methods

Participants, setting, and study design

Our study and use of human subjects was approved by our institutional review board. We recruited students from all first and third grade classrooms at a suburban, public elementary school in the midwestern US. At the school, 45% of students qualified for free and reduced lunch, and 11% were classified as English Language Learners. Overall, 55 students participated in the study (28 first graders, 27 third graders). The study's design involved a pretest, midtest, and posttest, all of which took place individually with a researcher at a table in a hallway of the school. The three tests included items where students had to explain what was happening in video clips of a hypothetical student programming Awbie to move, items to debug buggy code, and the items presented here. For the intervention, students participated in three programming sessions before the midtest and three programming sessions after the midtest. During the intervention, students worked with a pair and played Coding Awbie, a tangible programming game using the Osmo system. The pairs also engaged with a series of correct and incorrect worked examples (complete or incomplete programs) either before their first three sessions or last three sessions to provide them with further opportunities to problem-solve around the use of the programming commands in the game (see Bofferding et al., 2022). All individual and pair sessions were video recorded, and we took notes on students' responses to the items for this analysis.

Background on coding awbie

Coding Awbie is a tangible programming game that young students can play on the iPad. Using the Osmo^{TM} gaming system, students use tangible programming pieces (movement actions, direction arrows, and numbers) to make commands for their lines of code (see Table 2). Awbie must jump over bushes and trees, and if he runs into or jumps onto one of them, which we considered faulty programming, he will bounce off of it. A mirror on top of the iPad reads the code that students place in front of the iPad and then runs the program. In the game, students try to program the character, Awbie, to collect strawberries and get to the end of each level.

Table 2

Examples of How to Use the Tangible Coding Pieces to Move Awbie

The parts of the program run from top to bottom as follows:

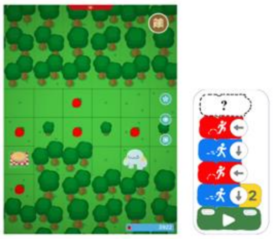
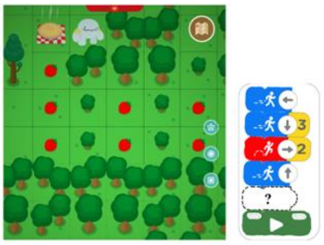
	Walk right 2	Students can turn the arrow on the button to change the direction they want Awbie to go.
	Grab up (1)	When grabbing, Awbie stays on the current square and reaches into the next square. If no number is used, it defaults to the value of 1.
	Jump down 3	A jump skips a space, so if Awbie jumps three times, he would have moved six spaces from his starting point.

Data sources and analysis

In this paper, we focused on three "missing programming command" items from the pretest and posttest. These items reflect incomplete worked examples. Each item had a picture of Awbie (the character to move) in a scene from the game, which had a series of strawberries for Awbie to collect. Near the picture, we also listed lines of code that when run needed to fulfill the goal of Awbie collecting all of the strawberries. However, in each item, one of the programming commands (i.e., line of code) was missing. Across the three items, one had the first command missing, one had a middle command missing, and one had the last command missing (see Table 3). The three items were similar in that they each had a slightly non-intuitive element. With the first command missing item, students needed to program Awbie to go up past the first strawberry, rather than collect the first strawberry and jump left over the bush. In the middle command missing item, students needed to have Awbie collect the strawberry on the beaver before finishing walking down the long line of strawberries. For the last command missing item, students needed to realize that Awbie was jumping all the way to the right before going up and then jump back to the left. During these tests, students reasoned about these items. We asked students to figure out what command (movement, direction, and number) should be in the missing spot in order to make Awbie collect all of the strawberries. We presented the same three items on the midtest and posttest but changed the order of the items each time. Given the time needed for students to complete the sessions, there was about one month in between each testing session, and students gave no indication that they recalled what they had answered on the previous occasions.

Table 3

Three Missing Command Programming Items and Analysis Categories

	First missing	Middle missing	Last missing
Missing programming command item			

Works without faulty code	*walk up 2*	*walk left 2* or *jump left 1*	*jump left 1*
Works with faulty code	If a student used the command *walk up 3* (incorrect number), Awbie would bounce off of a tree but still collect all of the strawberries.	If a student used the command *walk left 3* or *jump left 2* (incorrect number), Awbie would bounce off of a tree but still collect all of the strawberries.	If a student used the command *jump left 2* (incorrect number), Awbie would collect all of the strawberries and continue jumping. However, students often thought that *jump 2* meant Awbie would jump to the second space (as opposed to jump over a space and land two times), so we treated this as similar to a bug.
Does not complete the goal	Although *jump up 1* (incorrect action) would help Awbie get to the final strawberry, he would jump over the first strawberry, so this command would not properly complete the code.	Students might try to put two lines of code in the missing spot, such as *walk left one, hand left one* (incorrect number, incorrect action - extra), which would get the strawberry by the beaver but would not properly complete the code.	Students might jump in the wrong direction, such as *jump up 1* or *jump right 1* (incorrect direction), which would not help Awbie get the final strawberry.

For our analysis of each item, we identified common debugging strategies (see Table 1). We then focused on results from these three items in terms of whether students identified a command that worked without bugs, a command that worked with bugs, or a command that did not complete the goal (i.e., would not result in Awbie collecting all of the strawberries; see Table 3). When students did not provide a command that worked without a bug, we categorized their bugs into incorrect movement actions, direction arrows, numbers, or a combination of those. For example, students might use the wrong movement (e.g., a jump instead of a walk) or use an extra movement (e.g., insisting two commands were missing). For direction bugs, students either did not specify a direction or gave a wrong direction. For number bugs, students either had Awbie move too little (e.g., walk one space when he should walk two spaces; number too little) or too much (number too much). Some students skipped an item or insisted the missing code went in a different location in the program. If a movement or number resulted in Awbie hitting a bush or tree but still completed the goal of collecting all of the strawberries, we considered this as working with faulty code. After categorizing the bugs, we then investigated how students' commands and bugs differed among the items and how they changed over time, focusing our discussion of results on the pretest and posttest.

Findings

Across the pretest and posttest, students used several debugging skills as they attempted to identify a command that would work in the missing command programming items. For the first command missing item, students primarily relied on *pattern matching* and thought Awbie would only need to walk up 1. However, some students would *trace the code* by simulating the movement of Awbie on the paper as they figured out or checked the program. For example, on the first command missing item, Goat5, a female third grader, originally traced the code and said, "It would be *go* [walk] *up* (with the one implied), and then he'd go up." With her finger, she motioned Awbie moving up one space to the first strawberry and then showed his next movement would be jumping left over the small bush to another strawberry (see Table 3) while saying, "Jump, and then, it doesn't." At this point, she used an *understanding the code* debugging strategy and realized continuing the code would not allow Awbie to get the strawberry at the top, so she revised her initial command and said, "It [walk up] does have a number. Two."

On the middle command missing item, students often *traced* the beginning half of the code but then wanted to *reprogram* Awbie so that he would walk all the way down instead of stopping part way. Sometimes students suggested a programming command that would result in faulty code but would still result in Awbie collecting all of the strawberries. For example, on the middle command missing item, Horse8, a female third grader, used *pattern matching* by quickly indicating that Awbie should "go here" and pointed to the missing strawberry. She then moved her finger along the square to count the spaces he would move–including the spot where Awbie would be standing before moving–getting three (instead of two). As a consequence, she qualified her statement of how Awbie should move by indicating he would have to move three spaces. If Awbie would move three spaces to the left as the missing command, he would bounce off of the trees (what we could consider a bug), but he would still complete the rest of the code.

On the last command missing item, students primarily used a *tracing the code* debugging strategy. In some cases, students did so incorrectly, resulting in them choosing a missing command that would not complete the program correctly. For example, Robin1, a male first grader, traced Awbie walking left 1 and walking down 3. However, when tracing how Awbie jumped right 2, he only jumped once (perhaps thinking a jump of two was moving two spaces). He then walked up one but still had two strawberries left. Therefore, for the missing code, he thought Awbie would still need to jump right and then walk down.

Overall, from pretest to posttest, all students improved in correctly identifying a command for the missing command across all three items (see Table 4). The largest gain was for the last command missing item (first graders: 25%, third graders: 34%, and total: 29%).

Table 4
Percent of Students' Responses with Commands Working without Faulty Code (with Faulty Code) on Pretest and Posttest Missing Command Programming Items

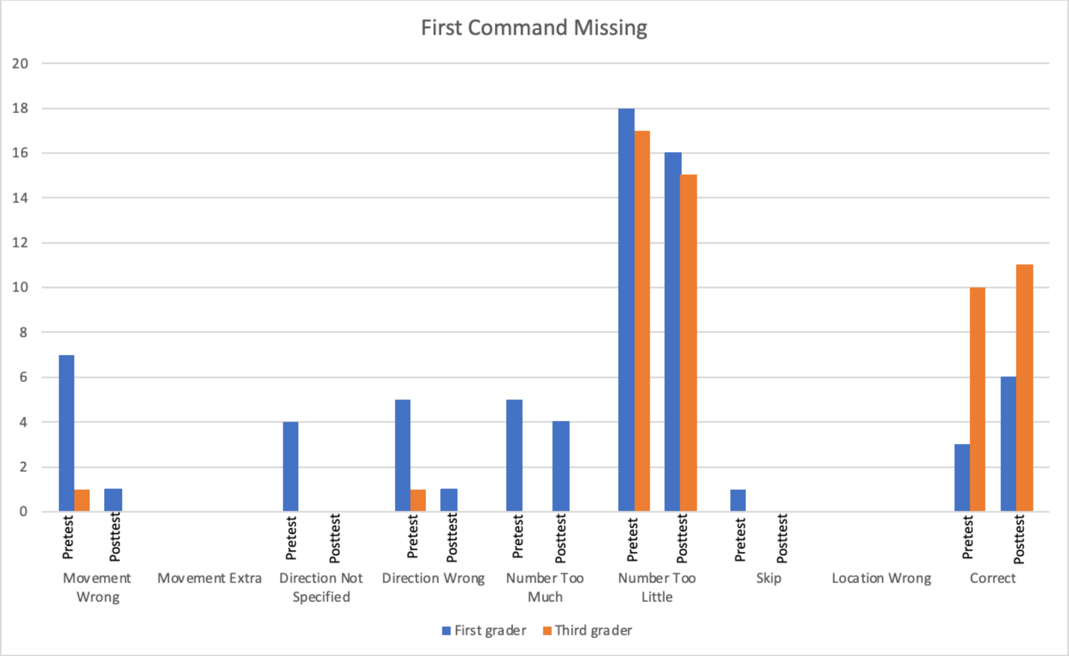
	Grade level	First command missing	Middle command missing	Last command missing
Pretest	First graders (*n* = 28)	14% (25%)	21% (28%)	4% (11%)
	Third graders (*n* = 27)	37% (37%)	15% (26%)	22% (41%)
	Total (*N* = 55)	25% (30%)	18% (27%)	13% (26%)
Posttest	First graders (*n* = 28)	21% (32%)	36% (43%)	29% (36%)
	Third graders (*n* = 27)	41% (41%)	41% (45%)	56% (71%)
	Total (*N* = 55)	31% (36%)	38% (43%)	42% (53%)

Note. Percentages in the parentheses represent students' responses with commands working with bugs.

On the pretest, across the three items, students were most likely to identify the correct command (without bugs) on the first command missing item. There were interesting differences between the types of bugs students made among the three items (see Figures 1, 2, and 3). In particular, when the first command was missing, students typically thought they only needed to move Awbie up one space instead of two (i.e., *number too little* bug). Once they saw that moving up one space would work with then jumping left, they were less likely to continue tracing through all of the code (see Figure 1). Interestingly, this trend did not change much by the posttest.

Figure 1

Number of Coding Choices Made on the Pretest and Posttest First Command Missing Item



On the middle command missing item, students were most inclined to program Awbie to continue walking downward on the pretest (and even more so on the posttest). Therefore, they both had the direction wrong but also thought they only needed to move Awbie one space (see Figure 2). On the last command missing item, students had difficulties with the direction, movement, and number. The difficulties with the last command missing item, particularly on the pretest, was that students' varied interpretation of the code led them to trace the code differently. Interestingly, the third graders had a few students on the last command missing problem who programmed Awbie to jump left 2 (instead of jump left 1), which worked with faulty code (since Awbie jumps too far to the left after collecting the last strawberry). First graders continued to struggle with the direction.

Figure 2

Number of Coding Choices Made on the Pretest and Posttest Middle Command Missing Item

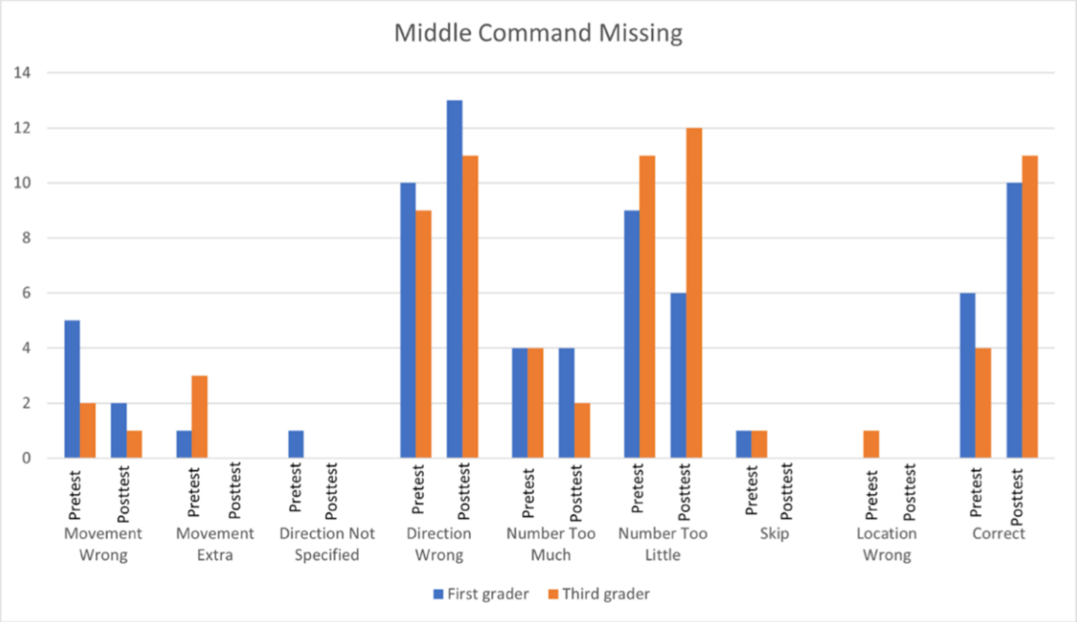
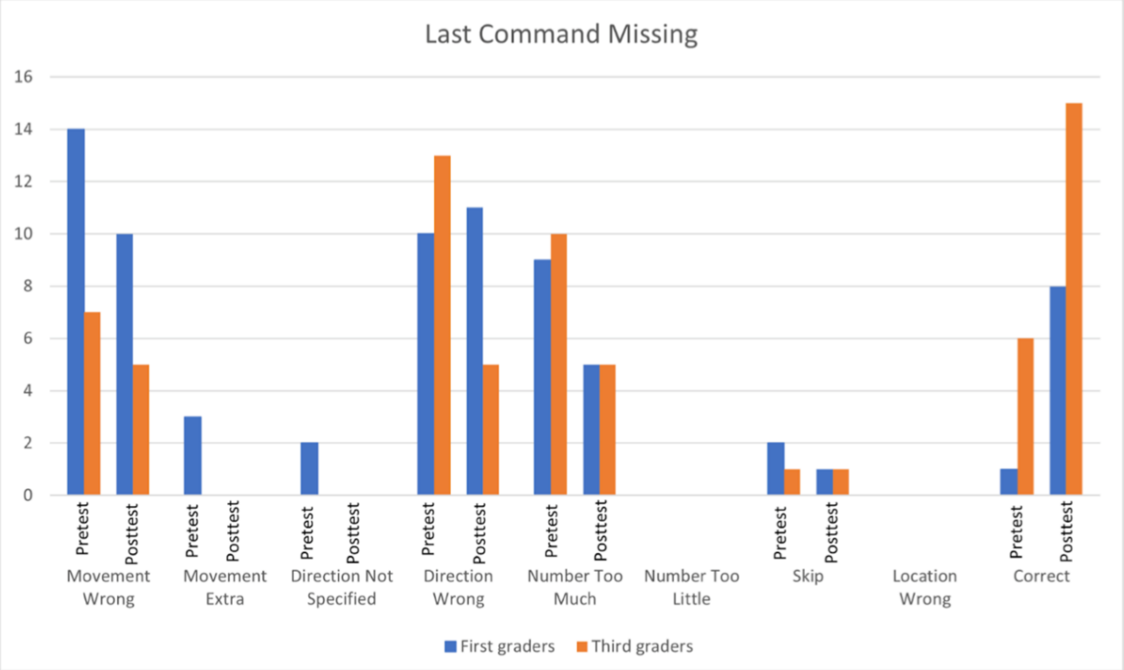


Figure 3
Number of Coding Choices Made on the Pretest and Posttest Last Command Missing Item



Discussion and implications

Overall, our study extends the work around young students' problem solving and debugging skills when they begin to learn to program. The results from this study indicate that young students' efforts to debug might depend on several conceptual factors, including which types of movements they need to debug, whether they can change surrounding code, and whether the bug (in our case, missing code) occurs at the beginning, middle, or end of the program. Students may have had more difficulty with the last command missing item on the pretest because they had to interpret a lot more code before determining the missing command, providing insight into their understanding of the code (e.g., Hanna, 2015). The missing middle command item was initially difficult for many students because they wanted to reprogram the entire end of the program. By the posttest, they had more experience debugging their own code, which may have made it easier for them to figure out a piece in the middle of the program. We were surprised to see that there was little improvement from pretest to posttest when the first command was missing. Students who continued to struggle might benefit from more explicit encouragement to trace their code (e.g., Murphy et al., 2008) to make sure their programs work beyond the first few lines of code. Tracing the code with the actual coding pieces might also help those students who indicate the wrong direction of movement (particularly if the difficulty was with right versus left directions). Having the coding pieces could illuminate if the direction they picked and the word they used to describe the direction align. Finally, some students, especially on the last command missing item had Awbie jump to the left two times instead of one. Their choices might have resulted from not understanding how the jumps work or because they counted different squares. In either case, having the option to run the code in the game environment could help students receive feedback on their debugging efforts.

Although in our study students identified the missing code during individual interviews, having students discuss the items in a whole class setting could help them pay attention to different parts of the code and support their problem solving and debugging. In particular, some students wanted to change the program to work around the missing code (i.e., similar to revising the goal, Dahn & DeLiema, 2020). Students could provide reasoning for their choices of the missing code or how the remaining code could be changed, and their peers could agree or disagree. Such sharing could illuminate situations, such as with the middle code missing, where there are multiple correct answers (i.e., walk left 2 versus jump left 1). Such discussions would also provide the opportunity to have students compare and discuss the differences between using a walk and a jump command within the programming game.

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Research as Relational: Stories of Ever-Present Learning Between Undergraduate Research Interns and Project Researchers

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Abstract: This paper consists of two stories that span three years of a learning sciences research project in order to demonstrate how 1) participating in this project shifted how undergraduate interns understood themselves as researchers and as practitioners within our project—and in other communities—in relation to our shared research; and 2) in turn, how the research practices in our project community shifted in relation to their participation. We leverage Lave and Wenger's (1991) legitimate peripheral participation framework as a way of showing how the learning and becoming of "newcomers" in a research community of practice can influence research practices within that community. As stated in the ISLS 2023 conference theme, this analysis helps us consider expansive ways in which we might want to "sustain our community" so we are becoming a community of practice where we make space for supportive and generous forms of relationality.

Introduction

According to Lave and Wenger (1991) learning is relational, becoming, and always happening. That means as researchers, our ever-developing practices of inquiry support learning as we grow and change with others. We take Lave and Wenger's statements to heart to reflect on what it means for a community of learning scientists working on a shared project to learn with undergraduate interns as "newcomers" to this community. In particular we consider relations between learning and identity at the intersection of multiple, sometimes conflicting, communities of practice in the context of the Participating in Literacies and Computer Science (PiLa-CS) project. We tell two stories that span three years of the project to demonstrate how 1) individual undergraduates' becomings in a learning sciences research community influenced their identity development in and across disciplinary contexts (e.g., creative writing and social science research) and 2) these newcomers' shifts influenced what counted as research practice in our community. Thus, we consider the importance of how our learning and becoming is intertwined through research.

Our stories feel important for learning scientists to contend with as we engage in research with newcomers all of the time, and as a field we are striving to broaden the ways of knowing and becoming that we engage in in our own research practices (Bang & Vossoughi, 2016; Zavala, 2016) in order to "sustain our community." Internships especially serve as a vector for communicating what it means to be a researcher, who is meant to take up that role, and what they are allowed to do as one. An exploration of the process of becoming a researcher and engaging in research from the perspective of individuals with marginalized identities in the field is critical to reckoning with how gatekeeping prevents the growth of new and established researchers and the community as a whole (Tanksley & Estrada, 2022). Tanksley and Estrada's work focuses on the ways in which the prioritization of whiteness as property and source of power affects the perceived legitimacy and authority of Women of Color researchers within Research Practice Partnerships. Our paper borrows the insider-outsider perspective to analyze how practices from other communities that are not held in esteem within typical research communities can change the course and character of the research done within a project when they are instead viewed as worthwhile and valid.

Analytic framework

Lave and Wenger's (1991) legitimate peripheral participation (LPP) as a theory of learning disrupts many of the common conceptions of what learning is and how it happens. First, and most importantly, it posits learning as inherent in social practice, as opposed to an outcome of deliberate teaching. This means learning is *always* happening, whether there was an intention to teach or not. As learning is not the direct consequence of intentional teaching, what is learned in any given situation may not be at all related to what was intended to be taught. In this way, learning unrelated to a teacher's intentions becomes more visible during analysis. For example, undergraduate interns on a research project might pick up on ideas that it is possible and necessary to remove their biases from field observation, thus sanitizing the context provided by their own identities or experiences. Additionally, LPP rejects the idea that knowledge can be abstracted, and that learning is about the acquisition of pure or "general" knowledge that can be applied in any and all situations. So even the proposition that one can "write objective field notes" is impossible according to these scholars. Instead, Lave and Wenger argue that all knowledge is situated in both the context in which it was learned and the specific circumstances in which it is applied, in contrast to theories of learning that posit that learning is the collecting of concrete knowledge in the brain. LPP focuses on learning as a result of the interaction between the people that are present as a community of practice. It is their interactions with each other that causes learning to occur. Thus, LPP asserts that learning is relational.

Lave and Wenger (1991) also put forth the notion that learning is becoming: that learning causes shifts in an individual's identity as they move from newcomer to old-timer, and since learning is *always* a result of social practice, a learner's identity is also always shifting. Furthermore, being a newcomer to a community of practice means that the assigned tasks may be simpler and much lower stakes, yet no less useful than those of a full participant and still contribute to the practice as a whole. On a larger scale, communities of practice shift their overall identity in the same way: as strangers are added to the community in the form of newcomers, they bring their own identities and practices to the pool, thus shifting the identity of the community as a whole. These new ideas sometimes align with those of the old-timers, and sometimes do not. Communities of practice often strive for continuity of shared practices, but the fact that old-timers are constantly replaced by "newcomers-turned-old-timers" guarantees a shift in practices as time goes on. Thus conflict between ideas and practices arise, and it is up to both newcomers and old-timers— who invariably need each other in order to maintain the community of practice, making their paths inextricably intertwined— to negotiate the shared future of their community. As we take the time to reflect on the sustainability and future directions of the learning sciences, we find Lave and Wenger's (1991) framework important for illuminating tensions between learning from the history and past practices within the field and our hope of expanding and shifting it towards more humanizing ends. In particular we seek to question the push to sanitize our humanity and perspectives from "sciences" in ways that work to separate them from our learning. When we understand learning as a form of becoming we can begin to conceptualize research as a process of learning in relation to and with others. As apprentices and mentors in the learning sciences, we seek to disrupt processes that assert the dominance of certain ways of knowing as rigorous and scientific and others as inferior.

Methods

Context

Our stories of learning come from the Participating in Literacies and Computer Science (PiLa-CS) project. PiLa-CS is an NSF funded grant that began in 2017 focused on partnering with teachers to integrate CS into their classrooms in ways that explicitly support bi/multilingual learners in developing CS literacies. Over the past five years the research community on the project has consisted of faculty member PI and co-PI's, postdoctoral associates, graduate assistants, undergraduate interns, and teacher partners who have come and gone and shifted roles within the project (e.g., Sarane was one of the first undergraduate interns hired on the project and is now the only intern working on it, and Sara began as a graduate assistant, became a postdoctoral fellow, and is now a research scientist on the project). The majority of the interns who have been a part of the project's history have been Women of Color, while those who were not came from other often marginalized backgrounds. The project itself has also shifted its focus, beginning with working in classrooms with teachers to develop and utilize a curricular approach for their students to now working on building professional learning communities consisting of teachers who can support each other to do similar work. Interns have worked on ethnographic data collection in classrooms, animation and graphics for pedagogical videos, and co-design of curriculum with teachers for their classrooms. They have supported logistics, materials creation, and workshop design for year-round teacher professional development and for a summer professional learning community (PLC). Interns also created storytelling artifacts to reflect back to teachers their generative learning trajectories as equity-oriented CS educators (e.g. editing data from a summer PLC into documentary episodes about teachers' learning). Many also attended project team meetings and gave ongoing feedback on project activities and writing.

Our stories come from the first two authors' experiences. I (Sarane, first author) am a Black girl from the Bronx. I grew up with a love of storytelling that, with help from a strong interest in anime and Japanese culture, had grown to encompass a fascination with language and its usage in general. I came to the project in the fall of 2019 as a freshman creative writing major. While taking a class on the Structure of Modern English, my professor posted a flier recruiting undergraduate interns from CUNY and NYU for the PiLa-CS project. I didn't know any

Spanish, but I had spent four years learning Japanese, and specifically enjoyed learning about the structure of different languages and the way cultural values are reflected in grammar and vocabulary and vice versa. I had experience teaching Scratch during a previous internship, and this project seemed like an opportunity to delve further into language use in the everyday and how it can be used in creative or non-standard ways to convey ideas to each other, even across language barriers.

I (Lauren, second author) am a white, Jewish woman from the suburbs of Chicago. I grew up with a love for creatively communicating ideas whether it was choreographing dances, reading autobiographies written by funny women, or choreographing to chapters from the audiobook of Bossypants (Fey, 2011). I came to the project in the winter of 2022 as a postdoctoral associate, fresh off of defending my dissertation (there were three days between my defense and starting this job as a postdoc; it was a quick turnaround and a big transition). As I was hurtling towards finishing up my PhD, I was on the job market in the Fall of 2021 and came across the posting for a new PiLa-CS postdoc. I was interested in joining the project because of its focus on expanding the multimodal resources for STEM learning, related to my dissertation research which focused on expanding sensemaking resources in STEM learning through choreographic inquiry practices. During my interview for the position I was enamored by the way both (co)PI's and graduate students asked and rephrased questions in generous ways, giving me multiple opportunities to express my thoughts. I was excited at the prospect of doing important equity-focused work in STEM education and becoming a member of a community that respected and lifted up the voices and concerns of all participants regardless of "rank."

Data

Data for this analytic storytelling came from Sarane and Lauren's lived experiences as newcomers on the PiLa-CS project. As part of reflecting on our experiences we also referenced and reviewed documented reflections undergraduate interns left behind before their time on the project ended, artifacts interns created as members of the research team (e.g. documentary episodes, website text), and recruitment flyers – all created over three years of the project. Our stories were told in conversation with what we heard and read from our undergraduate collaborators. We wrote our stories down, shared them unedited, and in the process of sharing them made comments to each other. As detailed in the next section, the data for the paper was co-created between Sarane and Lauren in the fall of 2022 (after the incidents in both stories occurred) through writing and commenting on stories about our experiences as newcomers on the project and thus our methods for data construction and analysis became closely intertwined.

Data analysis

The analysis for this paper began with multiple meetings in which we (Sarane and Lauren) reviewed artifacts from undergraduate interns' participation on the project and reflected on our experiences as/with undergraduate interns on the project. We read previous interns' reflections and detected themes in these gifts, such as feeling valued in this community, identifying as a researcher and a disciplinary practitioner in another field (e.g. undergraduate major), thinking about their majors in new ways as a result of their internships, and becoming a lodestar for other Black and Brown students that looked like them. As we started to collect quotes from various interns surrounding these themes, we found ourselves returning to stories from when we first joined the project that we had told each other orally. It was clear to us that our experiences as and with undergraduate interns on the project were consequential in shaping certain research pathways and differed from the collection of quotes we had accumulated. Influenced by Sarane's experience and history as a creative writing major we chose to take a memoir approach to our storytelling (Cannady, 2015). Whereas autobiography, its counterpart, focuses on getting facts exactly right, often by fact checking them to assure accuracy, memoir focuses more on a person's memory of the event and how it made them feel. Thus, in memoir, the stories that are told are tied explicitly to the identity of the author and how they interpret the world around them, making them extremely personal. Drawn to our experiences as forms of analysis we each created a written version of the stories we had shared about our experiences as newcomers. We then swapped stories, leaving comments on the other's story that highlighted noticings about our learning on the project.

Our methods for storytelling put practices from memoir into conversation with practices prominent in autoethnography. Autoethnography is often used as a way to directly oppose methods of cultural research that seek to scrub the researcher from the narrative, thus hiding the biases and/or insights that are an inherent part of their perspective. Instead, autoethnographers, especially those from marginalized backgrounds, seek to both write and analyze stories about themselves that illuminate the many shades of their lived experiences, and connect their individual stories to larger cultural narratives in a way that sheds new light on them (Ellis, Adams, & Bochner, 2011). One important byproduct of memoir as a method of storytelling is that memoirs can sometimes be little worlds of their own, causing an interesting phenomenon to happen when they come in contact with other people's viewpoints. In the work that inspired our methodology, Jennifer Lundan's *Evidence in Track Changes* (2016), this dissonance between the viewpoint of the author and that of her mother, who experienced the same moments but came away with a much different interpretation of them, became part of the text through her mother's comments on her writing. Even though their viewpoints contradicted each other often, neither were false, creating conflicting yet equally true realities. Our stories don't conflict, but our different perspectives and life experiences provide for rich observations when they come in contact with each other. Sarane's story took place three years ago in the fall of 2019, when she was still a newcomer to the project, while Lauren's story was more recent (only 9 months ago in the winter of 2022), when she was a newcomer and Sarane was a more established member of the project. Commenting on each other's stories allowed us to bring our various expertise in conversation with each other in a way that allowed us to be newcomers and old-timers at the same time. Since our stories were about times in the project when we were newcomers, comments allowed us to share perspectives gained since we became older-timers in this and other communities.

Findings

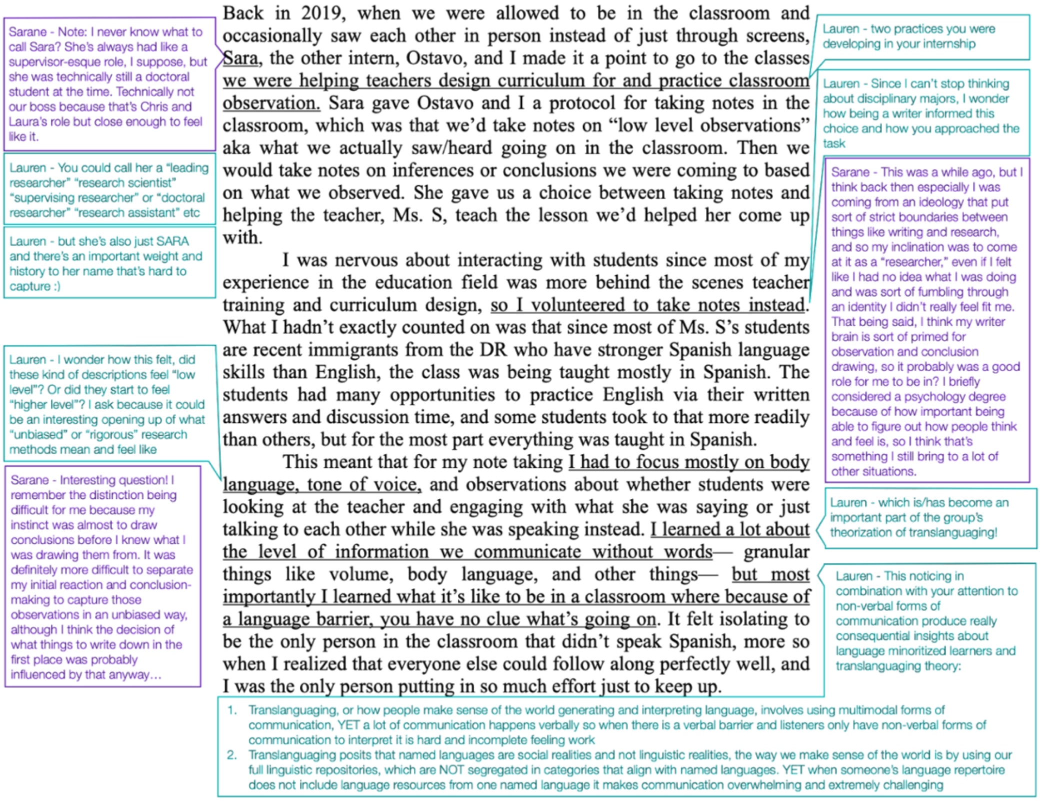
Our findings consist of two stories with commentaries told and responded to by Sarane and Lauren. These unedited stories come from times when we were newcomers to the project, negotiating personally and communally what it meant to be a researcher and research in this particular community of practice. We encourage you to read through the stories in the following figures in any way that you please (Toliver, 2021) (1). This might entail reading through the primary, center story text once and then reading again and stopping to attend to comments as they pop up, or reading through both in a first pass. Both the stories and the dialogue through the comments are meant to be engaged with.

Story 1: Sarane's first experience as a researcher in the field

Sarane's story is about her first time conducting observations in a classroom with the research team in the fall of 2019, a moment that was consequential for her in coming to identify as a researcher and thinking about the phenomenon of study on the project (bi/multilingual learners' experiences in CS classrooms). You can find this story in Figures 1 & 2 along with Lauren's commentary and a few responses to these comments from Sarane (1). At this point we recommend reading story 1 as it is shared in Figures 1-2.

Figure 1

Sarane's story with commentary from Lauren and responses from Sarane (Part 1)



Back in 2019, when we were allowed to be in the classroom and occasionally saw each other in person instead of just through screens, Sara, the other intern, Ostavo, and I made it a point to go to the classes we were helping teachers design curriculum for and practice classroom observation. Sara gave Ostavo and I a protocol for taking notes in the classroom, which was that we'd take notes on "low level observations" aka what we actually saw/heard going on in the classroom. Then we would take notes on inferences or conclusions we were coming to based on what we observed. She gave us a choice between taking notes and helping the teacher, Ms. S, teach the lesson we'd helped her come up with.

I was nervous about interacting with students since most of my experience in the education field was more behind the scenes teacher training and curriculum design, so I volunteered to take notes instead. What I hadn't exactly counted on was that since most of Ms. S's students are recent immigrants from the DR who have stronger Spanish language skills than English, the class was being taught mostly in Spanish. The students had many opportunities to practice English via their written answers and discussion time, and some students took to that more readily than others, but for the most part everything was taught in Spanish.

This meant that for my note taking I had to focus mostly on body language, tone of voice, and observations about whether students were looking at the teacher and engaging with what she was saying or just talking to each other while she was speaking instead. I learned a lot about the level of information we communicate without words— granular things like volume, body language, and other things— but most importantly I learned what it's like to be in a classroom where because of a language barrier, you have no clue what's going on. It felt isolating to be the only person in the classroom that didn't speak Spanish, more so when I realized that everyone else could follow along perfectly well, and I was the only person putting in so much effort just to keep up.

Sarane - Note: I never know what to call Sara? She's always had like a supervisor-esque role, I suppose, but she was technically still a doctoral student at the time. Technically not our boss because that's Chris and Laura's role but close enough to feel like it.

Lauren - You could call her a "leading researcher" "research scientist" "supervising researcher" or "doctoral researcher" "research assistant" etc

Lauren - but she's also just SARA and there's an important weight and history to her name that's hard to capture :)

Lauren - I wonder how this felt, did these kind of descriptions feel "low level"? Or did they start to feel "higher level"? I ask because it could be an interesting opening up of what "unbiased" or "rigorous" research methods mean and feel like

Sarane - Interesting question! I remember the distinction being difficult for me because my instinct was almost to draw conclusions before I knew what I was drawing them from. It was definitely more difficult to separate my initial reaction and conclusion-making to capture those observations in an unbiased way, although I think the decision of what things to write down in the first place was probably influenced by that anyway…

Lauren - two practices you were developing in your internship

Lauren - Since I can't stop thinking about disciplinary majors, I wonder how being a writer informed this choice and how you approached the task

Sarane - This was a while ago, but I think back then especially I was coming from an ideology that put sort of strict boundaries between things like writing and research, and so my inclination was to come at it as a "researcher," even if I felt like I had no idea what I was doing and was sort of fumbling through an identity I didn't really feel fit me. That being said, I think my writer brain is sort of primed for observation and conclusion drawing, so it probably was a good role for me to be in? I briefly considered a psychology degree because of how important being able to figure out how people think and feel is, so I think that's something I still bring to a lot of other situations.

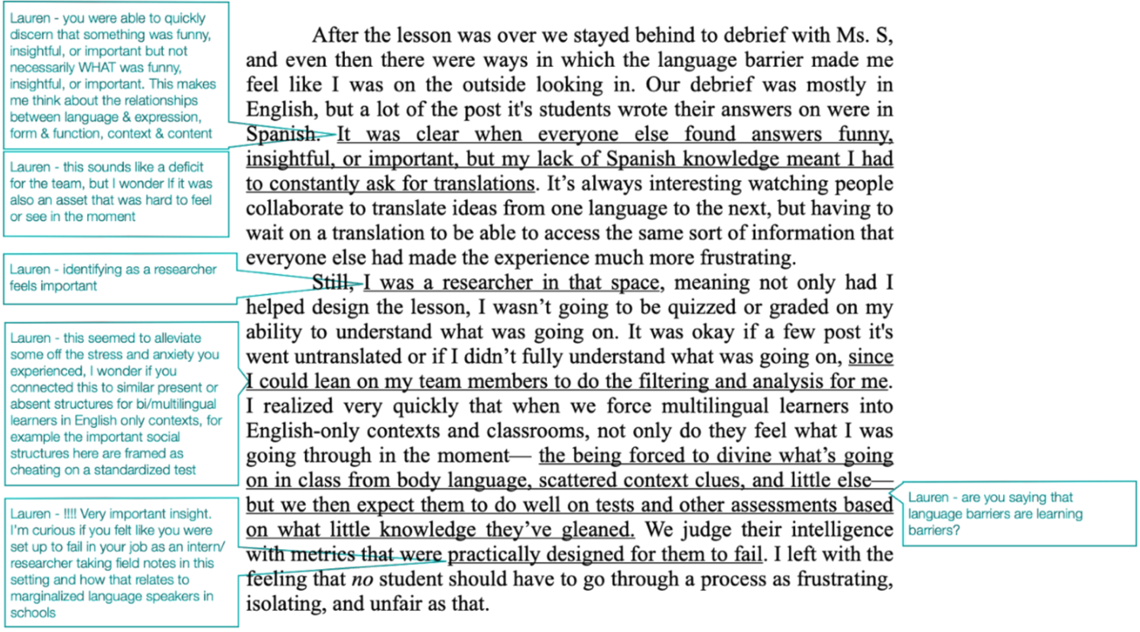
Lauren - which is/has become an important part of the group's theorization of translanguaging!

Lauren - This noticing in combination with your attention to non-verbal forms of communication produce really consequential insights about language minoritized learners and translanguaging theory:

1. Translanguaging, or how people make sense of the world generating and interpreting language, involves using multimodal forms of communication, YET a lot of communication happens verbally so when there is a verbal barrier and listeners only have non-verbal forms of communication to interpret it is hard and incomplete feeling work
2. Translanguaging posits that named languages are social realities and not linguistic realities, the way we make sense of the world is by using our full linguistic repositories, which are NOT segregated in categories that align with named languages. YET when someone's language repertoire does not include language resources from one named language it makes communication overwhelming and extremely challenging

Figure 2

Sarane's story with commentary from Lauren and responses from Sarane (Part 2)



Lauren - you were able to quickly discern that something was funny, insightful, or important but not necessarily WHAT was funny, insightful, or important. This makes me think about the relationships between language & expression, form & function, context & content

Lauren - this sounds like a deficit for the team, but I wonder If it was also an asset that was hard to feel or see in the moment

Lauren - identifying as a researcher feels important

Lauren - this seemed to alleviate some off the stress and anxiety you experienced, I wonder if you connected this to similar present or absent structures for bi/multilingual learners in English only contexts, for example the important social structures here are framed as cheating on a standardized test

Lauren - !!!! Very important insight. I'm curious if you felt like you were set up to fail in your job as an intern/ researcher taking field notes in this setting and how that relates to marginalized language speakers in schools

After the lesson was over we stayed behind to debrief with Ms. S, and even then there were ways in which the language barrier made me feel like I was on the outside looking in. Our debrief was mostly in English, but a lot of the post it's students wrote their answers on were in Spanish. It was clear when everyone else found answers funny, insightful, or important, but my lack of Spanish knowledge meant I had to constantly ask for translations. It's always interesting watching people collaborate to translate ideas from one language to the next, but having to wait on a translation to be able to access the same sort of information that everyone else had made the experience much more frustrating.

Still, I was a researcher in that space, meaning not only had I helped design the lesson, I wasn't going to be quizzed or graded on my ability to understand what was going on. It was okay if a few post it's went untranslated or if I didn't fully understand what was going on, since I could lean on my team members to do the filtering and analysis for me. I realized very quickly that when we force multilingual learners into English-only contexts and classrooms, not only do they feel what I was going through in the moment— the being forced to divine what's going on in class from body language, scattered context clues, and little else— but we then expect them to do well on tests and other assessments based on what little knowledge they've gleaned. We judge their intelligence with metrics that were practically designed for them to fail. I left with the feeling that *no* student should have to go through a process as frustrating, isolating, and unfair as that.

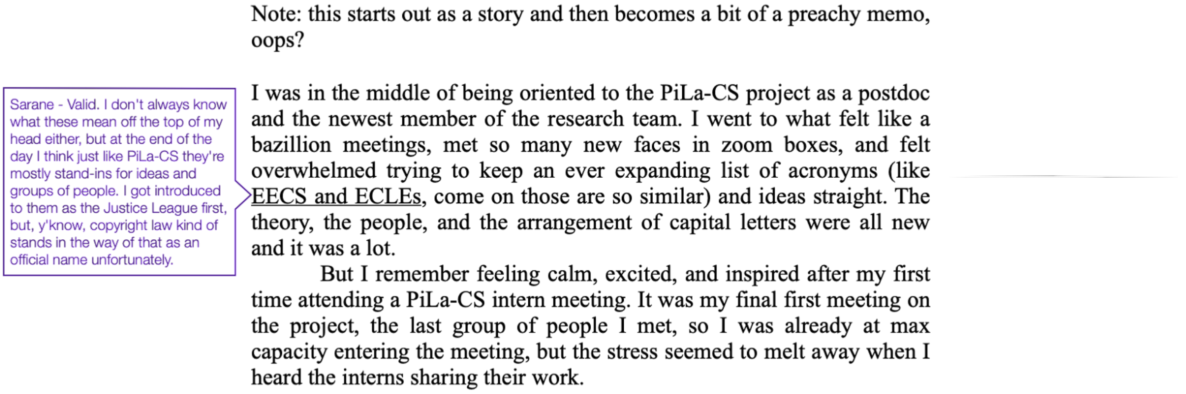
Lauren - are you saying that language barriers are learning barriers?

Story 2: Lauren's first introduction to the project's undergraduate interns

Our second story comes two and a half years after Sarane's first experience in the field as a researcher when Lauren joined the project as a postdoc, meeting Sarane and the other undergraduate interns for the first time during one of their weekly intern check-in meetings. You can find this story in Figures 3-5 along with Sarane's commentary (1). At this point in time we recommend reading story 2 as it is shared in Figures 3-5.

Figure 3

Lauren's story with commentary from Sarane (Part 1)



Note: this starts out as a story and then becomes a bit of a preachy memo, oops?

Sarane - Valid. I don't always know what these mean off the top of my head either, but at the end of the day I think just like PiLa-CS they're mostly stand-ins for ideas and groups of people. I got introduced to them as the Justice League first, but, y'know, copyright law kind of stands in the way of that as an official name unfortunately.

I was in the middle of being oriented to the PiLa-CS project as a postdoc and the newest member of the research team. I went to what felt like a bazillion meetings, met so many new faces in zoom boxes, and felt overwhelmed trying to keep an ever expanding list of acronyms (like EECS and ECLEs, come on those are so similar) and ideas straight. The theory, the people, and the arrangement of capital letters were all new and it was a lot.

But I remember feeling calm, excited, and inspired after my first time attending a PiLa-CS intern meeting. It was my final first meeting on the project, the last group of people I met, so I was already at max capacity entering the meeting, but the stress seemed to melt away when I heard the interns sharing their work.

Figure 4

Lauren's story with commentary from Sarane (Part 2)

I don't remember all of the details, but I remember Danielle, a NYU film major at the time, shared an episode of the documentary she was working on for the project. Danielle had edited clips from project data in a teacher PD into a public facing documentary episode to share how teachers got to know their students and their students' language practices. Maybe it was Danielle's calm demeanor, or the soothing music she had chosen as the backdrop to the episode that helped ease any uneasiness I was feeling at the time, or maybe it was the clear evidence of how careful and thoughtful she had been with the responsibility of telling teachers' stories, the way she allowed the care teachers brought to their practice to shine on the screen. The care put into this video (am I using the word care too much?) made me feel like I was in good hands myself in this community.

Sarane - Wendy's intention from day 1 as part of the team has been about telling marginalized peoples' stories in ways that is both respectful to them and values their input above all else, and is in conversation with ideas of storytelling as a form of protest that have been developed by Latinx artists and thinkers called testimonios. Her insight into building off that work respectfully have been integral to the team as we share the stories of our teachers, and I think no one has taken up that mantle more than Danielle and her documentary episodes. There was a lot of pressure and expectation (and love and support, obviously) surrounding what we hoped to get out of these videos and I think she took all of that and made something really beautiful!

My jaw was on the floor, this was beautiful, this was amazing. The conversations the team was having about how to tell these teachers' stories in clear and nuanced ways were just wonderful. Artistic research was being leveraged as academic research. Documentary filmmaking and editing are both artistic and research practices, something that I value myself and always try to bring out in my research on dance, choreography, and STEM learning. My new community not only got it but was making it happen in such meaningful ways. I was in awe, I felt like I belonged, and that there was a lot for me to learn in this space.

Sarane - I think I'm the sort of person who has grown up around a love of science and exploration my whole life. My mom used to buy those kiddy science kits and do the experiments with my brother and I as a kid, and my (brother's, technically) godmother gave me a real microscope and beakers and stuff like that as gifts. I think, especially going to a school like Bronx SCIENCE that valued science and math more than other things, I got really jaded about the positionality of the humanities vs the sciences in our society? So my instinct whenever I get told a "truth" about the sciences-- for instance, what should or shouldn't count as computer science-- my first instinct is always to push back against it. I think it's felt like "fighting" the idea of academic research, but seeing it posited almost as a different approach, a new way of getting at the same thing, feels... good? Yeah.

Sarane - I guess the point of my whole big comment above is that the thing you clocked instantly didn't feel to me like we were using art as research? Not that we WEREN'T doing that, but to me it felt like as much as we call it a research-practice partnership, and we had to go through the whole research certification process to work with kids and such, it still felt to me almost like we were being allowed a space to do artistic things where we would usually be made to do research instead. And I think the fact that your perspective allows both the research and the art to be one and the same and starts from a place where they're equally valuable is really amazing.

After being introduced to every corner of this project I confidently discerned that the most innovative work on the project was coming from undergraduates who were supported and given space to bring their passions and expertise to the project as forms of valued and rigorous research.

Over time as I got to know the interns and their work better I came to see how not only were their developing perspectives and expertise supporting the aims of the PiLa-CS research, but their involvement in the project was supporting their own development. I found this particularly striking with respect to their majors in school for Danielle the film major, Kyla the Computer Science major, and Sarane the creative writing major.

Sarane - Capitalization

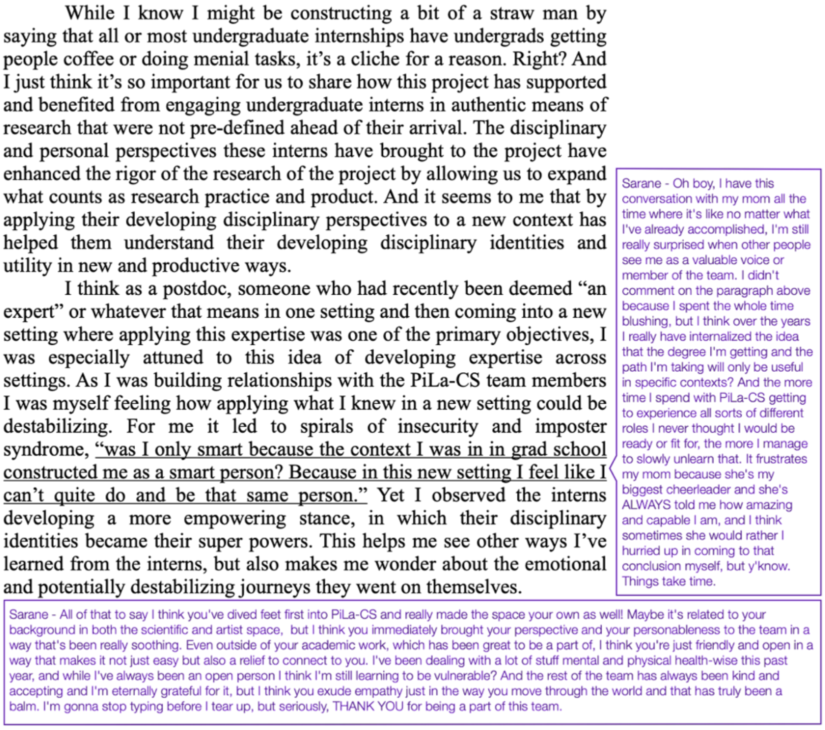
While Danielle was crafting documentary episodes, Kyla and Sarane were supporting a middle school teacher with curriculum development for her after school coding club. The ethical dimensions of coding were an important concern in the development of this curriculum as the teacher wanted to center what students cared about in the unit. Kyla saw a significant disconnect between the CS curriculum she was carefully developing and the CS curriculum she was experiencing herself as an undergraduate CS major. She openly questioned and critiqued her own course requirements, sharing that she felt like there was a big hole in the ethics of coding and becoming a coder in her own course requirements. How can a university turn out so many coders without ever asking them to consider the ethics of their work?

Sarane - Again related to the essay I wrote in the comments above (oops), but this is the thing about the way we talk about science majors. Obviously I'm not one myself so I don't know what those conversations are like from the inside outside of my high school experience, but there's almost this feeling like "what we're doing is smart and noble and important and things like English or philosophy or literature are a waste of time," and I think it creates this environment where it's OKAY to not think about ethics or the real-life affects of your work on different populations as long as you're creating something innovative and new. And it feels like you SHOULD be taught to value history classes, or English literature, or even philosophy, because how else are you supposed to know the historical ways in which tech and innovation has hurt people and thus avoid replicating it yourself? Then again, if you don't care who you hurt, then what do those things matter?

And last but not least Sarane, the heart and soul of the intern community and one of the longest running members of the research team was one of the most insightful thinkers I have been lucky enough to work with. It was and continues to be a common occurrence that Sarane's utterances are written down as key insights, or sometimes were even recorded as explanatory footage for Danielle's documentaries. When Sarane speaks everyones' ears perk up with extra attentiveness because we know her ideas are insightful and generative. This positioning, however, does not necessarily match Sarane's disciplinary expectations. She has shared with the project on multiple occasions that as a creative writing major her mentors have told her that she only has two relevant career options: (1) become an academic or (2) work in publishing. Yet on PiLa-CS her expertise as a writer has helped the research team in multiple ways from her insights as a collaborator to her written work on our website to share the meaningful stories from the project with others.

Figure 5

Lauren's story with commentary from Sarane (Part 3)



While I know I might be constructing a bit of a straw man by saying that all or most undergraduate internships have undergrads getting people coffee or doing menial tasks, it's a cliche for a reason. Right? And I just think it's so important for us to share how this project has supported and benefited from engaging undergraduate interns in authentic means of research that were not pre-defined ahead of their arrival. The disciplinary and personal perspectives these interns have brought to the project have enhanced the rigor of the research of the project by allowing us to expand what counts as research practice and product. And it seems to me that by applying their developing disciplinary perspectives to a new context has helped them understand their developing disciplinary identities and utility in new and productive ways.

I think as a postdoc, someone who had recently been deemed "an expert" or whatever that means in one setting and then coming into a new setting where applying this expertise was one of the primary objectives, I was especially attuned to this idea of developing expertise across settings. As I was building relationships with the PiLa-CS team members I was myself feeling how applying what I knew in a new setting could be destabilizing. For me it led to spirals of insecurity and imposter syndrome, "was I only smart because the context I was in in grad school constructed me as a smart person? Because in this new setting I feel like I can't quite do and be that same person." Yet I observed the interns developing a more empowering stance, in which their disciplinary identities became their super powers. This helps me see other ways I've learned from the interns, but also makes me wonder about the emotional and potentially destabilizing journeys they went on themselves.

Sarane - Oh boy, I have this conversation with my mom all the time where it's like no matter what I've already accomplished, I'm still really surprised when other people see me as a valuable voice or member of the team. I didn't comment on the paragraph above because I spent the whole time blushing, but I think over the years I really have internalized the idea that the degree I'm getting and the path I'm taking will only be useful in specific contexts? And the more time I spend with PiLa-CS getting to experience all sorts of different roles I never thought I would be ready or fit for, the more I manage to slowly unlearn that. It frustrates my mom because she's my biggest cheerleader and she's ALWAYS told me how amazing and capable I am, and I think sometimes she would rather I hurried up in coming to that conclusion myself, but y'know. Things take time.

Sarane - All of that to say I think you've dived feet first into PiLa-CS and really made the space your own as well! Maybe it's related to your background in both the scientific and artist space, but I think you immediately brought your perspective and your personableness to the team in a way that's been really soothing. Even outside of your academic work, which has been great to be a part of, I think you're just friendly and open in a way that makes it not just easy but also a relief to connect to you. I've been dealing with a lot of stuff mental and physical health-wise this past year, and while I've always been an open person I think I'm still learning to be vulnerable? And the rest of the team has always been kind and accepting and I'm eternally grateful for it, but I think you exude empathy just in the way you move through the world and that has truly been a balm. I'm gonna stop typing before I tear up, but seriously, THANK YOU for being a part of this team.

Discussion conclusion

The structure of our methodology means the discussions around these stories are recursive. Each layer of analysis becomes fodder for new conversations, preserving our thoughts and feelings and allowing us to build on them in the future, serving as artifact and analysis at the same time. Similarly, LPP (Lave & Wenger, 1991) posits that shifts in identity and practices are related as the relationships between newcomers and old-timers change over time.

Undergraduate interns' shifts in identity inside and outside of our research

These stories helped us crystalize how undergraduate interns' identities with respect to our research community and to their "major discipline" communities shifted in relation to each other. For Sarane, her emerging identity as a researcher was in direct conversation with her identity as a writer. Some of these tensions came out in her story, sharing how when she first joined the project she felt "strict boundaries between things like writing and research." Yet, Lauren saw lots of connections between Sarane's practices as an established writer and emerging researcher, such as feeling most comfortable writing field notes but feeling conflicted about trying to remove her perspective and bias to take scientific, "objective" ones. Lauren wrote about how Sarane repeatedly shared the limited career paths she had been told were possible as an English major (teacher or publisher) and contrasted that with how Sarane's writing practices have been used to write material for PiLa-CS's website and for our methods in this analysis. Sarane is a central and successful member of the PiLa-CS research team, evidence that her writing practices can be generative and productive outside of those pathways. Lauren also shared how Kyla began to question why ethical considerations were taken into account in the CS curriculum she was co-developing for middle schoolers but not for undergraduates like herself. For Kyla, being a computer scientist now meant needing to think about the ethical implications of her work, and not having formal spaces to think about this in her coursework increasingly frustrated her. The confluence of multiple identities within the context of our research community led to the emergence of new, critical perspectives on disciplinary practices for the undergraduate interns such as Kyla's questioning of her university's CS curriculum and Sarane reclaiming the power of reinstating her perspective, "the I in research," into her academic writing.

Our research community's shifts in relation to undergraduate participation

The research practices we engaged in as a community also shifted. Sarane wrote about attending to body language when she felt lost on her first day of field work and Lauren commented on the connection between Sarane's experience and the PiLa-CS team's shifts in theorization: conceptualizing translanguaging in terms of a larger range of multimodal communicative resources (e.g., gesture, emojis) and not just verbal language use. The intern projects, such as Danielle's documentary episodes and Kyla's identifying as a CS teacher interactive timeline, also became new forms of analysis. These analytic artifacts had a meaningful impact beyond the usual formal academic papers in our project team and our dealings with practitioner partners. Seeing how teachers reacted to having their stories told back to them was a highlight from our PD work together. Lastly, the methods and structure of this paper developed out of changing research practices in our team as autoethnography morphed into writing memoir-like excerpts with each other.

As our practices grow and shift so does our attunement to the importance of relationality in learning. We found while engaging in these new research methods that what we shared became more personal, making salient parts of ourselves that had not seemed so before. This was present when Sarane shared stories about insecurities her mom tried to help her unlearn in response to Lauren sharing insecurities about her imposter syndrome in her story. Sharing and commenting on each other's stories was a vulnerable process that sometimes felt scary and uncertain. It took a lot of reassurance and conversations before we felt comfortable sharing them with each other, yet what came from our sharing and comments brought value to bringing our perspectives together. We reassured each other about our contributions to the team, whether theoretical or interpersonal, through our comments. In the process of crafting this paper we continued to grow and learn from each other because learning is always happening as a relational enterprise and thus new forms of relationality are always blossoming. We are excited at the prospect of cultivating these supportive and generous forms of relationality, something we feel should not be taken for granted in research contexts.

Conclusion

As Lave & Wenger (1991) posit, learning is relational, becoming, and always happening. Thus it is not a surprise that undergraduate interns' identity development in the context of their internship was tightly connected to observable shifts in research practices within our community of practice. Since internships are often vectors for communicating what it means to be a researcher, it is important for research communities to reflect on and make explicit how interns contribute to shifts in research practices. This has allowed us to collaboratively reimagine what counts as research using both the goals and experience of senior project members and the interests and expertise of interns. Senior members of the team trusted undergraduates as experts in their major discipline while also widening the potential applications of these disciplines, allowing their contributions to meaningfully affect the future of our community.

Endnotes

(1) We have replicated the text of our stories and comments in a google doc so that anyone who uses a screen reader can read it with ease. https://docs.google.com/document/d/1_xQvK_veyVp-6RjbZAwBTnneV2MLBYjf/edit

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What Counts? Play as a Mechanism for Disrupting Participation Patterns in School Mathematics

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Abstract: This paper explores how making space for mathematical play can disrupt existing participation structures in classrooms and create space for inclusive and robust mathematical engagement. We analyze one episode of children's play that involved counting and unitizing to measure a rocket created with Magna-Tiles, addressing two research questions: 1) How does children's collaboration during a playful activity contribute to mathematical activity? 2) How did one child (Quentin), who is often removed from mathematics, participate in this activity? Our findings reveal how the collective interactions that led to this moment involved Quentin's sustained engagement, which was outside the norm for him. Quentin was a full participant in the counting and unitizing episode and his thinking had status and was valued by others. This episode points to the possibilities of play as a transformative space that affords creates opportunities to engage in mathematics in ways that disrupt patterns of exclusion.

Introduction

The goal of this paper is to explore how making space for mathematical play can disrupt existing participation structures in classrooms and create space for inclusive and robust mathematical engagement. We situate this analysis in a collective moment of mathematical joy and rigor, which involved four playmates engaging in rich mathematical thinking. We examine how this moment emerged, and specifically, how the act of play—of exploring and sharing materials, and of posing one's own question for inquiry—contributed to this moment. To understand both the final moment and the trajectories of play that contributed to its development, we draw on literature about humanizing mathematics, about disrupting structural racism that leads to alienating participation practices, and about the potential of play for transforming engagement.

The focal moment occurred approximately one month into the school year, during a period of free play in a kindergarten classroom. The four students in analysis, Laura, Briona, Max, and Quentin, chose to play with Magna-Tiles, transparent 2-D shapes with magnets along the sides that can be joined. Throughout the episode, the children played both independently and together. However, one creation received the most attention and the most resources a tall "rocketship" built by Laura that required many magna tiles. About 10 minutes into their free play, taking a pause from his own creation, Max turned the group's attention towards Laura's rocket. What initially began as a single student's reaction to the grandeur of Laura's creation eventually evolved into a mathematically rich conversation involving all four students, as seen in the transcript below.

1 Max: Dude, this is a tall, it's a tall building! *(Looks at rocket and smiles).*
2 Briona: It's a toy rocket! *(Walks around K, touches top of rocket, and smiles. Returns to seat).*
3 Max: Wait so it has levels? *(Gestures at rocket).* The building has levels. One, two, three, four, five, six, seven. *(Points to each level of rocket for each counted number, then pauses).* Eight. *(Points to roof).* Eight levels! This thing has eight levels! *(Looks at Quentin and gestures towards rocket while smiling).*
4 Briona: It's eight levels cause it's a hotel. *(Looks at rocket).*
5 Quentin: One, two, three, four, five, six, seven. *(Touches each level of rocket, excluding roof, for each counted number).* Seven levels! *(Looks at Max).*
6 Max: I thought it was eight levels. *(Looks at Quentin).*
7 Briona: You're counting too much. *(Walks around Laura to rocket).* One, two, three, four, five, six, seven, eight. *(Touches each level of rocket, including roof, for each counted number).*
8 Laura: No that's the roof. *(Touches roof).* There's no layer to the roof. *(Turns to face other students).*
9 Briona: The roof don't count. *(Looks down at table).*

This moment was significant for several reasons. First was the *collective engagement*—all four students were involved in this conversation, exchanging ideas and taking turns, as seen in turns 3, 4, 5, 6, and 7. Second was the *mathematical content* of the students' discussion: counting that demonstrated one-to-one correspondence (turns 3, 5, and 7); and debating about minimally defining characteristics of a set (turns 8 and 9). Third was the fact that this occurred *independently and spontaneously*, as no adult was present, and the students were never asked to count (their only task was to play). And finally, was the *absolute joy* that was evident amongst the group. The students were smiling, laughing, and generally celebrating the eye-catching creation of their peer. It was a moment of mathematical joy, mathematical rigor, and legitimate mathematical inquiry.

This episode is also an instance of *disruption* of established participation practices in the classroom. In this class, math instruction typically involves working on prescribed tasks that are highly structured, with little space for spontaneous decision making. Thus, free mathematical play served to disrupt the typical practices around what it means to do math. Equally importantly, these different mathematical practices resulted in very different forms of participation for the students. Max, who is often quiet and hesitant to share what he knows, was talkative, engaged, and initiated the mathematical inquiry in the episode (turn 3). Quentin, who is frequently excused from the mathematical work of the class because his behavior is seen as disruptive, was engaged, collaborative, and offered his own mathematical expertise as a legitimate contribution to the group's discussion. In what follows, we consider how this spontaneous moment developed between the four students, and how it served to disrupt existing structures of what it means to do math, and who gets to participate in the activity.

Literature review and framing

Although play is acknowledged to be a crucial aspect of general well-being (Brown, 2009; Gray, 2011), and an important mechanism for learning (Vygotsky, 1967), it is also often dismissed as non-essential and is quickly removed as a consequence for bad behavior or to bolster instructional time (Chang & Coward, 2015; Jarrett et al., 1998; Massey et al., 2021). Consequently, play is becoming increasingly scarce in classrooms, even for the youngest kindergarten students. Although this is a problem for any subject, we argue that play in mathematics classrooms is particularly important to consider, as the discipline is often introduced in prescriptive ways that primarily focus on computation (Wager & Parks, 2014). This creates a challenge when supporting learning, for while prescriptive and streamlined activities are an efficient solution to the task of moving large numbers of students through many topics, it does not support students to develop robust number sense. Further, the practices that such approaches to teaching mathematics require, such as a focus on efficiency, speed, and memorization, are known to undermine students' enjoyment and deep understanding (Boaler, 2002; Boaler & Staples, 2008). In contrast, classrooms that offer time for exploration, that emphasize reasoning and understanding over accuracy and speed, and which place student identity at the center of instructional design, have been found to support a more productive relationship with the domain of mathematics (Grant et al., 2015; Gresalfi, 2009).

The mathematician Francis Su describes his own vision for mathematical engagement as follows: "I hope that…you can see yourself as a *mathematical explorer*, who can think in mathematical ways and who is welcome in mathematical spaces" (2020, p. 12). As Su and others explain, "expert" engagement with mathematics involves exploration, play, aesthetical judgement, and joy (Bergen, 2009)—terms that are not commonly associated with school mathematics. However, when students are invited to engage with mathematics in this way, they have opportunities to reason about the why of mathematics, to engage in the "call-and-response" of mathematics, when "…the mathematics calls out to the explorer and asks, 'What do you notice? What do you wonder?' and the explorer responds with an observation" (Su, p. 54).

Play not only offers the potential to disrupt mathematical practices, but it also can serve to disrupt who gets seen as mathematically capable. Many scholars have argued that mathematics classrooms are sites of white supremacy, offering narrow conceptions of what counts as mathematical excellence (Ladson-Billings, 1998), recognizing only some kinds of thinking and people as mathematically relevant (Joseph et al., 2017), and conflating mathematical aptitude with overall intelligence (Martin, 2019). While these practices interfere with students' likelihood of engaging with rich mathematics in general, they are particularly problematic for students of color, who are more likely to have less-qualified teachers (DeMonte & Hanna, 2014), to be removed from school by suspension (Gregory & Roberts, 2017), and to face stereotyped low expectations for their mathematical success (McGee & Martin, 2011; Nasir & Shah, 2011).

Analytic framework

This paper connects with the concept of play in two ways. In addition to grounding our analysis in studies of the potential efficacy of play, as described above, we also use the concept of play as an analytic framework to explore the potential of play as a productive practice. Specifically, we explore whether and how play offers a potential inroad to the question posed by Martin: "What can and should refusal of dehumanizing and violent mathematics education look like in principle and practice?" (2019, p. 461). This is also responsive to the proposal made by Joseph et al., (2019), who wrote: "A second area for further research is the idea of humanizing Black girls by creating a space for play—a place for them to be happy, gregarious, social, and "goofy" …. Our emerging analysis illuminates that when the Black girls in this study were afforded the opportunity to be both serious and silly, they were more engaged in mathematics learning" (pp. 149). However, before making the fundamental error of romanticizing children's activity, we note that play is not a panacea—it characterizes a form of human interaction that is fraught with the same perils, biases, and oppression that characterizes all interactions (Bryan, 2020). We know that children's play can be racist, mean, gendered, and exclusionary. Although it has the potential to liberate students from the conventions of the discipline, it by no means transcends the everyday structures that dictate our interactions. Therefore, even as we look for sites of potential disruption, we must stay vigilant at noticing the ways it might fail, lest we contribute to the continued reproduction of mathematics reform that ultimately serves to change nothing for students who are already being oppressed by its structures (Martin, 2019)

Although there is variation among the definitions of play, most involve characterizations of spontaneity, interest, choice, and pleasure (Brown, 2009; Burghardt, 2010). This is not to say that play is divorced from rules or constraints—part of what makes play enjoyable is the opportunity to explore in relation to a set of existing structures (Ginsburg, 2006). In this work, we define play as pleasurable activities where children can explore, engage with interesting materials and make choices. We use this understanding of play to explore how and why young children constructed their own rich mathematical engagement, and how, in doing so, they managed to include all members of their group in reaching a conclusion. We look at students' interest, their agency, their mathematical reasoning, and their emotions, to better understand whether and how situating mathematics in the context of play was ultimately productive for the group. In so doing, we ask the following questions:

1) How does children's collaboration during a playful activity contribute to discussions about the rocket?
2) How did one child, who is often removed from mathematics, participate in this activity?

To address these questions, we analyzed each student's specific contributions, both leading up to and during this episode, and how play afforded their collective mathematical engagement towards Laura's rocket.

Methods

Participants and context

This episode comes from the fourth day of co-designed "play lessons," which focused on the properties of shapes, part of a larger study about how early-grades teachers integrate play into their mathematics teaching. The teacher, Ms. Rosinsky, co-designed lessons that included whole-class introductions and reflections but predominantly centered on guided play centers, in which students engaged with playful mathematical materials. At the end of the lesson children were invited to choose a table and play with mathematical toys—no other instructions were given. Children played at these free play stations for approximately 15 minutes.

The four students in analysis, Laura, Briona, Max, and, Quentin, chose to play with Magna-Tiles. Laura is a white girl who was typically quiet but attentive in mathematics lessons. Brionna is a Black girl who generally worked independently, particularly during center work. Max is a Latino boy who was often reserved but engaged during mathematics activities. Quentin is a Black boy who was often called out for not paying attention or for disrupting his peers. In general, Quentin often spent time during math lessons at the back table, rather than sitting on the rug with the rest of the class engaging with the lessons. For example, in the activity before the free play episode, the children were participating in guided math centers. At his table, in response to other children who were making loud noises, Quentin started to yell, "QUIET! QUIET!" A moment later, the teacher came over to Quentin and guided him to a table on his own.

We collected data in two forms: observation notes and video. Observation notes served as the initial place we used to identify the focal moment, which was then selected for in-depth analysis collectively. Video was taken by a GoProMAX, a small camera which sat in the middle of the table and captured a 360-degree visual field. The video can be replayed either by flattening the image as you might unwind a sphere, or by swiveling the view in 360 degrees, seeing only a subset of the view at a time. We looked at the video first as a flattened view to see the entire group and then looked closely at each child. The episode lasted approximately 16 minutes, beginning with their first negotiations about play rules to the deconstruction of their creations during clean-up.

Analysis

The analysis began with all seven members of the research group and all five cooperating teachers watching the video. We discussed the instance and shared ideas about what was taking place in the video. These initial viewings confirmed that the instance of collective engagement felt important and interesting and was worthy of additional investigation. A smaller group used interaction analysis to analyze the video more closely, first developing an emergent set of inductive codes, and then a second set of inductive codes that we used to document the ways that children were working together, how they were working independently, and when and how their work came into contact, as depicted in Table 1. Our final analysis focused our view on the ways each child contributed to the final moment of "counting the levels," attending to the construction of the rocket, and the times and ways that different children felt that its size was worthy of commentary and documentation. Ultimately, we used this coding to tell a story of each of the four children and the ways their work came together.

Table 1

Final Set Of Codes Used To Examine Each Student's Contribution to Laura's Rocket

Resource Codes	Mathematics Codes	Intention Codes
Sharing	Counting	Articulating Plan
Grabbing	Discussing Unit of Measurement	Articulating Imagined Storyline
Protecting	Fitting	
Co-Building	Making Shapes	
	2-D Building	
	3-D Building	

Resource codes focused on the ways students shared, grabbed, and protected resources, and co-built alongside Laura. We also coded for each student's *mathematical* contributions, which included counting, discussing the unit of measurement, fitting shapes together, making shapes from other shapes, 2-D building, and 3-D building. Finally, we considered the ways students communicated their intentions by coding for moments when students articulated a plan or imagined storyline. From the codes, we crafted narratives of each student's trajectory towards the focal moment with Laura's rocket, which formed the basis of our conjectures about the participation practices and mathematical opportunities that their free play afforded.

Findings

We begin with a brief story of each of the four children, before turning our lens to their collective work.

Laura

When Laura sat down at the table, she immediately asked "Can we build together?" However, even as she was speaking, she slid a stack of squares over and placed them directly in front of herself and started to build. It appeared that Laura already had an idea in mind of what she wanted to do, as there was no observable exploration of shapes. Instead, she took several squares off the pile and arranged them into a net of five squares, which she then folded into an open-topped cube. Although she did not hesitate when laying down the 2D net, she did pause when folding up the sides (because Magna-tiles are magnetic, you must place the tiles adjacent to each other in order for them to stay up). For her first cube, Laura placed a square on top, then removed it. She then created a second cube using the same 2D net to 3D cube strategy, this first by counting off five squares from her pile of squares, and then time adding it on top of the first cube. She continued to build a tower using this method for every single level, stopping only to defend her resources or to secure the resources that she needed for the roof of the building. Laura's building required many Magna-Tiles, something that her group mates noted and challenged her about. Overall, despite Laura's expressed interest in working with her peers, much of her free play was characterized by single-minded determination. She rarely participated in conversation with the other members of her group, and stayed focused on her design until it was completed. After its completion, she was happy to engage with her peers and began to build with Brionna, before the group's attention turned to the height of her rocket.

Briona

From the onset of her free play experience, Briona consistently weaved in and out of her own Magna-Tile creation and Laura's rocket, which predominantly showed up in the form of sharing resources and protecting resources. Briona very quickly articulated her imagined storyline of constructing a three-dimensional garden house. This initially consisted of fitting large squares together to form a cube; however, as she approached the roof of her garden house, she realized the limited resources at her disposal and thus turned to the group to articulate her plan and elicit help. She stated, "I need four!" to her fellow playmates, but did not specify which shape. Therefore, Laura shared small squares and Quentin shared small triangles, but neither shared the large squares that Briona had been using up until that point. Briona explored with these shared resources by forming large squares from the small squares to construct the remaining side and roof of her garden house. This period of exploration was notable, as it led to a shift in Briona's original plan. In creating shapes, rather than already having large squares, she experimented with forming shapes from other shapes, eventually realizing that she no longer needed the small triangles that Quentin had shared with her. Consequently, Briona shared these triangles with Laura, who later sought this resource to complete the end of her rocket.

Briona was also instrumental in protecting Laura's resources. For example, as Briona worked on the roof of her garden house, she realized that she needed another small square, which Quentin then removed from Laura's rocket and placed on Briona's roof. Briona, however, quickly removed this piece and returned it to Laura's rocket. In other instances, Briona went so far as to create a physical barrier between Laura's rocket and the other students by putting her arms around the rocket to protect it from Quentin or Max. Although she was invested in her own garden house, she appeared equally invested in contributing to and protecting what Laura had created.

Max

Like Briona, Max's fluidity between independent and collaborative play also contributed to the focal moment of analysis. Of the four students, Max took on a more explorative approach, rather than executing an articulated plan. Although he did eventually decide to construct his own rocket, which differed considerably from Laura's, his initial play began as collecting various shapes that other students were not using. After evaluating the resources that he had available, he started fitting small triangles together to create a two-dimensional pattern, similar to how tiling might occur. As Laura's rocket became taller and taller, Quentin started commenting on its height, which then caught Max's attention. Noticing that Laura's rocket was almost complete, he gathered four isosceles triangles and handed them to Laura, stating, "Here Laura! For your end. Here for your end. That's for your end." Laura took these triangles and although she did not end up using them for the tip of the rocket, she did include them as embellishments on the sides. By sharing these resources, Max demonstrated an early investment in Laura's rocket. Like Briona, he frequently negotiated the materials that he was willing to share (or not share) based on a consideration of his own construction in relation to Laura's.

Quentin

Quentin was fully engaged with the Magna-Tiles, working independently most of the time. He said he was creating a car which then morphed into a bus as the play progressed. There were only a few instances where his attention was directed toward anything other than his own building. The first occurred when Quentin was out of Magna-Tiles and started looking for more. It was during this instance that he noticed Laura had many pieces, resulting in the interaction reviewed above. After this initial interaction, Quentin kept the Magna-Tiles that he took from Laura and continued building his structure for roughly one minute. He then looked up at Laura's rocket and exclaimed, "What!" and pointed at the rocked and started to count as he pointed to the different pieces and noticed that she had "seven stacked." In one instance, Quentin made a square out of 2 triangles and offered it to Laura, although this was his only contribution of physical objects to her rocket. Beyond this one instance, Quentin only attended to her rocket when he was looking for more pieces for himself or others and when he was counting the layers. As the playing progressed, Quentin directed Max and Briona to take some pieces from Laura as she had the most. Quentin even took one square piece from Katharine's rocket and gave it to Briona, who immediately gave it back to Laura. After Quentin had finished building his structure, he played with it pretending it was a car. He moved it around, making noises that sounded like a car accelerating or turning quickly. He then stepped away from the table just as Max counted eight levels of the rocket. This drew Quentin back to the table as he ran over and counted seven levels. Quentin's engagement and participation in the counting episode were collaborative and not disruptive toward the other children or the teacher.

The focal moment—Mathematical play as disruptive

As indicated earlier, these interconnecting trajectories of play resulted in collective inquiry into the question of the height of Laura's rocket. The moment began with Max's observation—and seeming delight—at the height of Laura's creation (turn 1). Briona echoes this endorsement, gesturing to the very top of the rocket (which is above her head). Although this was Laura's creation, insofar as she is the person who created and stacked each cube, each member of the group has contributed by protecting or offering resources for its creation. Perhaps as a consequence of these contributions, all children at the table seemed equally delighted by the rocket, and perhaps even a bit proud of its scale. However, what turned this into a mathematical moment was Max's decision to *count* its levels as a means of documenting its height (turn 3).

Figure 1
Laura's rocket

(1) Max: Dude, this is a tall, it's a tall building! *(Looks at rocket and smiles).*
(2) Briona: It's a toy rocket! *(Walks around K, touches top of rocket, and smiles. Returns to seat).*
(3) Max: Wait so it has levels? *(Gestures at rocket).* The building has levels. One, two, three, four, five, six, seven. *(Points to each level of rocket for each counted number, then pauses).* Eight. *(Points to roof).* Eight levels! This thing has eight levels! *(Looks at Quentin and gestures towards rocket while smiling).*
(4) Briona: It's eight levels cause it's a hotel. *(Looks at rocket).*

At this point, at least two members of the group were invested in connecting Max's count with evidence of the scale of the creation. Mathematically, this was an important moment, particularly for new kindergarten students. Max's counting is sophisticated in that it demonstrates *one-to-one correspondence*—counting each item separately, only once. His counting also demonstrates *cardinality*—knowing that the last number counted refers to the total number in the set. This act of counting—of documenting the height of the rocket—appears to continue to give Max delight, and he shares his excitement by turning towards Quentin as he speaks, smiling (figure 2).

Figure 2
Quentin counting the levels of Laura's rocket

(5) Quentin: One, two, three, four, five, six, seven. *(Touches each level of rocket, excluding roof, for each counted number.* Seven levels! *(Looks at Max).*
(6) Max: I thought it was eight levels! *(Looks at Quentin, smiles).*

In turn 5, Quentin undertakes his own count of the rocket, again demonstrating one-to-one correspondence and cardinality, but this time arriving at a different number—seven—due to excluding the roof in his count. Max does not dispute Quentin's count, but instead seems to simply remark on their different numbers, finding this amusing, as demonstrated by his smile and laugh (turn 6). In this moment, Quentin's experience in the mathematical conversation is different from what we typically observed in the class. First, and most noticeably, Quentin was a part of the mathematical work, not removed from it. Second, his participation was invited by his friends, and his contributions were valued and ultimately endorsed. Quentin's contributions to the rocket were often related to resources, as his interactions with the other children were mainly about Laura having the most and Quentin trying to gather or share her resources. Notably, Quentin was engaged in this Magna-Tiles free-play activity in ways we (the first and third authors) had not observed previously. He sat and quietly played while he independently built his structure. He shared a piece he built with Katharine. He attended to Laura's rocket and was even drawn back to the table after he walked away to participate in a conversation about the number of levels in the rocket. Quentin's engagement was productive and collaborative, which deviated from his frequent patterns of disrupting others.

> (7) Briona: You're counting too much. *(Walks around Laura to rocket).* One, two, three, four, five, six, seven, eight. *(Touches each level of rocket, including roof, for each counted number).*
> (8) Laura: No that's the roof. *(Touches roof).* There's no layer to the roof. *(Turns to face other students).*
> (9) Briona: The roof don't count. *(Looks down at table).*

Briona and Laura also enter the conversational space, introducing a new idea—what ought to be counted in the determination of the number of levels contained in the rocket. Briona's count—which also demonstrates one-to-one correspondence and cardinality—includes the roof, echoing Max's approach. However, Laura—the rocket's creator and therefore apparently the definitive voice on its components, sides with Quentin, asserting that "there's no layer to the roof," a perspective immediately affirmed by Briona. In this interaction the children's conversation about what counted as a level (turns 3-9) reflects an important mathematical concept related to measurement – *unitizing*. As the children discussed what counted, they were discussing the unit of measure to determine the height of the rocket. In their conversation, it was determined that the unit was the levels, rather than the individual pieces of Magna Tiles.

Conclusion and implications

This study explored an episode of free play that resulted in children's spontaneous and joyful engagement in a conversation about measurement and counting. This moment served to disrupt typical math practices in the classroom which involved students working on questions and problems that were posed by the teacher and was instead a moment when the children themselves articulated a mathematical question and went about answering it themselves, collectively. This moment also served as disruption for one child, Quentin, who was a full participant in counting and unitizing, and whose thinking had status and was valued by others.

In contrast to the idea that play might take time away from mathematics instruction, this episode suggests that play can create new opportunities for mathematical engagement, which has the potential to transform and disrupt what it means to do math and who is seen as mathematically competent. The play activity and the participation norms that were established for this free play activity allowed children to talk, laugh, play, and move around the classroom at will. Children were also encouraged to think about mathematical concepts like shape attributes and counting, but the goals were less narrowly defined as compared to the playful mathematics lessons and math centers that occurred before the episode. As a consequence, this episode created space for young children to engage in problem posing, asking a question (how tall is it?) that was interesting and important to all students in the group. It was not a requirement but rather a choice to count and discuss what gets counted. In addition, the activity created space for Quentin to engage productively—he participated for a sustained time, returned to the conversation after leaving, and was not disruptive to the children around him. His contributions were considered by other students, and valued—it was clear they regarded him as a legitimate and important member of the group. Thus, we argue that play acted as a mechanism for disrupting and transforming patterns of exclusion. We conjecture that other activities that offer these kinds of freedom and engagement to children have the potential to disrupt patterns of exclusion in similar ways. However, to this promising note, we also offer the observation that play did not disrupt all ingrained participation structures, as the activity of the group centered the demands and wishes of a single child: a while girl who effectively dominated resources through a combination of whining and demanding. The instance needs to be considered from that lens as well, as we must take seriously whether and how we might truly challenge and disrupt a broad range of existing inequities and hegemonic practices (Bryan, 2020).

This study adds to the literature on learning through play in early grades as it highlights another way that play can create opportunities to learn. The literature on learning through play, particularly after pre-school, is very small, and such rich examples add to our burgeoning understanding of what playful mathematics learning looks like. The findings also offer an example of possible strategies to disrupt ingrained classroom practices, such as patterns of exclusion, authority, and positioning of children. Future work may explore how offering play rather than taking it away can impact the participation of children in classrooms beyond this single case study. In fact, a limitation of this study is that it is focused on a single instance, which inspires but does not persuade that free play is necessarily always mathematical. While we do not make such a claim, we note that continued research is necessary to identify the conditions under which free play can become mathematical, work that we will continue as the project continues and we collect more data about student learning through play.

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Incorporating Community and Citizen Science into Schools: How Youth Develop Science Identity in California Forests

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Abstract: Community and citizen science show promising outcomes of democratizing scientific endeavors by engaging non-professionals in scientific research. Thus we incorporated this program model into elementary schools to support youths'' science learning. Informed by multiple threads of scholarly works - *situated learning*, *figured worlds*, and *place-based learning*, we collaborated with teachers and community stakeholders to design and implement a forest monitoring protocol to study fire behavior and invasive species in a local Northern California forest. After analyzing 15 youths' post-program interviews, we found that youth-focused community and citizen science have great potential to support youths' development of scientific knowledge, practice, and identity. Using authentic scientific tools and collecting place-based data not only supports youths' disciplinary practice learning but also mediates their science identity development by broadening what counts as science and how and where science is executed.

Introduction and background literature

Through engaging non-professionals in authentic scientific research processes, Citizen Science (CS) and other participatory approaches to science can serve as critical channels for broadening participation in scientific research and promoting equitable access to scientific data (de Sherbinin et al., 2021). Citizen Science and related programs support scientists in collecting larger volumes of ecology and environmental science data (Silvertown, 2009) across a wide geographical area, which could otherwise be an impossible task, and simultaneously open up opportunities for laypersons to directly engage with research to advance scientific knowledge (Bonney et al., 2009), in formal education settings (Lüsse et al., 2022) as well as informal settings (Ballard et al., 2017). More importantly, this approach has the potential to empower participants to take ownership of the scientific data and develop a deeper understanding of their local environments, and ultimately, take action to make changes and establish a healthy nature-culture relationship. However, many scholars argue that to realize this potential and strengthen the reciprocal relationship between scientists and citizens, these programs must go beyond data collection and engage participants in the full process of generating scientific knowledge, including data analysis and disseminating the findings to outside audiences (Ottinger, 2010) to drive community-level change. Specifically, we refer to Community and Citizen Science (CCS) includes participatory approaches to research and monitoring primarily driven by scientists but also includes community-driven endeavors, where members of the public co-create the project focused on community needs and interests, incorporate local knowledge and expertise, and are involved in defining what research questions are asked methods design, and findings generated and disseminated (Harris et al., 2020).

Alongside emerging interest in CCS as a way to make science processes and structures more democratic, scholars in education are calling for more equitable approaches to science education for rethinking science literacy from individual disciplinary knowledge to a collective endeavor (Bang & Medin, 2010; Roth & Barton, 2004; Songer & Kali, 2022). This expansive view of scientific literacy not only extends the goal of science education to also include the understanding of scientific practices, such as collaborative argumentation and reasoning (Andriessen & Baker, 2022), but also using science as a vehicle for societal change. The Next Generation Science Standards argue that science education's ultimate goal is to help youths deepen their understanding of the natural world, recognize the urgency of environmental issues, and take cautious actions to make changes (NGSS Lead States, 2013; Roth & Barton, 2004). Some argue this must include creating informal learning spaces to broaden participation and support multiple ways of knowing (Bang & Medin, 2010). We argue with Songer and Kali (2022) that CCS represents a *coevolutionary connection* between science education and the Learning Sciences fields, with the potential to strengthen youth's disciplinary knowledge, science practices, and crosscutting concepts through situated and place-based learning.

As hundreds of CCS projects worldwide have started to engage schools in studying environmental threats and impacts on planetary health, there is enormous potential for CCS to transform science learning (Roche et el. 2020), particularly in elementary schools (Trautmann et al., 2013). Research has shown that youth-focused Community and Citizen Science (YCCS) serves as a promising approach for fostering the development of agency and identity among participants (Ballard et al., 2017; Calabrese-Barton & Tan, 2010; NAS, 2018; Nasir & Hand, 2008). However, limited research has been conducted on the impact of YCCS in school settings. As more teachers and schools adopt YCCS programs for youth learning (Trautmann et al., 2013), there is an increasing need to understand what is required to develop YCCS projects in schools (Barron et al., 2016). This raises the question of how best to incorporate authentic, community-relevant scientific research into the fabric of formal school systems at large scales, and whether or not these programs yield impactful science learning while also contributing to local environmental problem-solving.

Little to no empirical research on science learning outcomes of YCCS exists for the elementary-level age group, particularly in school settings (NAS, 2018). Researchers and educators assume that youth participation in scientific research and monitoring will support engagement in scientific reasoning practices (NAS, 2018), and address required Next Generation Science Standards (NGSS, National Research Council, 2012). However, there is much variation within YCCS program design and therefore learning outcomes from engagement in educational settings. To address these gaps, we designed and examined a YCCS program centered on elementary students conducting forest monitoring to address California's unprecedented increase in catastrophic wildfires in recent years, resulting from historical fire suppression policies and the effects of climate change. These factors redefine Northern California's wildfire season and directly impact rural communities throughout the Western U.S.. This project provides a test bed to examine the links between real community engagement by students and schools in locally important science questions and science learning outcomes for youth (Calabrese Barton, 2012).

This empirical research addresses the literature gaps and informs the broader community of formal education professionals, environmental educators, and ecologists seeking to understand and undertake YCCS initiatives. It also addresses questions about how the design, duration, and intensity of a YCCS program impact various outcomes for student learning (NAS, 2018). To guide our study, we ask the research question: ***how does collecting locally relevant place-based forest data during a Community and Citizen Science Program foster students' development of the three aspects of the Environmental Science Agency?***

Theoretical framework

Learning as the change of participation in the community of science

This study defined learning as an ongoing change of participation in the community (Lave & Wenger, 1991). Informed by this perspective, we examine learning through the change of participation, which includes how participants interact with conceptual and physical tools used in the science community (Sadler, 2009), how their science identity develops, and how youths exercise agency in their community (Calabrese-Barton & Tan, 2010)., Learners' participation in CCS programs can both be supported or constrained by physical tools depending on their accessibility to the learners (Ghadiri Khanaposhtani et al., 2022). More importantly, tools have the potential to afford and constrain the science identity formation depending on the relations constructed among the learners, activities, and tools (Weidler-Lewis, et al., 2022). We also view identity and agency as fluid, situated, and constructed in practice and in relation to the tools use, the activities and the community the youth are part of. Though identity and agency are two different constructs, Basu et al. (2008) argued that as learners construct their identities through interaction within communities of practice, the process of *coming to be* provides opportunities for learners to exercise their agency to alter one's environment *to become*. In this way, developing disciplinary knowledge is another critical step in supporting identity development and exercising agency. As learners' knowledge in the subject deepens, they start identifying their own expertise in science.

To theorize learners as becoming change agents, we applied Holland et al.'s (2001) *Figured worlds* to conceptualize the design of the space as allowing students to develop a new identity, to voice their positions in the world, and to alter the world towards their visions as re-establishing a healthy nature-culture relationship with the environment (Calabrese-Barton & Tan, 2010). Stemming from this, for this research, we use the Environmental Science Agency (ESA) framework to conceptualize learning for the YCCS programs (Ballard et al., 2017). This framework prioritizes disciplinary science knowledge and youth development of identity and agency with science as the key learning practices we seek to observe. Specifically, ESA includes three aspects: 1) the science content knowledge and skills to ensure accurate data production, 2) self-identification with roles within the community of practice, and 3) a sense of agency to apply scientific findings to leverage for change (Ballard et al., 2017).

Place-based data collection as an approach to support learning

Place-based learning as a pedagogical approach is central to and "foundationally implicated" in science education and CCS (Bang et al., 2014; Roth & Lee, 2004). Grounding learning within the community and place where youths are familiar with and personally connect to, this approach can facilitate learners to create meaningful learning experiences and ultimately empower youths as agents of change (Gruenewald, 2003). Though place or place-base was not used in Vygotsky's writing, he argued that the knowledge constructed through youths' everyday personal experiences as spontaneous concepts plays a foundational role in developing scientific concepts (Vygotsky, 2012). Spontaneous concepts, or youths' initial observations, serve as the steppingstone for learning scientific concepts or disciplinary knowledge developed historically within the scientific community. That is, the spontaneous concepts need to be sufficiently differentiated for the disciplinary knowledge to develop systematically. In other words, to develop scientific concepts or disciplinary knowledge, youths need to develop spontaneous knowledge to reflect upon. From the environmental education perspective, Kudryavtsev et al. (2012) conceptualized the sense of place as *place attachment* and *place meaning* which captures both the emotional bonding and symbolic meanings that people created to the place. When accompanied by first-hand data collection within CCS, youths can use their place-based expertise, including geographical, emotional bonding, and social and cultural dimensions of place, to inform their scientific work (Bouillion & Gomez, 2001). This includes using their understanding of place to contextualize their data findings (Taylor & Hall, 2013) for learning and, more importantly, developing pro-environmental behaviors as a result (Bang et al., 2014; Kudryavtsev et al., 2012).

Method

YCCS program overview

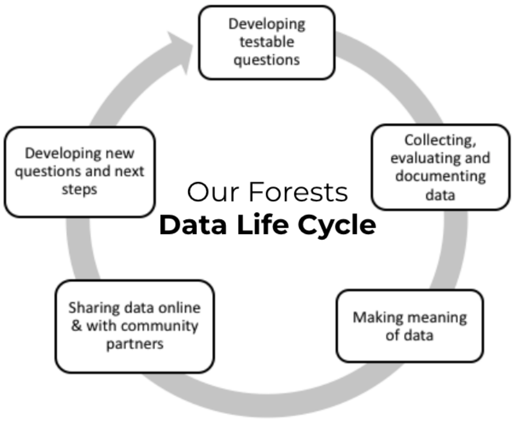
This project was a collaborative program development and research project between university researchers and a community-based watershed organization in Northern California, USA. In the first fully in-person, our program development team partnered with a county-wide school district (3rd through 5th-grade students and their teachers), local forest scientists, and land managers to design and implement the forest ecology protocols. The protocol consists of monitoring and assessing sites near partner schools for variables such as forest density, recruitment of pines and oaks, fuel load, and biodiversity, as well as the lesson plans that they delivered for each class at the forested field sites and in the classroom. The curriculum and program consist of a year-long program that includes 4 all-day visits to the nearby forest investigation zones (FIZ) specific to each school, a "share-out" lesson where students present to their forest scientists community partners, several teacher-led classroom lessons for building foundation knowledge about the program and local forest ecology.

Curriculum design

Informed by place-based environment learning theory, this YCCS program design focused on developing a forest monitoring protocol and accompanying lessons on data needed by local forest managers for managing fire risk and invasive species. Together with designated forest managers and iterative feedback from teachers, the community-based watershed organization led the development of forest ecology protocols for students to monitor and assess sites near their school for variables such as forest density, recruitment of pines and oaks, fuel load, and biodiversity. The 2021-22 iteration of the curriculum included 4 field investigation activities throughout the year-long program. Each activity started with a classroom lesson, followed by a field trip to each school's forest Field Investigation Zone. Based on our team's previous research on YCCS (Ballard et al., 2017; 2020) and building from sociocultural (Lave & Wenger, 1991) and critical perspectives (Roth & Barton, 2004; Basu et al., 2009), we intentionally focused the design of the curriculum on three mediating YCCS Design Features. We argue that the Design Features play an important role in supporting youth to situate themselves within a scientific community of practice (Calabrese-Barton & Tan, 2010).

The three Design Features reflect the NGSS Science and Engineering Reasoning Practices and are framed around the community science notion of the Data Life Cycle (Bird et al., in press): 1) place-based data collection, 2) making meaning with data, and 3) sharing findings on forest ecology data with community partners to understand forest health and fire resilience to answer important questions about measures in their local forest (see Figure 1). First, youths collected place-relevant ecological data during 4 field investigations of a nearby forest site (some traveled by bus for 20 min, others walked to the site). These data were used to inform land management decisions throughout the year. Second, youths analyzed data they gathered, scaffolded and facilitated by our program development team and teachers, including graphing their data to visualize the results. Finally, youths shared their findings with local communities and land managers to use that information to increase forest fire resiliency.

Figure 1
Design Features - Data Life Cycle (Bird et al., In press).



Data collection and analysis

Overall, we used a case study design (Yin, 2013) and collected ethnographic informed data in this study. After observing all 15 classes from 4 schools during the first field investigation, 10 classes were chosen based on how they represent all participating grades at the 4 schools and for teachers' level of interest and eagerness in the program. Researchers worked with each focal class teacher to select 5-8 focal students per class and conducted ethnographic observations of all field-based and in-class forest investigations (5 days each), and post-program semi-structured interviews with focal youths. Researchers conducted semi-structured interviews with photos from the students' forest investigations to spark recall. We used semi-structured interviews (Merriam, 2014) with focal students to understand how and when data collection mediated and/or hindered the development of aspects of the ESA. Interview questions centered on topics relating to student experiences in the program, their thoughts on the health of the forest ecosystem, and on understanding if students demonstrated ESA. We made analytic memos immediately after each field observation and semi-structured interviews to capture researchers' reflections and initial processing of these data (Mile, Huberman & Saldaña, 1994).

The findings in this article resulted from analyzing interviews of three 4th-grade classes with 15 focal students participating in the first year of the in-person program. Challenges related to the COVID-19 pandemic, fluctuations in student attendance, and unfavorable weather conditions caused some focal classes to have incomplete sets of researcher-derived data. As a result, the findings from three 4th-grade classes were chosen for this study for their complete datasets. Interviews with 15 focal youth (ages 9-10) underwent thematic coding analysis (Braun & Clarke, 2006) conducted by two researchers using Dedoose software. The first and the second authors familiarized ourselves with interview transcripts from each case and discussed the preliminary findings and patterns to ensure a shared understanding among coders. This effort resulted in focusing on three aspects - Environmental Science Agency, data collection activity, and sense of place. Transcribed interviews and memos were coded using Dedoose qualitative software individually, then calibrated between two researchers to reach a consensus across 2 coders. Coding focused on thematic schemes: 1) each of the 3 aspects of the Environmental Science Agency (ESA 1-3), 2) each of the 3 key Design Features (data collection, analysis, sharing results with an outside audience) and 3) Sense of Place (Kudryavtsev et al., 2012). ESA thematic coding disaggregates the three elements of ESA into codes and includes student affective experiences. Thematic coding indicated when youth were engaged in data collection in different settings.

Findings

The findings from our in-depth analysis show that involving students in the entire data life cycle enabled students to take ownership of their scientific work throughout the program but seemed to limit their personal sense of agency when tools were not accessible. We focus here on the findings around learning linked to students participating in Data Collection resulting from the in-depth analysis of 15 students' interviews. Overall we found that nearly all students could describe not only what data were collected and how, but also for what purposes, providing evidence of their learning a range of forest science content knowledge, skills, and practices. Specifically, students demonstrated disciplinary knowledge such as plant identification of poison oak and key tree species, fire behaviors, controlled burns, forest density, species diversity, and abundance associated with the data collection phase. Below we focus on selected key findings about the specific data collection and data analysis activities that frequently lead to particular aspects of the Environmental Science Agency.

Finding 1: Using authentic scientific tools helps mediate students' development of scientific knowledge and practices and, ultimately, science identity

Students described using forest science measurement tools as an inseparable part of data collection and as useful and fun experiences. Specifically, throughout all 15 interviews, we found tools were often contextualized as physical tools (Figure 2) used to measure in the field, such as Biltmore sticks (used to measure tree diameter) and quadrats (to delineate areas for measuring understory plant diversity). For example, Logan (all student names are pseudonyms) mentioned in his interview that "*Um, it was fun 'cause, um... 'Cause I don't really get... I don't really use those tools at school or at home, so it was fun to use them out there. And it was useful 'cause we were able to, um... We were able to measure things, and we were able to identify things better*". Interestingly, without prompting, Emma extended the tools to also include cognitive tools such as graphing (a data visualization) as useful tools to help them learn along with other physical tools. When asked how it felt to use the graph, Emma shared that "*Um, I liked using them a lot because it helped. And like those others, other tool, tools we use, like the Biltmore stick and the quadrat, I think it was at least as helpful as those*".

Figure 2
Youths used scientific tools to collect data

Using authentic scientific tools in the program also seemed to mediate what it meant for students to identify themselves as a scientist or as doing science. We saw the tools seemed to signal a scientific identity to students since it is the "*real"* tools used by the scientists. Seeing or hearing that the same tools students used were legitimate scientific tools inspired those who used the same tools in the program to identify themselves *as having a* science identity. As Gideon explained in the interview, he felt like he was doing science or feeling like a scientist because he saw the community partner (a local forest scientist) using the same tool in the field with them. He then continued to show his amazement after seeing how a quadrat created from PVC pipes (figure 2, right) can be a "*real"* tool: *"Cause we were using things that, uh, I would not even imagine would be 'real'. Like the quadrat. I wouldn't even think that would be it. I would just think that they would just draw, uh, a circle or something like that and they would count the plants in that"*.

In fact, students clearly equated using scientific tools with doing science. As tools are highly contextualized and associated with data collection activities, students seemed to associate scientific practice with using tools. The intention of incorporating science tools into the curriculum was to create authentic learning activities to conduct scientific research on a local environmental challenge to support youths to exercise their agency, even if only imagined or discussed. When students were asked the question in their one-on-one interviews, "*Would you utilize any of the skills or knowledge you learned in Our Forests outside the program*" in addition to mentioning the use of plant identification skills, students frequently responded, "*Yes, if I had access to the scientific tool*".

Finding 2: Students' development of a sense of place, scientific knowledge, practices, and identity were closely intertwined

We found a strong and reciprocal relationship between students' developing sense of place and developing scientific knowledge and practices. First, our data analysis showed that youths' sense of place was connected to their embodied creation of scientific knowledge in the places where they live and the inherent responsibility for stewarding these landscapes as a way to scientific contribution and as a result of them developing ESA. The design of each field trip was combined with a classroom portion. When researchers asked kids which portion they liked better, almost all 15 kids shared that they liked working in the forest better. Youths made a distinction between doing intellectual science such as reading and writing and the embodied and direct experience of science, creation of scientific knowledge, and contribution to science in the place with space. As described by Luke, "*like you're actually, um, in the forest so you can have a lot like better sources, not just like a document that they hand you. But like you can actually be in the moment and like get the information for yourself and write it down.*" Luke made a distinction between reading and hearing about the forest and the direct experience of the scientific knowledge, "*Because, um, cause then like you're actually there and you're not just talking about it".* When research asked Olivia to describe her role or contribution to the project, Olivia responded: "*I felt like I was in my place, just like doing what I needed to do, letting the grown-ups talk*".

The intertwining relation among sense of place and disciplinary knowledge, practice, and identity was also demonstrated by their ability to transfer their knowledge to daily life. Students reported that plant identification was a skill they developed during the program and reported that they were able to share this knowledge with others, specifically family members that enjoy the outdoors. For example, Austin shared that "*Yeah. When I'm hiking, I tell, um, like my parents that, that plants named that and that plants named that*". Students also responded that they see and think about the forest differently now that they have gone through the Our Forests program. This finding suggests that scientific knowledge and skills have the potential to deepen students' sense of place. For example, Amelia shared *"Cause now, like, I know more stuff about it. It's more interesting than it used to be"* to address the researcher' question on whether she now saw the forest differently.

The analysis also showed that engaging youths in scientific research to study the place, in the place, and about the place helps transform their experience to broaden their perception of science. When asked whether youths would prefer the classroom or the forest to study, Julia shared that she would prefer the forest because the forest is more spacious than the classroom. As the researcher followed up with the question "*how did it make you feel when you were doing science in the forest", Julia shared,* "*Well, it's just, like, you're not just doing science in some lab where it's like everything's just white. You actually get to do it in, like, a place where like, what you're studying. Like, you don't just do it in a lab where you're studying it. You're studying what you're in, I guess*". Julia's sharing demonstrated how the YCCS program changed her perception of what a scientist looks like and where science happens. During the interview, she shared that she realized science is more than just wearing a white coat working in a lab, but also includes "*studying what you're in*".

Discussion

The scientific tools used in the program not only served as the physical tools to collect forestry data but also as the entry point to enter the scientific community legitimately (Lave & Wenger, 1991). Youths use authentic scientific tools in collecting and analyzing forestry data to help create a *figure world*, as described by Holland et al. (1998), for them to imagine their new actions and identity - as someone who does science or is a scientist. However, scientists or doing science was not confined to the use of tools, but more importantly, the use of fundamental scientific observation skills to form a hypothesis, collect data, and further document the observations accurately to ensure the data accuracy (Eberbach & Crowley, 2009). From identifying trees to using tools to collect and analyze data, all 15 students demonstrated strong observational skills in the field trips, but none credited exercising this important skill as doing science or being a scientist. Since the emphasis was placed on the tools to gather scientific data throughout the program, we suspect that the students were attributing a greater sense of power to the tools producing the data as opposed to recognizing how they've already exercised agency such as the deployment of tools as resources (Basu et al., 2009) and use their sensory skills as tools to observe. Alternatively, placing too much emphasis on the physical tools may establish a linear model and a means to an end, i.e., students are simply a cog in the wheel instead of being the driver of scientific knowledge creation. Additionally, for students to develop ESA fully, we argue that there's a need to support them to adopt an expansive definition of tools to also include all levels of the scientific process, from developing the research question(s), to analyzing the data, and sharing their findings (Roth & Barton, 2004).

The goal of creating community-based science education is "to foster students' development of keen appreciations of the places where science and technology intertwine smoothly with one's experience of life" (Roth & Lee, 2014, p. 271). In achieving the goal of transforming the place into a learning setting, place-based learning approaches also need to support youth to exercise *creative agency* (Headrick, 2017) to reimagine their relationship to place and to develop new ways of observing, noticing, and viewing beyond familiarity to the place. Apart from its role in disciplinary knowledge learning, a sense of place in this study embodies an emotional form and broadens students' perception of what counts as science. As Amelia explained in the interview, the engagement in scientific research helped her develop positive experiences in the forest and allowed her to see the forest differently. Place-based Community and Citizen Science programs have the potential to deepen youth's sense of place by leveraging their deep *place attachment*, along with intentional instruction to create new *place meanings* through observing, identifying, and measuring (Kudryavtsev et al., 2012). As a result, youths developed different views, which go beyond seeing the place differently, but also science differently, as Eli stated in their interview (Bouillion & Gomez, 2001).

Our empirical research has shown that YCCS programs can bridge the gap between informal community citizen science and formal science education in elementary schools, blurring the binary distinction between formal and informal educational spaces. This research also addresses a gap in the current understanding of the learning outcomes for youth participants in citizen science programs inside and outside school settings The outcomes of this research can inform the design and approach of citizen science and science learning projects to yield best practices of citizen science programs for environmental education, including science learning, environmental stewardship, and civic engagement by youth. This research aims to make science more accessible, equitable, and generative for youths. The first finding suggests that, using scientific tools to collect real data alone is not enough to create an authentic learning environment in a YCCS program. Instead, we suggest instructors and facilitators to frame the meanings and purposes of using scientific tools and understand how tools support the greater meaning of the data collection and ultimate scientific practice (Sadler, 2009). With the goal of empowering youths, instructors should also take a step further and help youths recognize how they are also powerful instruments to science. As suggested by the second finding, we argue that place-based data collection played an important role in supporting youths in generating place-based scientific knowledge, using scientific knowledge to change daily life, broaden what it meant to do, and contribute to science.

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Caregiver Assessments of Learning During School Closures: Perceived Virtues of Practice-Based and Open-Ended Activities

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Abstract: Pandemic-related disruptions to normal schooling required educators to adapt academic activities for the home setting and caregivers to tailor them according to their unique circumstances. In this paper, we analyze caregivers' perceptions of activities that contributed to generative learning. We focus on documentation of 668 unique learning moments across 109 families and provide an analysis of the relationship between activity structure and caregiver ratings of enjoyment and meaningful learning. We find that (1) most families shared a mix of more and less engaging activities; (2) activities that centered inquiry, expression, or play were more likely to be perceived as highly engaging than those focused on skills; (3) caregivers perceived both practice-based and exploratory activities as generators of learning opportunities; and (4) caregiver ratings of enjoyment and learning were positively correlated. From these findings, we share three directions for future research to support fruitful collaborations between teachers, caregivers, and students.

Introduction

When schools across the United States closed in March 2020, learners, parents, and educators were confronted with the reality that our educational systems were not designed for remote instruction. Although buildings were shuttered to protect public health, most districts continued instruction during the academic year. Schools rapidly reorganized supports for academic learning, ranging from paper packets to synchronous class sessions, and approaches varied widely by school and classroom (Reich, 2020). Caregivers at home, including but not limited to parents, stepped in as proxy-educators to sustain academic learning. Often this involved securing additional materials, assisting with technical support, and learning to facilitate lessons (Barron et al., 2021). Although hundreds of quantitative studies have documented the stresses associated with arranging learning at home (e.g., Kuhfield et al., 2022) far fewer have described what forms of activities worked well (e.g., Greenberg et al., 2020). Conceptualizing enjoyable and meaningful learning experiences during remote instruction is essential for understanding variability in what schools were able to offer early in the pandemic and identifying innovative home-based practices that contributed to productive learning environments critical for children's growth and family well-being.

We contribute to this broader agenda with a remote diary study with families across the United States during the first phase of school closures in the spring of 2020. Our goal was to provide insight into the impact of the Covid-19 pandemic on family life and the ways families were adapting to remote learning. Using remote diary methods allowed us to engage caregivers as participant researchers, putting them in the role of documenting learning activities and providing reflections on the experience of remote learning more generally. Our data captured information about school- and home-initiated learning activities, caregiver assessments of children's engagement in and learning through activities, and families' approaches to supporting academic assignments or enrichment opportunities. For this paper, we analyze over 600 diary entries to characterize the nature of learning activities described and report comparative analysis of caregiver ratings of child enjoyment and learning based on whether the activity was more practice-based or open-ended.

Challenges of pandemic parenting

Families' experiences differed dramatically with more challenges faced by families who had fewer financial resources, lacked broadband access, and or had greater demands for work outside of the home (Davis et al., 2021; Vogels 2020). Across the developed world, caregivers struggled to access distance learning due to a lack of digital resources, lack of communication with the teachers, child learning differences, and limits of their own content and pedagogical knowledge (Bhamani et al., 2020). Caregivers were challenged to motivate their children to keep up with their academics. Parents reported children lacking motivation to engage with remote learning citing attention span, boredom, and missing their peers and teachers as contributing factors (Garbe et al., 2022) and struggling to focus (Lau & Lee, 2021). Another challenge to engagement was the burden placed on parents to guide their children through poorly communicated lessons (Fontenelle-Tereshchuk, 2021) and increased stress when taking on roles to support their children with distance learning, regardless of the type of support they offered

(Sonnenschein, 2021). Additionally, families were handling more than just remote schooling; learning to live in the pandemic and helping their children adjust to "the new normal" demanded caregivers' attention (Pozos, 2022).

Caregiver assessments of enjoyment and learning

The nature of enjoyable activities is particularly important to understand given the motivational challenges of remote schooling. Our focus on enjoyment is grounded in learning sciences research documenting the importance of playful, interest-driven, and meaningful learning in sustaining engagement. Engagement in learning is a multidimensional construct and includes affective, cognitive, and behavioral dimensions (Chi, 2022). Long-term interests, momentary catalysts of curiosity, or interactions with social partners can boost attention and support enjoyment (Hidi & Renninger, 2006). Children help shape learning opportunities by asking questions, contributing ideas, and designing playful learning settings as they pursue their social and domain related interests. In this view, sources of engagement are highly situated, dynamic, have roots in prior experiences, and often connected to idiosyncratic social or activity-based preferences (Azevedo, 2013). The design of learning activities can play a role in setting up these types of opportunities. In this paper, we foreground caregivers' reports of activities and their related perception of engagement and learning. We ask: (1) What did activities look like across families? (2) Is there a relationship between learner engagement and activity type? (3) How do ratings of activity enjoyment relate to ratings of learning from the activity? (4) Do caregivers judge exploratory activities as more meaningful for learning than those that are practice-based?

Methods

Ethnographic research with families has been a key feature of the literature on family learning and parent roles in supporting children's learning. However, Covid-19 challenged the field to quickly respond at scale to understand changes that families were experiencing within the constraints of public health orders. To document the impact of the pandemic on families as it unfolded and the ways in which families were adapting to remote learning, our team conducted a remote diary study with a socioeconomically diverse sample of families in the United States. Diary studies are a form of experience sampling (Csikszentmihalyi & Larson, 1984) allowing researchers to systematically collect participant reflections on moments in their lives as those moments occur. During May and June of 2020, several weeks after schools began closing, we collected daily documentation from 109 families across the U.S., with children aged 5-10 using dscout, a smartphone-based remote qualitative research platform. dscout maintains a panel of over 100,000 participants around the U.S. who are roughly representative of the smartphone owning population. This platform allowed our research team to interact with families and collect rich qualitative data without face-to-face contact, affording broader geographic reach and pandemic-safe practices (Takeuchi et al., 2021).

Participants

A total of 1,375 people from dscout's participant panel expressed interest in participating by completing an initial screener questionnaire, which included IRB consent to participate in research; 264 respondents fit our study criteria: (a) having a child between ages of 5-10 living at home, (b) the child's school had moved to remote instruction and was in session for the entire duration of the study, and (c) the applicant had given consent for their responses to be used for research. These applicants were sorted into three household income groups ($0-49K (15%), $50-99K (44%), $100K+ (41%)) and 37 participants were randomly selected from each group. In total, 109 participants from 28 states completed the study. While most participants were parents, some were other adult caregivers in the homes of children (for example, adult siblings, grandparents, live-in partners of a biological parent). Most (67%) were female and 55% self-identified as white, 16% as Black, and 15% as Latinx, 9% as Asian, and 4% as Middle Eastern or North African. In our final sample, 45% of families reported household incomes below the national median for families in the United States ($75,000) and 55% reported incomes above that level (U.S. Department of Housing and Urban Development, 2020), groups that we have used to investigate differences in findings across families that differ in terms of household income (Barron et al., 2021).

Multimedia diary entries

If caregivers had more than one child in grades K-5 at home, they were asked to select one to focus on throughout the study. Data collection was organized around five themes: (1) school-provided resources and connections pre-pandemic, (2) school-provided resources and connections during remote learning, (3) 6 examples of daily learning moments, (4) how the family learned about Covid-19, and (5) reflections on learning and family life during this time. For each theme, participants answered a series of questions using short videos, photographs, responses to multiple/choice and rating queries, and direct messages to the researchers. This paper focuses on caregivers' documentation of daily learning moments. Data for each entry included a 2-minute video (and transcription), of the caregiver describing and reflecting on a learning moment they observed that day, a photo of the activity, as well as multiple-choice items where caregivers reported social partners present (e.g., siblings, classmates, or teachers via videoconferencing), origins of the activity (e.g., school, caregiver, child, friend), content area (e.g., art, writing, math), resources leveraged (e.g., books, computing devices), time of day (e.g., early or late morning, afternoon, or evening), and challenges (e.g., time, content, technical difficulties). Caregivers also rated their perception of how engaged the child was in the activity (likert items with a 0-10 range) and how much they believed their child learned. Participants were asked to submit 6 examples, though some submitted more.

Analysis

To learn more about the unique learning moments shared by caregivers beyond the submission metrics queried, the 668 diary entry descriptions were organized by family and uploaded to an online collaborative qualitative analysis platform (Dedoose) and coded along multiple dimensions including broad categorization of the learning activity described, caregiver roles played in the learning moment, reflections on activity purpose, synchronous connections to classrooms (Pozos et al., 2022), and expressions of positive or negative affect. We focus here on our coding of the open vs. closed nature of the activity as this dimension emerged as a major category during open coding, was able to be clearly determined across entries, and maps broadly onto existing typologies of learning activities (e.g., Chi, 2021). Nine percent of the sample (n = 60) could not be classified because they lacked detail or were descriptions of a series of moments rather than a particular activity and were excluded from this analysis. In later rounds of coding with those learning moments with sufficient detail for activity analysis (n = 608), we identified subtypes of activities within these two broader categories (see Tables 1 and 2) and surfaced parent reflections about what worked or not, and why. The open-ended descriptions of the learning moments varied significantly in terms of length and level of detail provided about the content and context of a particular activity. Quantitative data were organized into two relational datasets for analysis in SPSS, one representing families (N = 109) and one representing learning moments (N = 668). Qualitative codes were exported from Dedoose and merged into the learning moments SPSS file, supporting analysis of the moments' unique characteristics and how moments played out across different families, as well as comparative analysis of the characteristics of activities rated as more and less engaging.

Findings

(1) Families documented a wide range of open-ended and practice-base activities

Across the 668 shared learning moments, families described a rich and varied set of activities. Of the coded learning activities, 59.0% (n = 358) were classified as practice/skill development, indicating moments where a child received direct instruction and/or practiced a skill through repetition with few if any choices made by the learner (Table 1). Open-ended activities accounted for 41.0%, (n = 249) describing moments when the learner has some autonomy in how to proceed and where the final product or outcome may look different for different students (Table 2).

Of the total sample, three quarters of the activities (75.6%) originated from school, 16.5% were initiated by parents and other caregivers at home, and 7.0% were initiated by children. Activities originating from school were more likely (64.9%) to be focused on skill/practice ($X^2 = 28.822$, $p<.001$) while those sparked by families were more likely to be open-ended (parent-initiated activities were 59.9% open-ended ($X^2 = 12.276$, $p < .001$) and child-initiated activities were 65.1% open-ended ($X^2 = 10.840$, $p < .001$)). Tables 1 and 2 illustrate the range of activities within these two types through thematic descriptions and examples. Most families shared examples of both open-ended and practice-oriented activities and a mix of school-required and family-initiated options.

Table 1
Practice/Skill Development Activity Types and Examples

Subtheme	Descriptor	Examples (including child grade in school)
Workbooks	Working through paper skill-based worksheets and workbooks	● Filling in numbers on a number line on a worksheet with numbers 1-100, while counting out loud (K) ● Adding multi-digit numbers with decimals through a series of problems on a math worksheet (grade 5)

Individualized learning platforms	Activities using skill-based individualized learning platforms (including those that are game-like but focus on basic skill building)	● Answering math questions to earn points and win battles on Prodigy, a game-based content site (K) ● Picking topic sentences to fit a reading passage on IXL, a site marketed to teachers and families to prepare kids to meet state standards (3)
Direct instruction through video	Synchronous video classes or assigned videos that include content "lectures" and/or comprehension and practice activities	● Watching teacher-created video of teacher demonstrating cursive writing (2) ● Attending a live zoom session with teacher and class to check math homework (5)

Table 2
Open-Ended Activity Themes and Examples

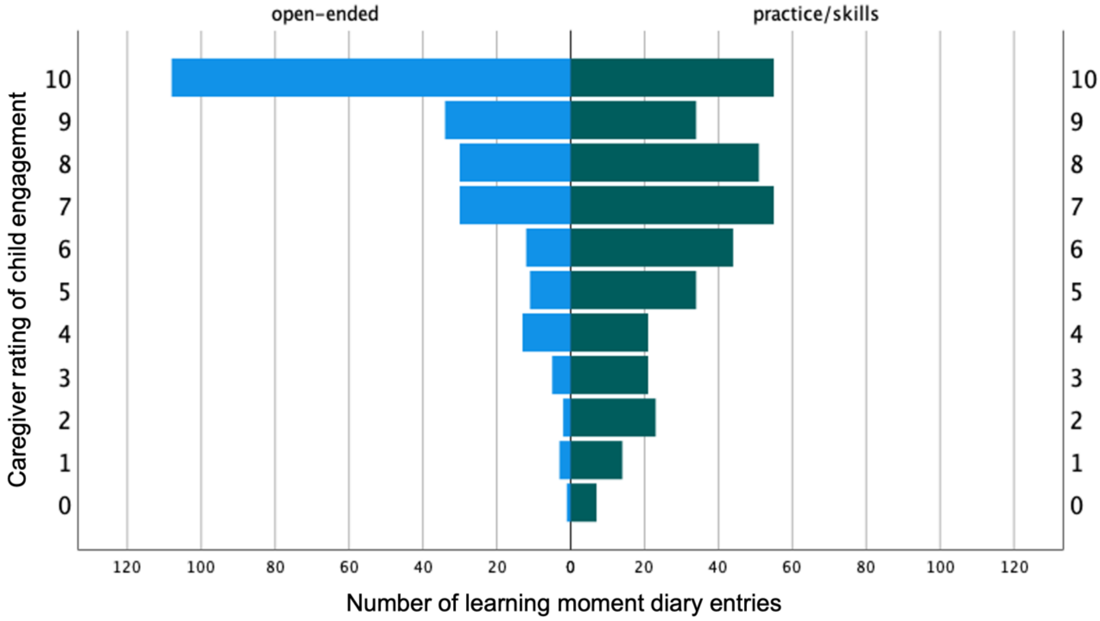
Subtheme	Descriptor	Examples (including child grade in school)
Inquiry	Investigating, observing, documenting, doing research	● Exploring and making observations during sea visit, then co-creating and writing a story with parent (K) ● Recording observations of plant growth in a plant journal, part of a longer-term planting project (3)
Exploratory	Reading or talking to learn about a topic, including open-ended discussions that go beyond comprehension, watching media on a topic that is chosen by the child	● Watching an instructional video from teacher explaining a social studies assignment to research an inventor and using Google to conduct research (3) ● Participating in a "makerspace" class learning about earthquakes and preparing a presentation on how earthquakes happen (4)
Constructive and expressive	Building, making, and designing; crafting stories; making music and art; sharing during online show-and-tell	● Siblings construct model solar system from a kit (K) ● Learn to sew with a sewing kit from Etsy (1) ● Making cupcakes with mom and practicing measuring and translating measurements (K)
Play-based	Play-based such as games, toys as context for learning	● Identifying and discussing animals and food chain as part of playing a board game with family (K) ● Playing interactive online Pictionary during a live Zoom session with whole class (2)

(2) Caregivers perceived higher learner engagement during open-ended activities

For each learning moment submitted, caregivers rated how engaged their children were on a scale from 0 ("they were pretty bored") to 10 ("they were having a ton of fun"). The quantitative ratings by parents show that most families, regardless of their unique circumstances, noted fluctuations in how enjoyable learning activities were for their child and most caregivers included at least one instance of a highly engaging activity (rated above the median) in their diary records (77% percent of families). Figure 1 shows the number of activities by rating for both activity types, showing scores skewing higher more extremely for open ended activities. In fact, open-ended activities were three times as likely to be rated a "10" than those categorized as practice/skill development (45% vs. 15%).

This pattern held when mean ratings of engagement were compared. Caregiver ratings of engagement were higher for learning moments that were more open-ended ($F(1,606) = 73.771$, $p<.01$). The mean rating of enjoyment for the skill development/practice activities was 6.38 (SE = 0.134) while for those activities that were classified as inquiry/project based, the mean was 8.18 (SE = 0.161).

Figure 1
Histogram of Caregiver Rating of Child Engagement Rating by Activity Type



While ratings of engagement were higher for open-ended activities, Figure 1 makes clear that there is variability within open-ended experiences and that highly engaging moments were observed by caregivers across activities in both categories. Our analysis of caregiver documentation of activities is guided by an understanding of learning as collaboratively constructed by children, caregivers, and teachers and embedded in a broader sociotechnical ecology made possible by the specific material, conceptual and relational resources that were available (Barron, 2006). Taking a sociotechnical systems view to understand the emergence of learning opportunities is particularly important given the reliance on digital and networked resources to connect homes and schools. This systems perspective aligns with caregivers' documentation of moments. Across activity types, caregivers note engagement supported by social interaction, flexible content, and opportunities for choice and exploration often connected to personal interests. Below we provide descriptive examples from caregiver accounts to illustrate the types of activities that were perceived as highly engaging within our open-ended and practice-based categories.

Collaborative, project-based opportunities were often rated by parents as highly enjoyable for learners, sometimes leading children to do more than what was required or to request similar experiences. For example, Jake described an assignment that involved building and measuring the interior of a tent, an activity that led to the whole family pitching in for more than two hours and left both father and his fourth-grade son interested in doing additional measurement-related projects. Some examples were parent initiated, such as when Tene realized her third grader was missing out on art she asked him to use online resources to design a city, encouraging him to be expansive and personal, challenging him to include spaces that he would like to have in this imagined future place. Other caregivers described inquiry projects that encouraged exploration of local environments along with varied opportunities for documentation. Todd took his son to the local beach to find sea stars, sea anemones, and small crabs, "just kind of exploring…the environment around you, and making some observations, and working on you know what observations are, and what is an observation, and then kind of working that into a story that we wrote out together…We had a lot of fun, we were able to get out of the house and explore the area around us. … it led to several conversations throughout the course of the day about the environment around us and the ecology of the ocean around where we live."

Engaging practice-oriented activities often utilized digital resources with interactive features—including game structures, personalized content, digital libraries that allowed children to choose books based on their interests, and use of video—that reduce frustration and tedium expressed in other practice-based learning moments. For example, Ava describes her first grader, who is "really into science and likes sharks, fish, all that kind of stuff," accessing EPIC through her Chromebook to "look for books that she was interested in." As she finds a few books about sharks and whales, Ava notes that EPIC has a feature that reads aloud to the child, highlighting words for her to follow along. Ava says her child is excited to read on EPIC (going beyond weekly reading expectations) and is learning science content. In another example, Anna describes the fun her first grader is having doing a collaborative math quiz on Kahoot! with her class, citing the game-like aspect and friendly competition with classmates.

(3) Caregivers associated higher learner engagement with more learning

While the relationship between learning and engagement is well documented (e.g., Chi, 2021), we were interested to learn how caregivers associated the two dimensions in their own observations of learning at home. Along with ratings of engagement, caregivers were asked to rate the learning taking place during each activity, on a scale from 0 = "I don't think they learned anything" 10 = "Lots, my child is spending meaningful time learning in this activity!" The average learning rating across the 668 activities was 7.44 (SD = 2.22). Ratings of engagement and learning were found to be moderately positively correlated, $r(666) = .40$, $p = <.001$.

(4) Caregivers perceived child learning from both practice and open-ended activities

Interestingly, an ANOVA indicated no significant difference in terms of perceived learning for the different activity types ($F(1,606) = .058$, $p = .810$), indicating the parents saw the value of both types of learning experiences. Those activities that were more focused on practice and skill development had a mean rating of 7.59 (SE = .110) while those that were more open-ended had a mean rating of 7.63 (SE = .133).

Summary and future directions

In this paper we provided an analysis of caregivers' perceptions of enjoyment and meaningful learning, two potential virtues of the home-based learning activities children experienced. The exploratory nature of our method invited caregivers to submit a wide range of examples. While we found that three times as many open-ended activities were rated as highly engaging as practice-based activities, parents also observed engaging practice-based activities. In other words, the activity structure was only one characteristic of a highly engaging experience. Practice-based activities were appreciated for supporting independent work, flexible pacing, feedback, game-like feel, and entertaining narratives. More open-ended activities were valued for supporting creativity, imagination, affordances for family collaboration, and shared exploration. These activities are productively understood as co-created by the efforts of teachers and caregivers, children.

Schooling in the US and across the globe continues to undergo multiple stressors as extended pandemic disruptions to daily life and well-being take their toll. In this report, we focused on positive learning experiences that are important to build upon going forward. These results need to be put into the broader context of national data that projects growing inequities, trauma, and an urgent need for reimaging educational environments (Azevedo, et al., 2020). A major concern is the loss of learning opportunities, particularly for families with less technological access, less prepared teachers, and fewer financial resources to supplement school learning with extra materials, tutors, and enrichment activities. Our sample was unique in that all caregivers were technologically connected and comfortable using a remote tool to engage in our study. And, like all accounts based on self-report, views into how interactions emerged and evolved are limited. At the same time, asset-based approaches that capture caregivers' appraisals and observations are critically important. Our findings have implications for future work that will build on asset-based perspectives of caregivers supporting their children's learning at home. We outline three directions below.

Longitudinal portraits of learning and well-being over time

The extensive prior work on family resilience shows the importance of understanding the dynamics of well-being in relation to systems of support, opportunities for relief, and the impact of new pressures as acute stressors become chronic (Patterson, 2002). At this point in time, families around the world are continuing to cope with the aftermath of remote learning, remote work, and economic stressors. Research designs are needed that span multiple units of analysis; our project has followed up with fifty of our original sample with analyses of pandemic learning pathways underway. Although tracking individual's learning is important, developing approaches that include family and community level practices, resources, and well-being measures will be essential for supporting innovation in the design of resilient communities (Greenberg et al., 2020; Lee, 2010). Asset mapping of public access to technologies, availability of informal educational institutions like libraries, availability of parks and other shared resources will be important as well as data that conceptualize how networks are activated (Pinkard, 2019; Erete, et al., 2020).

Design-based research on family-school-community partnerships

Educators and caregivers alike are working hard to support children as they also adapt to their own ongoing challenges stemming from the social, economic, and health related shifts in daily life. As empirical studies of how teachers and learners are coping are still in their infancy, this moment provides unique opportunities for research and design. As policy-focused reports have pointed out, providing Internet access and high-quality devices is a top priority for equity (Darling-Hammond et al., 2020). However, equally important is theorizing and designing novel forms of relational learning. Many parents are extremely creative and responsive learning partners yet are under-confident in their capacity to teach. There is significant potential to advance models that help parents understand the validity of multiple ways of knowing and affirm diverse approaches to supporting their child's development in consequential ways as brokers, collaborators, and interested co-learners (Barron et al., 2021).

Evolution of remote methods that can yield policy and theory relevant data

In this study we leveraged an industry-facing remote diary tool to study families' experiences. The software was designed to allow for the collection of quantitative data, video-records, and photographs, as well as to interact with participants via messages or live-video interviewing. These features are powerful, but there is significant potential for the future development of tools better suited to the Learning Sciences and other related fields (e.g., adding capacities for brief learning assessments, incorporating tools for collecting biometric health data, screenome data and analytic tools that could speed data analysis. Our experience with this method indicated that parents enjoyed interacting with researchers around their child's learning and that the opportunity to reflect on their own parenting experiences was valued (Barron et al., 2021). Future research might develop research designs that offer learning resources, capture examples of learning interactions, and include standardized measures of learning and of well-being. These forms of data would also yield opportunities for a variety of analytic techniques including discourse and interactional analysis that could be connected to measures of learning and engagement.

Conclusion

As our field continues to reflect on this unprecedented period of pandemic-linked school closures and prepare for a future that includes new forms of remote and hybrid learning that can handle disruptions and support more equitable opportunities, it is essential to recognize and build on the implicit collaboration between teachers, caregivers, and children. The variety of activities and structures to support learner engagement that emerged from the emergency collaboration between teachers, caregivers, and children provides a basis from which to intentionally design learning bridges between home and school. In these future designs, it will be essential to position caregivers as learners and co-designers, families and schools as educational teams, and children as active participants in their own learning while addressing historic patterns of inequities and advantages that were manifest during this unplanned experiment in distance learning. The Learning Sciences has an important role to play in curating research that will help families and educators learn from our collective experience, especially in ways that foreground engagement in learning and reimagine what education might look like with true collaboration at the center.

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Learning to be a Science Teacher: The Worries, Joys, and Vulnerabilities of Exploring New Pedagogies

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Abstract: This paper unpacks forms of socioemotional engagement that emerged in professional development (PD) efforts in the RepTaL project across two sites, as researchers helped elementary school teachers expand their practices around teaching science with representations. Authors analyzed video data from teachers at both sites, using interaction analysis to highlight the social and emotional layers of one-on-one and group PD interactions. Findings suggest that PD spaces afford many opportunities for expressing epistemic affect, in which teachers articulate and collaboratively process emotions that emerge as they build understanding around scientific representations and science teaching. Our analysis showcases forms of socioemotional engagement that were visible as teachers took up the conceptual work of teaching science in new ways, highlighting emotional and social engagement as core interactional processes that support teacher learning.

Introduction

The goal of this paper is to unpack forms of socioemotional engagement in the professional development (PD) of elementary teachers. Engagement is a multidimensional construct consisting of cognitive, emotional, social, and behavioral dimensions (Fredricks et al., 2004; Sinha et al., 2015). In this analysis, we explore how teachers socioemotionally engaged in the complex cognitive work of learning new science teaching practices involving representations. By socioemotional engagement we mean interactional evidence of public displays of emotion (emotional engagement), as well as the building and maintenance of social bonds (social engagement). Both are distinct forms of engagement that can overlap in practice to influence how collaborative interactions unfold. Within this overlapping space, we pay particular attention to the *epistemic affect* of teachers, which are emotional experiences that emerge in the process of building new knowledge (Jaber & Hammer, 2016a). Epistemic affect is a unique form of emotional engagement that highlights how learners navigate the emotional aspects of conceptual work (e.g., frustration at a difficult problem, excitement at finding a solution).

This analysis of teacher socioemotional engagement is situated in the RepTaL project across two research sites, as researchers worked with elementary school teachers to expand their practices around teaching science with representations. RepTaL works to engage teachers in learning how representations can support students in learning about science phenomena, and then learning how to integrate them in their teaching (Danish et al., 2021; Pierson et al., 2022; Lee et al., 2022; reptalproject.org). Using representations in elementary science is tricky for teachers because representations are rarely discussed explicitly in teacher training, and many teachers already struggle with implementing effective inquiry learning (Danish et al., 2021; Prain & Waldrip, 2006). Professional development (PD) with representations presents teachers with additional responsibilities, often without on-the-ground support that is crucial to introducing new pedagogy (NASEM, 2022; Gibbons & Cobb, 2016). Our PD model creates a teacher-centric learning environment via long-term, collaborative relationships between teachers and PD facilitators. This approach involves viewing teachers simultaneously as experts in their grade-level and as learners in science teaching, a position which honors teachers' classroom knowledge while considering scaffolds they may need as learners of new forms of practice. This analysis considers how PD can be designed to support teachers' long-term success through a focus on socioemotional engagement, grounded in our efforts to help teachers integrate representations into their practice.

We seek to (1) understand teachers' socioemotional engagements within long-term professional development designs, and consequently (2) share teachers' own explanations about the benefits of their socioemotional engagement.

Theoretical framework

When working with teachers in PD, our designs must account for the dual identities of teachers as both educators and learners (NASEM, 2022). As teachers expand their science teaching practices, they are also expanding their identities as science learners (Askew et al., 2021). Research on factors influencing learner engagement highlight the core role that socioemotional dimensions play in unfolding classroom interactions in terms of sustaining engagement and deepening learning (Humburg, 2020; Ryu & Lombardi, 2015).

For example, in considering how to deeply engage science learners, Jaber and Hammer (2016a, 2016b) conceptualize epistemic affect as a central dimension of scientific inquiry. In their conceptualization of epistemic affect, across multiple papers, Jaber & Hammer (2016a, 2016b) describe both distinctly positive affective epistemic work of scientists (e.g., joy, excitement, reward, pleasure, triumph, fulfillment, clarity, passion) that may come with the "feeling of knowing" (Jaber & Hammer, 2016a, p. 160) and negative affective epistemic work (e.g., uneasiness, impatience, irritation, anxiety) that may accompany "the feeling of error and epistemic anxiety" (p. 160). They argue that the full range of affect is a part of how scientists are "driven by the 'intellectual and sleuthing challenge' (Lorimer, 2008, p. 392) of their work" (p.160). They make the clear claim that affect is "inherent in the work of science" (p. 160) and name "epistemic anxiety" in particular as what "compels us to support our claims with more evidence and to thoroughly weigh in the evidence before making up our minds" (p. 161). This affective work is distinctly "the affect *within* science" (Jaber & Hammer, 2016b; p. 190) rather than feelings about or towards science or scientific inquiry. Jaber and Hammer (2016b) also examine the role of meta-affect, or reflection and reframing of affective experiences, "for instance, perceiving confusion as motivation, associating puzzles and uncertainties with pleasure rather than intimidation, and perceiving inconsistencies as simultaneously bothersome and stimulating rather than menacing (Jaber & Hammer, 2016b, p. 194)." This epistemic affect can also engage teachers-as-learners, giving them emotional experiences that mirror what their students may feel during investigations in science class. PD coaches and teachers together can navigate these moments of puzzlement and uncertainty to highlight how teachers can support their students to engage in similar affective epistemic work.

In subsequent work, Jaber (2021) also states that as teachers learn to shift towards centering students' as epistemic agents in the classroom, we must in turn focus on teachers' own affective epistemic work in their inquiry about teaching science. As Davidson, Jaber, & Sutherland (2020) articulate, affective dimensions are always relevant in "the work of constructing knowledge or developing understandings" (p. 1012). In this way, we might consider multiple lines of scientific inquiry as relevant to supporting science teacher professional learning; first, the inquiry of students and teachers-as-learners as they engage in scientific phenomenon-first inquiry, and second the inquiry that teachers pursue as they build knowledge about their practices for science teaching. Both of these forms of inquiry can be understood as including epistemic affect as they both include "emotions, feelings, and dispositions that are experienced in the epistemic work of constructing and critiquing knowledge within epistemic pursuits and in reflection around those pursuits (Jaber & Hammer, 2016a, 2016b; Jaber, Southerland, & Dake, 2018)" (p. 1011) whether those pursuits are understanding science phenomena or teaching practice.

We examine how epistemic affect is central to supporting the socioemotional dimensions of *teachers*' inquiry as they explore representations and new professional practices. Within professional learning spaces for teachers, their inquiry into their pedagogy brings with it feelings professional scientists experience, such as "the joy of going at it" while gaining "a feeling" for the flow of professional activity (Keller, 1983) and playing with ideas and designs (Jaber & Hammer, 2016a) as they extend students' ideas towards expansive understandings of science. Our project focuses on helping teachers investigate their knowledge and use of representations, such as drawings and graphs, which are crucial to science and science learning (Tippett, 2016) and place epistemic agency into children's hands as they learn to read, make sense of, and create their own representations (Pierson et al., 2022). However, sifting through the variety of representational choices and possible features (Eilam & Gilbert, 2014) makes PD around scientific representations difficult. Teachers may also struggle with determining relationships between different representational forms (Schwarz et al., 2012) and centering students' diverse practices and epistemologies (e.g., Hudicourt-Barnes, 2003). Despite this difficulty, supporting teachers to understand and use multiple representations helps position students to build from them, foregrounding a variety of scientific concepts and practices (Gouvea & Passmore, 2017) which deepens student engagement with concepts (Lehrer & Schauble, 2015).

We wish to explore how professional development learning spaces create the setting within which teachers can engage in inquiry about their professional practice and students learning, and how in turn engage in inquiry with coaches, PD providers, and teacher peers creates opportunities for teachers' affective-epistemic sensemaking.

Project design & data collection

The RepTaL project is a design-based research study (DBR Collective, 2003) supporting elementary science teachers towards phenomenon-first science inquiry learning (NRC, 2012). Our professional learning designs aim to integrate teacher communities for collaborative inquiry into teachers' professional practice. This included shared commitments to immersive demonstration lessons for teachers as learners in phenomenon-first science inquiry (e.g., Crawford, 2012), student artifact analysis, reflections on video-recorded teacher implementations of lessons, and planning support. Through iterating on these designs over four years, our team has consistently held space for the affective-epistemic work of teachers as we seek to support their development in a shared vision of inquiry-based, equity-oriented science engagement (Crawford, 2012; Windschitl et al., 2018).

Our project team shares an explicit commitment to responsive designs both at the level of the communities served by each partner institution (Site A, Site B) and responsive in-the-moment professional learning implementations to meet the evolving needs of our teacher partners. Responsive design included attending to the needs of both sites. Both sites hosted whole cohort summer experiences focused primarily on immersive demonstration lessons and planning support. We conceptualized teacher PD as a form of inquiry in which teachers tested out science concepts in lessons together and gathered observations about how different representations functioned in learning activities. However, academic-year work was designed to attend to geo-spatial needs of both contexts. During the academic year, Site A, a small, rural Midwestern city hosted both virtual and school-based gatherings to attend to the larger distances between the university and teachers' classrooms. During the academic-year, Site B, a large Southeastern metropolitan city, hosted whole-cohort gatherings as teachers were able to travel to meet in person after school hours. In response to the needs of both sites and the expertise of each site's professional learning experts, we designed two different versions of academic year support for teachers' inquiry which share key features but centered the needs of teachers in rural and urban areas. These shared features included a focus on developing teachers' understanding of science and scientific representations, prompting teachers to reflect on their practices in terms of their emotions and support needs, and collaborative, community-oriented interactions between teachers.

Coaching model with one-on-one video reflection

In Years 1-2, teachers at Site A participated in a model of instructional coaching referred to as Holistic Individualized Coaching (HIC; Cross Francis et al., 2021; 2022). HIC is an individualized coaching approach that acknowledges and attends to the cognitive and affective nature of teaching and learning. In particular, in the context of professional development, teachers are considered learners. Thus, in preparing for and engaging with teachers, the coach considers the cognitive strain, dissonance and emotional fluctuations that typically accompany learning experiences, as well as teacher change processes. As the teacher and coach interact through cycles of individualized coaching, the coach tracks and remains responsive to shifts in the teachers' pedagogical content knowledge, orientations, identity, efficacy, and emotions. Prior to the first coaching session, the coach gathers data from teachers about these constructs in order to inform what the coach says and does in pre- and post-coaching conversations, as well as how the coach supports the teacher and engages with their students during the coached lessons. Prior to the post-coaching conversation, the teacher and the coach watch the video recorded lesson, then meet and discuss clips they both selected to workshop difficulties, unpack student responses, and build shared ideas about what works (or not) and what to try next. Central to the HIC model is the responsiveness of the coach, not only to the teacher's needs related to pedagogical content knowledge and instruction, but also to their psychological and emotional needs. In response to the pandemic and emerging teacher needs, Site A shifted to a collaborative PD model in Year 3 onward, in which teachers met once a month with facilitators and other participants from their school to try out potential science activities and reflect on representations and lesson ideas together.

Video club model with small group video reflection

Teachers at Site B participated in collaborative PD sessions with other teachers throughout the year to achieve similar goals. Sessions involved a combination of analyzing student work (Langer et al., 2003) to support reflection on expansive representational forms, and video clubs to reflect on students' sensemaking and repertoires of practice (Gutiérrez & Rogoff, 2003; Sherin & van Es, 2005). Our collective work features shared commitments accomplished through nuanced designs that attend to geo-spatial and other contextual needs of the local community. Additionally, all sessions at both sites were video recorded for analysis (Derry et al., 2010).

Data analysis

The goal of our analysis is to understand how teachers' socioemotional engagement, and in particular their epistemic affect, can be supported across different PD contexts and experiences. Therefore, we used a case study approach (Yin, 2013), following two teachers from each research site (Site A: Heather and Luna and Site B: Maria and Jill; all pseudonyms). The teachers were selected to represent a range of experience in the project at different points in time. At Site A, Heather (2nd grade) began participating in Year 1 and stayed on for four years, while Luna (Kindergarten) was a new participant in Year 4. At Site B, Jill (Kindergarten)–who heard about the project while lesson planning with fellow teachers–joined in Year 3 and stayed on through Year 4, while Marie (4th grade) began in Year 1 and left the project after Year 2. Our goal was to understand the range of socioemotional interactions teachers experienced across PD models, not to directly contrast teachers.

The first and second authors reviewed data at each site using AI-generated transcripts, content logs (Erickson & Schultz, 1997), and raw videos from the first year of each teacher's project participation. We began our analysis by reviewing data for instances when teachers and/or facilitators explicitly mentioned feelings around teaching practices and what teachers reported as the impact of affective interactions in the PD. More specifically, we analyzed two related forms of interactional evidence of socioemotional engagement: (1) explicit social support and collaboration between facilitators and teachers and (2) explicit display of emotional reactions (e.g., tears, laughter) within and around teaching science and representations. Once noted in transcripts, the original video was viewed using Interaction Analysis (IA) methods to "chunk" moments for analysis (Jordan & Henderson, 1995), and multimodal elements such as PD-generated artifacts were also explored in relation to video clips to triangulate data sources (Sakr, Jewitt, & Price, 2016). Across the two sites, common forms of socioemotional engagement were noted (e.g., similar emotions being expressed, similar forms of social support), and these overlaps in socioemotional evidence led to the development of the hypothesized patterns detailed below.

Results

Three patterns of socioemotional engagement emerged related to the influence of the PD and interactions in the PD activities with supporting epistemic affect: 1) holding space for worry and frustration, 2) expressing surprise, joy, and celebration, and 3) offering social support for the process of becoming a science teacher. Our results explore how teachers at each site demonstrated their emotional engagement through expressions of both negatively- and positively-valenced epistemic affect during their PD interactions. We also outline how the interactions between teachers and between teachers and facilitators supported teachers' learning as they identified, articulated, and negotiated the meanings behind their emotions.

Engagement form #1: Holding space for worry and frustration

As teachers planned for incorporating new forms of science representations in their instruction, anticipatory emotions such as anxiety or frustration were evident in their interactions with facilitators and each other. Teachers also reported experiencing challenges while implementing new instructional techniques. Luna (Site A, Kindergarten teacher) noted "feeling a bit uncomfortable" when reflecting on perceived missteps in a new lesson and said she "felt a little disappointed" when her students struggled to understand the material. To address teacher needs and encourage growth, while maintaining socioemotional support, interactions included using humor and relational care alongside problem-solving and sensemaking conversations in ways that affirmed teachers' perspectives and validated teachers' feelings.

In response to a teacher's expressed uncertainty about a suggested lesson, rather than offering prescriptive rules for how representations should be used, a facilitator at Site A said, "If [the students] get confused, I'll just take the blame," and the teacher and facilitator laughed together. These moments of light-hearted socioemotional support framed PD as a collaborative effort and uncertainty as part of the evolution of practice. Also, the Site A facilitator often opened up discussions with *wonderings* such as, "I wonder if you had considered reversing the order of these activities" or "I wonder what the students would do if…" These interactional moves promoted articulations of epistemic affect within the conversational space, and it allowed teachers to explain the emotional aspect of their pedagogical efforts–in this instance, the anxiety around balancing time and effort between science lessons and other subjects.

In response to these moments of negative affect, facilitators and teachers engaged in open reflections that honored teachers' emergent emotions and supported problem-solving discourse with an intention to avoid a deficit-based or judgmental framing of teachers' feelings. For example, at Site B, a small group of teachers worked with partners in an immersive PD lesson about electrical circuits to put a broken flashlight back together, using a diagram. During the lesson debrief, Marie told the room full of teachers and facilitators that she "was literally stuck" and "literally having a moment" trying to figure out "why don't the stinking thing work?" after she and her partner reassembled it. She continued: "I thought I knew, kind of, you know, mechanisms of how a flashlight works, so I was truly puzzled." In this discourse, Marie's tone, facial expressions, and gestures evidenced frustration with not being able to solve the problem in front of her.

Despite her frustrations, Marie described pressing on with her partner to fix the flashlight. They "tested and retested," they "checked the batteries," and they "went through a process of elimination" as a scientific inquiry. Upon hearing this reflection, a facilitator told Marie, “I love how you describe how you really *felt* that problem.” In validating Marie’s frustrations, the facilitator positioned emotions as relevant to learning through and about science. To turn the immersive learning experience into a teacher-centered perspective, the facilitator explained that Marie having these emotions as a learner made the lesson “feel like a success” because if “learners don’t feel puzzled” then “I am actually failing.” This facilitator move intentionally centered the struggle of inquiry within science learning, highlighting how teachers should consider emotional support for students (even emotions oft-perceived as uncomfortable or negative). After the facilitator explained how they set up the lesson with the flashlight, another teacher pointed to Marie’s ah-ha moment–which would not have occurred without her struggle–as key to scientific inquiry for learners.

By considering the role that epistemic affect plays in teaching, these interactional spaces made processing emotions not only permissible but expected, which also opened up opportunities for engagement with emotionally risky topics, such as challenging deficit-based assumptions about students. For example, Heather (Site A) described one student as “somewhere on the spectrum, I’m guessing. And so, it’s very important to him for things to be right.” In response, the facilitator reframed the conversation by noting that being preoccupied with accuracy is actually a great example of “thinking like a scientist.” The teacher later expanded on this framing, noting, with regard to students’ writing, that “scientists often write things down so clearly enough that somebody else can check it.”

At Site B, Jill confronted her own deficit-based biases when reflecting on her experience using a representation to match parent to offspring. Realizing how her choice of representation made visible the sensemaking of a kindergartener, Jill’s voice cracked with emotion as she explained that “because of what we were doing here [in PD], I’ve learned a lot about her, and became very aware that even when we try not to, we have bias [...] I was able to see a lot of what she knew because I got out of the way.” The facilitator normalized and validated this experience, saying, “Everyone in this room has–could look back and see ways we stood in the way, that we were the problem, or we didn’t make space…every student I’ve ever taught didn’t get this version of me.” This interactional move further opened the space for the whole community to identify and leverage emotions for powerful self-reflection.

Engagement form #2: Expressing surprise, joy, and celebration

In identifying epistemic affect as a way to make central socioemotional engagements, our PD models not only held space for teachers to process difficult feelings, but also provided opportunities to express excitement and joy about their work. PD sessions contained numerous moments of shared laughter and communal enthusiasm as facilitators and teachers shared interesting student responses and joked about missteps. When asked what surprised her about a lesson, Heather (Site A) noted her students’ impressive scientific observations, saying, “They were excited, they were motivated, and they seemed to understand it pretty well.” She often called out particular student responses in the coaching reflections with enthusiasm (e.g., “Wasn’t that cool?” and “That’s awesome, that’s really great thinking”). The facilitator emphasized celebrating teaching successes, saying things like, “You’re very good at this conversation about being like scientists” and “I’m seeing what you’re doing there, and kids are responding,” which helped balance teachers’ anxieties about new strategies with emphasis on where their teaching expertise was visible.

In a different instance during Summer PD at Site B, Marie expressed her surprise after an immersive lesson in which a facilitator conducted a short science lesson entirely in French. At first, Marie explained that she “felt horrible because having ELLs, there’s so much they don’t understand.” Through her tone and body posture, she displayed a sense of shock when she imagined how difficult it must be for her multilingual students to learn science in English. Nevertheless, Marie’s deficit-based notions quickly turned to something joyful when she described the French lesson as “very humbling” and “awesome.” Continually, Marie explained that while learning vocabulary she “loved the choices” that the PD facilitator presented in the lesson, and kept interjecting positive affirmations (e.g., “oh yes!”) as other teachers shared their thoughts about the experience. Marie’s surprise as well as her positive affect in response to gaining a new perspective on her ELL students’ experiences demonstrates how epistemic affect is often wrapped up in how teachers learn to consider the varied needs of their students.

Teachers were explicit about the positive feelings that emerged during PD sessions as well, reporting that they enjoyed opportunities to talk through their lessons with facilitators and teachers. Jill, a kindergarten teacher at Site B, reflected at the end of the first day of the Summer PD workshop that she was “excited about” working with other teachers to plan new lessons about equity-oriented science topics, explaining that it “sounds very joyful to me.” She also noted PD was “helpful just to be thoughtful and reflective,” highlighting in the same turn of talk how emotions and learning are interconnected in teachers’ own inquiries. This explicit recognition of excitement and joy became realized when, on the fourth day, Jill jumped from her seat to lead a group discussion in connecting lessons about the presence of urban tree canopies to issues of climate and social justice. Such moments that promoted epistemic affect positioned processing emotions as a core part of the work of teacher learning and practice.

Engagement form #3: Social support for the process of becoming a science teacher

In expressing and negotiating the range of positive and negative emotions that emerged during science teaching, teachers also socially engaged with one another in ways that built community support and held space for vulnerability. Many of the teachers came to the project not labeling themselves as "science teachers" and expressed hesitancy and discomfort when trying out activities and forms of representation that were unfamiliar to them. This potential discomfort was visible in some of the ways that teachers teasingly set boundaries for how the group should critique each other's work, with comments such as "don't discuss my spelling" and a worried "I just like, chicken-scratch wrote," when asked to share a diagram with the group (Site A, Luna's cohort). As the teachers tested out different scientific representations that they planned to use with their students, they used humor and laughter to dispel some of the tension that appeared to build up as they presented ideas for public discussion. One example at Site A was the "significant circle" activity, which asked participants to create a diagram of how plants are significant for their personal lives. This activity was intended to support emotional and social connections to science topics, and in creating and sharing their circles, the teachers demonstrated and experienced the kinds of vulnerability their students might experience when completing the activity in class. One teacher noted, "I was like, I don't remember how to spell this, I probably could've done it but I panicked," highlighting how the collaborative PD activities generated experiences of epistemic affect that helped teachers anticipate how their students might feel when working with scientific representations. The teachers talked through the different ways they might use the information their students would provide to guide the activity, sharing their expertise with each other in supportive and generative space.

To similarly build space for social support, Site B facilitators began the fourth year of summer PD with collaborative, relationship-building activities, such as sharing personal stories, developing community agreements, creating a community word cloud, and talking about past experiences within the project (Figure 1). Not only were these key tools in integrating the new teachers into the project alongside the veteran teachers, but they also indicated how the teachers themselves wanted to support each other as a collective. To create the community word cloud, all participating teachers were given a live url to share "what comes to mind when they hear the word community" using their mobile phones. These words then helped the group expand their sense of community into a broader list of agreements that we wrote down together and kept on display throughout the summer PD experience.

Figure 1

Community word cloud (left) and community agreements (right) created by teachers at Site B

- We commit to be a safe base for others.
- We will advocate for ourselves + others.
- We commit to being present.
- We commit to making space for one another.
- We commit to building relationships with each other + our students.
- We commit to generous assumptions.
- We commit to listening and asking questions.
- We commit to a brave, vulnerable, and transparent space.

Outcomes for teachers

Across these forms of engagement, we observed that socially and emotionally engaging with facilitators and fellow teachers helped participants to normalize the idea that a range of positive and negative emotions are central to the practice of being a science teacher. Teachers reported that the PD work helped them to think through difficult lessons, as well as to develop a better understanding of how to implement representations. Teachers also noted the value they found in sharing their emotions with other teachers and talking through ideas in a supportive space. For example, Luna (Site A) wrote in a post-PD reflection, "My understanding of representations has solidified after the article and discussion/activity tonight." Later in her Year 4 post-interview, Luna reflected on how these PD experiences influenced her teaching style overall, saying that she now uses a more "holistic style" where science is integrated into her various lessons, rather than keeping science, math, and reading lessons siloed from one another. Heather (Site A) reported benefits as well, explaining in her post-interview that her experiences helped her build lessons around science as an inquiry activity, rather than as basic information gathering and "whatever was in the book." Heather also noted that after four years in the project, "the other kids and teachers in the building think of me as the science teacher."

In her end-of-year interview, Jill (Site B) described the impact of participating in RepTaL in multiple ways. Specifically, we asked her how the practices and frameworks of the PD influenced her teaching throughout the school year. Jill "found it to be freeing because the ways things have been the last few years–because of the pandemic, because of the curriculum [they]'ve been asked to implement–[she] felt very constricted." Clearly, a major outcome for Jill was a feeling of freedom to explore her teaching in different ways. Because of this freedom, Jill noted that the science teaching practices she was implementing from her PD experiences "really made space for [her] to see the depth of knowledge of some of the students" that she "would have missed" otherwise.

Conclusion

Across these forms of engagement, we observed that opportunities to socially and emotionally engage with facilitators and teachers helped participants embrace a range of positive (i.e., joy) and negative (i.e., frustration) emotions as central to the practice of being a science teacher and doing science. Teachers reported that the PD work helped them to think through difficult lessons with the use of representations. Teachers also noted the value they found in sharing their emotions with other teachers and talking through ideas in a supportive space. Our paper argues that epistemic affect highlights socioemotional engagement as central to the growth of teachers' inquiry-based science practices. Teacher emotions are not secondary to the learning process; rather, they are evidence of deep learning and a teacher's investment in their craft. Our analysis highlights how teachers took up and valued opportunities both to 1) share their feelings in a supportive environment while working toward solutions, and 2) share their joy and success. We see these opportunities as inseparable from the intellectual work of PD; teachers made important conceptual challenges and solutions visible as they articulated and navigated these emotional experiences within inquiry about teaching practice. Setting up immersive PD spaces in which emotional and social aspects of teaching are honored and shared together provides teachers with opportunities to connect to the emotional work of both doing and teaching science.

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Quantitative Analysis of Mathematical Word Problems in the Estelle Reel Papers

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Abstract: In this work, we present a database of mathematical word problems intended for use within Indian boarding schools under superintendent Estelle Reel. The database was constructed via manual transcription from historical documents dating from 1905 to 1909. These documents also contain curriculum guidelines, lesson plans, and contextual information such as grade, author, and school. Quantitative analyses were conducted, such as determining the questions' distributions by grade and location. Natural language processing tasks, including frequency distribution analysis and sentiment analysis, were also applied to the database. Our findings show that the mathematical questions were primarily intended for early elementary school students and written by authors from the Western United States. These questions most commonly reference commerce, agriculture, or measurement. Further analysis of the most polarized questions demonstrates a clear political position embedded within them. We briefly discuss the historical context and implications of these findings.

Introduction, background, and objectives

Within the learning sciences, there is increasing equity-focused research examining the social and political contexts of learning (e.g., Esmonde & Booker, 2017; McKinney de Royston & Sengupta-Irving, 2019). At the same time, the field of mathematics education is developing ground-breaking approaches that put issues of racial equity and justice front and center (Crespo et al., 2022; Matthews et al., 2022), including critical historical inquiry (e.g., Joseph et al., 2021; Zelbo, 2022). Our work advances research at the intersection of the learning sciences and mathematics education by contributing a quantitative historical analysis of the mathematics curriculum used in Indian boarding schools during the late 19th and early 20th centuries in the United States.

The myth of mathematics education

The common wisdom around mathematics is that it is objective and, therefore, a neutral domain of social practice. Mathematics *education*, the story continues, is a politically neutral enterprise. What does the teaching and learning of math have to do with politics or history? While scholars have long argued against the apparent objectivity or neutrality of mathematics education (Bishop, 1990; D'Ambrosio, 1990), still more research that directly challenges this notion is needed. Our project, *Mathematical Reservations* (Gutiérrez et al., 2021), presents historical evidence that subverts the discursive formations that continue to leave mathematics education uncritically interrogated.

Indian boarding schools – where's the math?

The United States established and operated dozens of Indian boarding schools (IBS) from the late 1800s through the 20th century. Research has documented how IBS policies and practices aimed to forcibly assimilate Native American children into white American society and prepared them to become subservient workers (e.g., Lomawaima, 1994; Lomawaima & McCarty, 2006; Trennert, 1998), including through exploitation of the children for domestic and manual labor (Tanner et al., 2022; Whalen, 2016). There is growing scholarship focused on the IBS system, curriculum, operations, student experiences, and its intergenerational consequences (Adams, 2020; Lajimodiere, 2019; Williams, 2022). However, no research has examined the mathematics curriculum in Indian boarding schools and how it was used to enforce U.S. citizenship and values.

The overarching questions guiding the *Mathematical Reservations* project are: What types of mathematics were taught in IBS and why? How did the IBS mathematics curriculum promote federal assimilationist goals? These questions are important for two main reasons. First, the historical record is incomplete. Our archival research on the mathematics policies and curriculum in the IBS system has begun to fill this crucial gap in the literature. Second, emerging efforts for educational equity have paid little attention to the experiences of Native students, despite critical discussions on equity and justice in mathematics education regarding Black, Latinx, and multilingual learners. Deepening our understanding of the legacy of colonization—

how children were colonized through math—can inform new policies, pedagogies, and theories of learning that center the experiences of Native students today.

Quantitative historical analysis of math word problems in the "Estelle Reel Papers"

Estelle Reel served as the Superintendent of Indian Schools between 1898–1910 and was a crucial figure in the education and assimilation of Native children during her tenure. She wrote a uniform course of study (Reel, 1901) and developed training programs for teachers in the Indian service. The *Estelle Reel Papers* is a collection of primary documents related to her work and is well-known among historians and Indigenous Studies scholars (see Lomawaima, 1996). Here, we describe the construction and initial quantitative analyses of an extensive bank of mathematical word problems discovered in the *Estelle Reel Papers* collection. To our knowledge, these word problems had not been analyzed before our project.

Methods

Database construction

Source documents

The *Estelle Reel Papers* collection, housed at the Northwestern Museum of Arts and Culture (NWMAC) Research Library and Archives, contains several boxes of historical documents, including biographical material, curriculum and lesson plans related to IBS, information on educational administration and Indian affairs, newspaper clippings, and photographs representing everyday life in Indian boarding schools across the U.S. We were graciously granted electronic copies of the contents of four folders (9-12) from "Box 1," labeled "Arithmetic." Combined, we received 225 scanned pages of materials.

There is limited information on the exact origins of the arithmetic problems in the *Estelle Reel Papers*. The museum authenticated the records as part of Estelle Reel's work with the Office of Indian Affairs, but we do not have the exact dates for the documents. We narrowed the relevant dates to 1905–1909 by cross-referencing some schools and teachers with other records. This period was around when Reel conducted summer institutes for teachers working in Indian schools. Given Reel's plan to professionalize the IBS teacher corps (Lomawaima, 1996), teachers likely submitted these worksheets for Reel's review as part of the summer institutes and later used them in curricula she designed. In some instances, the worksheets are labeled with the teacher's name, some of which can be confirmed in the historical record. Many of the problems are labeled as "pupil," which suggests they were authored by students.

Transcription

To construct a problem bank, arithmetic word questions were transcribed "by hand" into Excel spreadsheets. This task, as well as data cleaning and lemmatizing, is completed manually rather than automatically so we could simultaneously analyze and form qualitative impressions of the questions and information available. Additional information provided with the math problems (such as grade level, author information, school information, etc.) was included with the entries. Purely numeric problems (no words) and questions unrelated to mathematical practices were excluded. Similarly, long, multi-part, often Q&A-style lesson plans and commentary on curriculum and/or pedagogy were also excluded. Transcription was completed without correction to spelling, grammar, punctuation, or other typos. A few examples of "typical" questions are reproduced below:

> If John can sew on 4 buttons and James can sew on 2, how many can both sew? (Kindergarten, Rainy Mountain, OK)
>
> If we pay each man $1.50 per day, how much do we pay 5 men for 1 day? For 7 days? (Grade 3, Charles Ammon, Blackrock, NM)
>
> About 1500 bushels of potatoes were harvested. What was the yield per acre? (Grade 5, Pupil, Haskell, KS)

Data cleaning

After the word problems were transcribed, several data cleaning tasks were required, mostly completed "by hand" and on a case-by-case basis. First, spreadsheets were standardized to contain the same columns of information as follows: Question, Grade, Author Name, Author Position, School Name, School Location, Notes, and Folder.

Schools that did not list their state were cross-referenced with the list of Indian boarding schools in the 2022 Federal Indian Boarding School Initiative Investigative Report (Appendices A and B).

Several authors appeared across multiple folders with differing titles or types of additional information. In these cases, information was combined in a way that retained all available data. For instance, the author "Chas. E. Burton" from Grand Junction, appearing in Folder 9, was determined to more than likely be the same person as "C. E. Burton, Superintendent" from Grand Junction in Folder 10. Therefore, all questions written by this author were given cross-referenced additional information; Author: Chas. E. Burton, Position: Superintendent, School: Grand Junction, Location: Colorado.

Finally, we addressed duplicate and "nearly-duplicate" database entries. True duplicates (identical questions and additional information) were deleted, with one copy retained. When multiple entries had identical questions yet differing amounts of otherwise identical additional information (i.e., both questions attributed to the same author, but one also lists grade level,) the entry with more information was kept. If the additional information was different or contradictory between the otherwise identical questions (such as different grade levels), all distinct entries were kept.

After accounting for differences in additional information, "nearly-duplicate" questions were addressed. For questions that were "essentially identical" up to one or two words, abbreviations, and/or spellings in a way that did not change the meaning of the question nor its mathematical solution, one was randomly selected to keep. If the questions differed by a number, it was considered a distinct question, and all versions were retained.

Analysis

Natural language processing (NLP) analyses such as frequency analysis and sentiment analysis were conducted. Unlike in the construction of the database, most of the tasks described below were automated using the Natural Language ToolKit (nltk) library (Bird et al., 2009) for Python programming language. For frequency analysis, the questions were tokenized (broken up into words), and stop words, numbers, and punctuation were removed. In addition to the standard list of nltk stop words, we excluded common words describing mathematical operations and their results, such as "many," "will," "much," "left," "per," and "find" as well as any spelled-out numbers. Next, words with multiple spellings, abbreviations, plural forms, tenses, and the like are combined as one root word. For instance, "lb", "lbs", and "pounds" are all equated with "pound." Rather than using nltk's lemmatizer, this task was again completed "by hand" by iteratively viewing the top 100 most commonly used words, determining possible variations, then combining until the list consisted of only root words. Finally, the frequency distribution of the modified word list is calculated.

Sentiment analysis was completed using VADER (Valence Aware Dictionary and sEntiment Reasoner), a pre-trained model in the nltk library that uses rule-based values tuned to social media sentiments (Hutto & Gilbert, 2014). VADER was used to automatically assign to each question in the database a compound polarity score between -1 and 1. The model is sensitive to both polarity (positive/negative) and strength of emotion conveyed by words in its dictionary. A score of -1 is considered very negative, 0 is neutral, and 1 is very positive. The compound polarity score is computed by summing up the sentiment scores of each word of the question and then normalizing. For instance, the word "horrible" contributes a score of -2.5 for having very negative connotations, while "okay" carries a value of 0.9, corresponding to a somewhat positive sentiment. VADER can also identify negation ("not") and amplification ("very").

It is important to note that VADER may have a different vocabulary than IBS teachers and pupils nearly a century ago. Therefore, it is likely that training a model on different data could yield more contextually specific results. On the other hand, VADER is an extremely accurate classifier found to even outperform individual human raters (Hutto & Gilbert, 2014), hence we did not attempt to take further measures to ensure the scorer reliability of the model. Indeed, due to the convenience of a pre-trained and trusted model, the difficulty of learning historical texts (Piotrowski, 2012), and the qualitative nature of our sentiment analysis, we proceed using VADER.

Results

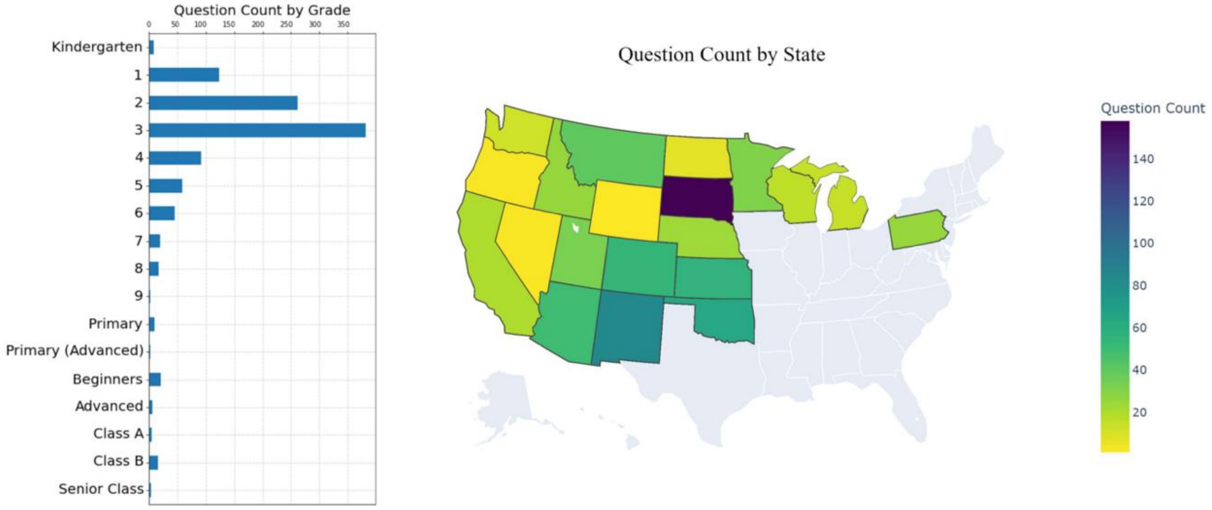
Summary statistics

The final problem bank database consists of 1604 unique combinations of 1576 word problems written by 98 authors from 63 schools across 20 states. Before cleaning, the total question count was 1741. In total, 1051 questions reported a grade, of which approximately 36% are intended for grade 3, 25% for grade 2, and 12% for grade 1. There were dramatically fewer questions for later grade levels, with a combined 3% for grades 7-9. See Figure 1 (a) for the exact distribution of question counts across all grades.

For 720 questions the school's location (by state) was reported or could be found in Appendix D of Federal IBS Initiative Report (Newland, 2022). Figure 1 (b) demonstrates the number of questions from schools within each state. The state with the most questions is South Dakota (158), from which there are eight schools in our dataset. New Mexico has the second most questions (84) from five schools.

Figure 1

Distributions of questions across grade (a) and state (b).



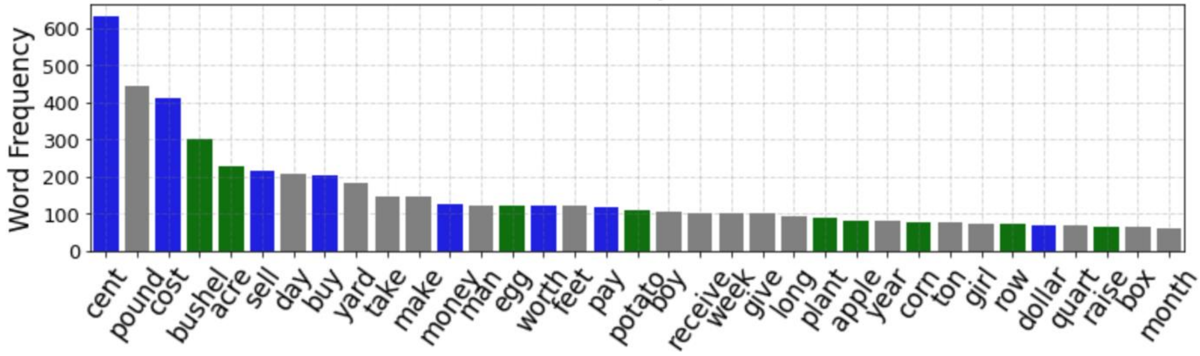
(a) (b)

Natural language processing

The frequency distribution of the most common words from database questions, post stopword removal and lemmatization, is shown in Figure 2. The most commonly used word is “cent” (combined with cents but not ¢), used 633 times followed by “pound” (combined with pounds, lb, lbs) used 444 times and “cost” (combined with costs, costed) used 411 times. Noting themes within the words, they were categorized into monetary words, farm words, and other. Of the top 35 most commonly used words, nine are related to money and eight related to farming, including two of each type in the top five.

Figure 2

Counts of the number of occurrences for the thirty-five most commonly used words from the problem bank. Colors correspond to monetarily-related (blue), agriculture-related (green), and other (grey).



Sentiment analysis yielded polarity scores indicating the “mood” of each question. The majority of the problems were labeled as very neutral with a polarity score of zero (n = 1213). Only 13 questions obtained a polarity score greater than 0.75 in magnitude (ten positive and three negative). Below are the three questions with the most negative polarity scores.

> [Write these numbers.] The late strike in Chicago cost the company twenty thousand dollars a day in fares, besides ten thousand dollars for property destroyed, while seven hundred fifty thousand people were deprived of their right to ride. The Freight Handlers' strike cost Chicago twelve million dollars in fruit, eggs, and other perishable stuff. (Grade 2)

> [Write these numbers.] The oleomargarin swindle takes seventeen million dollars, annually, out of the pockets of the poor (Grade 2)
>
> A doctor usually chargest $1.50 for a visit to a sick person if he does not go over a mile. A lady was sick for two weeks and the doctor called every day during that time. What was her doctor bill? (Grade 3)
>
> Similarly, the three questions with the most positive polarity scores are as follows:
>
> In playing a game of marbles a boy won 12 games and then lost 5. How many games did he win. He played another hour and won 13. How many did he win altogether?
>
> The Government farm produced this year 1350 bu. of potatoes from 9 acres of ground. The items of expense are as follows: for plowing $2.50 per acre, for harrowing, marking, furrowing and planting $2.00 per acre, for seed 12 bu. per acre at 60 cents per bu., cultivating 4 times 1 man and 1 horse 1 day each time, Paris green $27., harvesting 1 man and 1 horse 1 day for each acre, marketing 2 cents per bu. Allow $2. per day for the labor of a man and $1. per day for the labor of a horse. Allow 25 cents per acre for wear and tear of tools. Allow interest at 6% on land at $40. per acre, and taxes at $.002 on a dollar. What is the profit on 1 acre of potatoes if they are worth 40 cents per bu.? (Alice M. Peck, Hayward, WI)
>
> If we raise $25 worth of potatoes, 2 worth of beets, 5 worth of corn, 3 worth of tomatoes, 2 worth of cabbage, 1 worth of radishes,1 worth of peas, how many dollars worth of vegetables do we raise?

Discussion

In this work, we have described the construction and initial analyses of a new database consisting of mathematical word problems from the *Estelle Reel Papers*. Mostly, questions are intended for early-elementary school students with grades 1-3 comprising nearly three-quarters of the questions with documented grades. Less than five percent of questions were written for grades 7-9. Questions were primarily sourced from schools located in the West, Southwest, and Midwest.

Commonly used words are often associated with money, farming, and measurement. This is consistent with the assimilationist goal of the IBS system to force Native children to act and interact as white Americans (Adams, 2020; Child, 1998; Lomawaima, 1994). Furthermore, the emphasis on farming gives evidence that even math instruction in IBS was used to promote sedentary, farming lifestyles for Native Americans as part of a federal policy of Indian territorial dispossession and Indian assimilation through education (Adams, 2020; Newland, 2022).

A majority of questions were given polarity scores of exactly zero (approximately 76%). We acknowledge that this may appear to support the claim of neutrality of math and math education. However, it is important to know that classification was completed via an artificial intelligence model pre-trained on contemporary social media data. If the sentiment in the rules and training data is generally neutral regarding mathematical words and sentences, the model would have learned to classify them as such. Furthermore, neutral phrasing does not necessarily equate to neutral content. Indeed, bureaucratic and even "positive" language have oftentimes been employed by colonial powers to obfuscate violence and dehumanizing policies. Therefore, we use polarity scores and sentiment analysis with caution and as a tool to inform but not drive our analysis.

Nevertheless, the results of sentiment analysis indicate there are several questions that are far from neutral. It is interesting to note that the negative questions are particularly politically motivated, addressing freight worker strikes and Oleomargine, both considered a threat to farmers during that time (Burns, 2009). Furthermore, it is of interest to find that the question with the second most positive polarity score refers to the Government farm. The purpose of the positive phrasing in this question may be to influence students to see the Government, as well as farming, in a favorable way.

The purpose of this work is to introduce the database and provide several initial, broad, and quantitative descriptions. Further analysis of this problem bank is currently underway, including a discussion of gender roles and wage labor (Kim et al., 2023) and relationships with land and land ownership (Smith et al., 2023). We hope that this data will provide evidence and inspiration for other research directions, particularly those aimed at uncovering the political and sociological agendas of IBS and the role of the math curriculum as a tool to achieve them.

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Who Writes Tomorrow's Learning Activities? Exploring Community College Student Participation in Learnersourcing

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Abstract: Generating multiple-choice questions (MCQs) is a popular form of learnersourcing that benefits both the students' higher-order thinking and the instructors' collection of assessment items. To better understand the type of students that engage with learnersourcing activities and inform whether these interventions are targeting all students or just a select few, we deployed multiple optional MCQ generation activities across three courses at two community colleges. To measure if these interventions were reaching all students, we analyzed how students' demographic data and performance in the course influenced their participation in a set of optional MCQ generation tasks. We found that students who performed better on the formative and summative assessments in the course contributed a greater number of learnersourcing activities; however, most of the top 10% of students in terms of quiz scores did not make any contributions, likely because they did not perceive these activities as necessary.

Introduction

Having students develop assessment questions has a long history as a learning activity, one that has shown real benefit in supporting student learning (Aflalo, 2018). These types of activities integrate deep engagement around subject matter with critical thinking and creative practices (Denny, 2015). Through the instrumentation of this process, student engagement can be leveraged in ways that provide meaningful data around student interaction, in addition to new student-generated learning assets that can support future learners (Denny et al., 2017). This is known as a form of learnersourcing, where students complete activities that produce content that can be leveraged by future learners (Kim, 2015). The continual creation and improvement of these questions allows for a greater breadth of topic coverage, helps to identify well-constructed and valid assessments, and as a result, enables improved learning opportunities.

While asking students to write new quiz or exam questions is a time-honored approach in many classrooms, current learnersourcing investigations emphasize the online context, where students' efforts to master domain content within a digital learning environment can be effectively studied at scale (Glassman et al., 2016). Specific implementation of learnersourcing activities can vary greatly between instructors, however, particularly in whether completion of these activities are treated as mandatory or optional (Moore et al., 2021). This distinction between mandatory and voluntary implementation is important: students who are offered a choice in completing learnersourcing tasks perceive these activities as having a greater value, gain more autonomy in the course, and contribute higher-quality questions compared to students that are required to participate (Singh et al., 2021). Indeed, efforts to force student engagement may backfire; requiring these tasks can lead to student disengagement as they participate with minimal effort in order to satisfy the requirements of the activity (Khosravi et al., 2021).

On the other hand, making the activities optional comes with its own risks: the activities may be neglected by the students who could benefit the most from these interventions, as oftentimes only the most driven students choose to participate in optional tasks (Inglis et al., 2011). This type of self-selection would have an impact beyond the individual students for learnersourcing activities, as only the top performing students may be generating data and new questions. This would in turn influence the question banks, hints, analytics, etc. generated by the students, limiting the diversity of the contributions, creating potential bias in the generated content, and potentially excluding a novice point of view that could be beneficial to learners (Nathan et al., 2001). Ideally students of all backgrounds and knowledge levels would participate in learnersourcing activities, but previous work has indicated otherwise – that participation for these question generation activities can be as low as less than 5% (Denny et al., 2018). These findings are further complicated by where such investigations take place, with a majority of the learnersourcing activities being deployed at top R1 four-year universities around the world (Wang et al., 2019).

Therefore, more research is needed to investigate which students are participating in these learnersourcing activities, how these interventions work and who they are targeting. To this end, we deployed several optional MCQ generation activities in three online courses across two community colleges in the United

States. Accompanying these tasks is a demographic survey to help better understand the students in the courses. As students worked throughout the first four or five weeks of their online course, they were presented with several opportunities to generate a MCQ for the given unit they were working through. We analyzed which students were participating and how their demographics and performance in the course may have influenced their participation. Our two research questions are as follows: (1) How does student participation with learnersourcing activities vary by student demographics? (2) How is student performance in the course related to their participation in optional learnersourcing activities? Through the investigation of these research questions, our work makes the following contributions towards online learning and learnersourcing tasks. First, we provide insights into the attributes of students that participate in learnersourcing activities. Second, we derive a set of performance measures commonly found in online courses that can serve as predictors of student participation in related activities.

Theoretical framework

We research in a climate that has appropriately prioritized equity and brought the larger challenges of fairness and related ed-tech into sharper focus. In the context of learnersourcing, diverse student engagement is critical, not merely to support a research agenda, but also to expand learning materials to reflect the broadest possible student experience. In contextualizing this research, we first look at how student participation and performance in online courses are potentially influenced by their demographic background. We then detail the process of question generation as a learning activity and how these questions can be utilized. This approach works to prioritize students' prior knowledge as a critical input into the larger learnersourcing effort.

Online courses offer students different affordances compared to traditional in-person ones, which can be both beneficial and detrimental to learning depending on the student. A study by (Ruthotto et al., 2020) found that over 90% of the students enrolled in online computer science courses participated at least once, but overall participation rates ranged along a continuum from active to passive participation. They found that student participation within these courses varied by demographics, such as ethnicity and age. Particularly in STEM, evidence suggests that online courses can perpetuate enrollment and participation gaps for women or ethnicities that are traditionally underrepresented in these courses (Kizilcec & Halawa, 2015).

Student engagement with an online course can be defined by their participation in its learning activities (Gledson et al., 2021). Multiple studies have linked student performance to their engagement with the course materials, indicating that students who actively participate and do more activities have a higher chance to pass the course and receive a higher grade (Brunskill et al., 2018). While research supports the benefits of having students participate in optional activities found in online courses, other factors such as the demographics of the students may also influence their participation and ultimately their success in the course (Rizvi et al., 2019). For instance, student motivation in STEM courses can be affected by stereotype threat, causing a lack of a sense of belonging (Bathgate & Schunn, 2017). This lack of participation, particularly when it involves learnersourcing, presents several challenges that propagate throughout the course. When students have lower levels of participation, they do fewer activities, which can pose difficulties in modeling their learning (Long & Aleven, 2013). Students doing fewer activities also leads to less data being generated, which can hinder the efficacy of instructional interventions, such as recommending practice problems (Andrade et al., 2016).

Learnersourcing has been used in many online courses across a variety of domains, where students are typically tasked with generating questions, making hints, or providing feedback (Khosravi et al., 2021). Having students generate short answer or multiple-choice questions (MCQs) that can then be used as practice opportunities in the current or future courses is a particular focus of much learnersourcing research (Wang et al., 2019; Yeckehzaare et al., 2020). An obvious challenge that arises from optional activities is getting the students to participate with them and making a meaningful contribution (Carvalho et al., 2018). Previous research has demonstrated that completing optional course activities is strongly related to a student's performance in a course (Koedinger et al., 2015). As researchers and educators, we want students to participate in learnersourcing activities, given that such activities can provide useful learning data, contribute to the instructor's assessment question banks, and benefit student learning (Aflalo, 2018). However, it is important to understand what factors might influence students's decision to participate in these optional activities, as addressed in the study by (Singh et al., 2021). To determine if such activities are reaching all students in the course, or only those from the commonly represented demographics or top-performing group, we need to investigate these factors as they relate to students contributing to these learnersourcing tasks.

Methods

This study was conducted in three different courses at two 2-year community colleges located on the west coast of the United States. All three courses took place online during the fall 2021 semester and IRB approval was received for the survey and activities added to the courses. The three courses were introductory chemistry, advanced chemistry, and introductory statistics. The two chemistry courses were taught at the same community college, but by different instructors. Students taking introductory chemistry were required to have previously passed a course covering the topics of linear algebra. For the advanced chemistry course, students were required to have passed both a linear algebra course and an introductory chemistry course at the college-level. The statistics course was taught at a separate community college by a third instructor. The only prerequisite for students in that course was to have passed a college-level intermediate algebra course.

We utilize data that came from four to five week-long units that were used towards the beginning of each course. This data consists of student interactions in the course along with their performance on the quizzes found at the end of each unit. There were a total of 64 students across all three courses, who were taking the courses to receive credit towards their respective degrees. There were no students enrolled in both of the two chemistry courses. Table 1 shows the number of learners in each course, along with a breakdown of their self-reported gender, ethnicity, and first-gen status. It also includes the number of units, and therefore quizzes, in the respective course, as introductory chemistry had five units and advanced chemistry and introductory statistics had four units. Our demographic questions accepted free text input to allow students the highest flexibility in identifying their background.

Table 1

Breakdown of the students in each course, their demographic information, and the number of units

Course	Units	Students	Male	Female	First-gen	Hispanic/Latin	Asian	White
Introductory Chemistry	5	17	5	12	8	12	3	2
Advanced Chemistry	4	18	4	14	12	12	5	1
Introductory Statistics	4	29	6	23	19	15	6	8

All three courses were deployed on the same learning platform, known as the Open Learning Initiative (OLI), which has been used in previous studies involving online learning at community colleges (Bälter et al., 2018; Ryan et al., 2016). It contains functionalities akin to popular learning environments often utilized at universities or in MOOCs. Each unit in these courses was equivalent to a chapter in a textbook, consisting of five to ten related topics and taking up roughly one week to cover. The units contain multiple pages of instructional content featuring text and brief instructional videos. These webpages also host multiple low-stakes activities interspersed amongst the instructional content for students to use as practice opportunities. They include multiple-choice, short answer, essay, matching, and fill-in-the-blank style questions. All of these activities act as formative assessments, intended to provide students with instructional feedback. As such, they are completely optional and do not account for the students' grade in the course. Additionally, students may make any number of attempts on these activities, receiving instant feedback on their response with each attempt. In all three of the courses, each unit concludes with a summative assessment in the form of a quiz that tests students on the material covered in that unit. The quizzes consisted of only multiple-choice or fill-in-the-blank questions and ranged from 4 to 22 questions. Students' scores across all of the quizzes counted towards a low percentage (5-15%) of their final grade in the course. All student data collected from OLI is securely stored in accordance with its IRB approval. In addition to the OLI platform, students in these courses utilized a learning management system for the other parts of their course, such as submitting homework assignments or viewing announcement posts.

Data collection and analysis

Our dataset came from the four to five week-long units at the beginning of each course, with four primary components: 1) Demographic survey, 2) Formative assessments, 3) Summative assessments, 4) Learnersourcing activities.

Demographic survey

When students first accessed the learning environment which hosts the formative and summative assessments, they were prompted with a brief demographic survey to complete. The survey asked the students to specify their gender identity, ethnicity, and if they were a first generational (first-gen) college student in their family. Students that did not fully complete this survey were not included in the present study. Additionally, as many of the responses were free-form, we had two researchers standardize the student responses (e.g., fixing typos), during this process there were no discordant cases.

Formative assessments

Throughout each course there are multiple formative assessments, commonly referred to as problems, embedded amongst the instructional text and videos intended to provide the students with practice opportunities and immediate feedback. They consist of multiple-choice, short answer, essay, matching, and fill-in-the-blank style questions. These activities are optional and do not impact the student's grade in the course. Table 2 shows the total number of formative and summative assessments in each course – note that these do not include the count of the MCQ generation activities, which we describe below.

Summative assessments

The end of each unit concludes with a page summarizing the content that was covered in the unit. This page also contains a link to the unit's quiz that students complete for a small percentage of their final grade. It consists only of multiple-choice and fill-in-the-blank style questions that can be automatically graded. In this study, the smallest quiz contains 4 questions, and the largest quiz contains 22 questions.

Learnersourcing activities

At the end of each unit in each course, we placed a learnersourcing activity that prompts students to generate an MCQ targeting any concept they learned from the unit. The interface of the MCQ generation activity includes the brief instructions for the students. The two bullet points shown in the activity's instructions reflect the unit's learning objectives which the MCQ should target. The number of MCQ generation activities is equal to the number of units in the course.

Table 2

The number of formative and summative (quizzes) assessments in each course

Course	Formative Assessments	Summative Assessments
Introductory Chemistry	126	5
Advanced Chemistry	94	4
Introductory Statistics	37	4

Our primary variable of interest is student participation with the learnersourcing activities in their respective course. In this study, we consider a student as having participated in the learnersourcing activity if they submitted a contribution that contains a question pertaining to the course's learning objectives, a correct answer choice, and three distractor options. If a student submitted a blank response, a random string of characters, or made no submission, they were not counted as having participated in the learnersourcing activity. Note that it was rare for students to exhibit this behavior, as the vast majority of them either skipped the learnersourcing activities or made an honest effort in their contribution to generate a MCQ. To measure student performance on the formative assessments, we used their accuracy on the first attempt they made on the problem. If they correctly answered the problem on their first attempt, then they would have the first-attempt correct for that problem. Previous research indicates that a student's first attempt at a problem is a strong indicator of their knowledge of the material (Corbett & Anderson, 1994). In the forthcoming analysis we utilize the average quiz scores of the students, as it represents their performance in the course up to that current point in the course.

Results

To understand which students were participating in the optional learnersourcing tasks, we first analyzed their demographic information in relation to their potential contributions to the learnersourcing activities. Next, we investigated the different patterns of student participation and performance by looking at their interactions with the formative and summative assessments embedded throughout the courses.

Student demographics

In total, 37 of the 64 (*57.81%*) students participated in at least one of the learnersourcing activities in their respective courses. To further investigate student participation with the learnersourcing activities in the courses, we looked at the demographics for students that contributed to any of the MCQ generation tasks. A Fisher's exact test revealed that there was no statistically significant association between gender and participation with any of the learnersourcing activities (*p=.484*). Similarly, there was no significant association between first-gen status and student participation with the learnersourcing activities (*p=.794*). We also looked at participation on the tasks related to the students' self-reported ethnicity. A chi-square test of independence showed that there was no significant association between ethnicity and task participation, $X^2(2, N=64)=.27, p=.873$. Table 3 provides the count of students who participated in the learnersourcing activities in each demographic group.

Table 3
Student participation with any of the learnersourcing tasks and their demographic information

Participated in learnersourcing	Students	Male	Female	First-gen	Hispanic/Latin	Asian	White
Yes	37	9	28	26	23	7	7
No	27	6	21	18	17	6	4

For the 37 students that participated in at least one or more of the learnersourcing activities, we investigated if their demographic background had any statistically significant effect on the percentage of learnersourcing activities they completed. Note there were four learnersourcing opportunities in advanced chemistry and introductory statistics, and five opportunities in introductory chemistry. An unpaired two tailed t-test revealed that there was no significant effect of gender on the number of learnersourcing activities students worked on, *t(35)=.95, p=.348*, with females *(M=.59, SD=.09)* doing slightly fewer of the learnersourcing activities than males *(M=69, SD=.10)* on average. There was likewise no significant difference in the percentage of learnersourcing activities between first-gen students (*M=.62, SD=.08*) and others *(M=.61, SD=.13)*, *t(35)=-.12, p=.452*. A Kruskal-Wallis test was conducted to examine the differences of the students' self-reported ethnicity and the percentage of learnersourcing activities they completed. There was once again no significant differences in participation found between groups, *H(2)=0.516, p=.773*.

While students' demographic background had no significant association with their participation with the learnersourcing tasks or the amount of learnersourcing tasks they engaged with, we also looked at how this information might be associated with their overall performance and participation with the other material found throughout the course. We found no significant effect of gender on the percentage of other formative assessments done in the course, *t(62)=1.48, p=.144*, where males (*M=.54, SD=.11*) and females (*M=.41, SD=.09*) had similar participation levels. There was likewise no significant effect of gender on the average quiz scores, *t(62)=.61, p=.546*, with males (*M=.73, SD=.05*) and females (*M=.68, SD=.09*) receiving similar scores. Similar null effects were found for the formative assessments, *t(62)=-1.07, p=.287*, and quiz scores, *t(62)=-.83, p=.407*, between first-generation students ($M_{formative}=.46$, $SD_{formative}=.09$; $M_{quiz}=.71$, $SD_{quiz}=.07$) and others ($M_{formative}=.38$, $SD_{formative}=.11$; $M_{quiz}=.65$, $SD_{quiz}=.11$). Finally, a Kruskal-Wallis test revealed no significant formative assessment participation, *H(2)=3.913, p=.141*, or quiz scores, *H(2)=1.233, p=.539*, between students' self-reported ethnicities.

Student performance

We focus on how student participation and performance within their respective course might reflect their contribution to the learnersourcing activities. Our study showed that students who participated in the learnersourcing activities (*M=.62, SD=.07*) had a significantly greater percentage of the formative assessments completed in their respective course than those that did not (*M=.18, SD=.02*), *t(62)=-8.07, p<.005*. Relatedly, there was a significant positive correlation between the percentage of formative assessments done by the students with the number of learnersourcing activities they completed, *r(62)=.28, p<.005*. Table 4 provides the average amount of formative assessments completed in each course by students who participated or did not participate in the learnersourcing activities, including those students that only did the quizzes in these averages.

Table 4

Average percentage of formative assessments completed in the courses and the average quiz scores, out of 100, by students that participated in the learnersourcing activity (Yes) and those that did not (No)

Course	Learnersourcing Participation			
	Average Percentage of Formative Assessments Completed		Average Quiz Scores (out of 100)	
	Yes	No	Yes	No
Introductory Chemistry	73.71	26.98	72.83	67.00
Advanced Chemistry	61.70	10.99	67.50	73.03
Introductory Statistics	49.83	22.45	64.23	71.27

While participation in the course was positively correlated with doing the learnersourcing activities, as expected, we wanted to further investigate if these activities were more likely to be done by students already performing highly in the course or if it was a true mix of the students. We found that students who performed better on the formative assessments in the course were also more likely to contribute to the learnersourcing activities. These students who participated in the learnersourcing activities ($M=.48, SD=.10$) compared to those who did not ($M=.66, SD=.03$) had a higher percentage of correctness on their first attempt in the formative assessments, $t(62)=2.99, p<.005$. For the 37 students that participated in one of the learnersourcing tasks, there was also a positive correlation between the number of learnersourcing activities completed and the percentage of correctness of first attempts on the formative assessments, $r(35)=.35, p<.005$.

Next, we examined student performance on the summative quizzes at the end of each unit. Table 4 also shows the average quiz scores across all three courses divided into two groups based on if the students participated in any of the learnersourcing activities. We analyzed how a student's performance on the quizzes correlated with the amount of learnersourcing activities they completed. Ultimately, we found a significant positive correlation between a student's average quiz score and the number of learnersourcing activities they did in the course, $r(s)=.26, p<.05$. Interestingly, across all three courses, seven students had a perfect quiz average, receiving full credit for all four or five quizzes depending on the course. However, of those seven students, only one of them participated in the learnersourcing activities, contributing to all four of them in the advanced chemistry course.

Discussion

In this study, we investigated how student demographics and performance within online community college courses influenced their participation in a learnersourcing activity that involves generating a multiple-choice question. We found that 37 of the 64 students across the three courses participated in at least one of the learnersourcing activities; these students came from a variety of demographic backgrounds, expressed in terms of self-reported gender, ethnicity, and first-gen status. Our analysis revealed a correlation between the completion of formative assessments and the likelihood of students participating and contributing to a higher number of learnersourcing activities. Interestingly, the top 10% of students, as determined by their quiz score averages, did not participate in any of the learnersourcing activities.

We found no significant relationships between the students' demographic background and their participation with the learnersourcing activities. This may in part be due to our students primarily reporting the same gender and ethnicity, thus decreasing the potential diversity of our sample. While we did not identify any significant effects, our data indicates that a majority of the students from all the reported ethnicities, genders, and first-generation status made at least one contribution to an optional learnersourcing task. While we were encouraged to see that students of all backgrounds were participating, learnersourcing research should continue to collect demographic information to ensure all students are being reached by the activities and interventions. A core benefit of learnersourcing student-generated questions is that their unique perspectives and backgrounds can be incorporated into the questions they create, ultimately avoiding expert-blindspot and contributing to a more diverse pool of questions (Nathan et al., 2001). However, if the learnersourcing activities are skipped by students, knowing why they are not participating in them and the backgrounds of those students, could potentially inform methods on how to better include all students.

As expected, due to prior research in the area, student participation with the formative assessments in the course was positively correlated with their performance on the summative assessments (Brunskill et al., 2018). We found that students who did more of the formative assessment were also more likely to participate in the learnersourcing activities. There was also a strong positive correlation between the number of formative assessments done and the number of learnersourcing activities students completed. This further suggests students might follow a completionist approach when working through the online materials and not skip the learnersourcing activity, which has been previously reported by (Singh et al., 2021).

In addition, student performance on both the formative and summative assessments was found to correlate with participation and the number of learnersourcing activities completed. These results indicated that the highest performing students were skipping the task. As mentioned, 7 of the 64 students achieved a perfect score on all the quizzes in their respective courses, yet among these seven students, only one participated in the learnersourcing activities, doing all four offered in their advanced chemistry course. This brings into question if the optional presentation of the learnersourcing activities could be potentially excluding the lower performing students that might benefit the most from these interventions, as well as the top performing ones. While we seek to ideally find a middle ground and engage the full range of learners in the current study, such activities may potentially exclude both the most and least in-need students. The MCQs generated from these top students might be closer to the level of instructor ones due to the advanced domain knowledge they possess (Mitros, 2015).

Our contributions should be interpreted against the following limitations. The three community college courses used in this study feature students from three different self-reported ethnicities. While this is representative of the institution-wide demographics, courses at other community colleges might yield a different student population. Additionally, we focused our analysis on data from three STEM courses. Extending this research to more courses from other domains, including non-STEM ones, might provide a more representative sample of students. However, since previous learnersourcing work neglects to provide demographic information, our current focus provides a first step at investigating how the different student populations of a course might be contributing to learnersourcing tasks. Additionally, we did not ask the students to report their native language, which might influence students' willingness to participate in the MCQ generation process.

Conclusion

In this work, we investigated the optional participation of students in the form of learnersourcing, where they generated multiple-choice questions relevant to the course content. Across three community college courses, our results showed that student demographics had no significant effects on their participation with the learnersourcing activities. However, we had moderate participation from a wide range of students on the task across all courses. Our analysis suggests that students' likelihood of participation with a learnersourcing activity is more dependent on their participation and performance with the other assessments found in the course, rather than on their demographic background. Additionally, we identified several features of student performance in the courses that influenced their participation with learnersourcing activities. These findings demonstrated that better performing students were likely to participate in learnersourcing, yet students at the lowest and highest end of the performance spectrum may still neglect such activities. This work contributed the first study which explicitly investigates the demographics of students participating in learnersourcing activities. It demonstrates that optional learnersourcing activities can still garner participation from a diverse set of students. Future learnersourcing efforts may incorporate participation and performance analytics to encourage students to contribute to learnersourcing tasks.

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Assessing Young Children's Computational Thinking Using Cognitive Diagnostic Modeling

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Abstract: This study illustrates how Cognitive Diagnostic Modeling (CDM) can be used to assess fine-grained levels of computational thinking (CT). We analyzed scored responses to the *Computational and Spatial Thinking assessment* (CaST) from 271 children. We identified four key attributes required to solve tasks: *sequencing of codes, fixing a program, spatial orientation of an agent, and rotation on a point*. Results indicated that younger children did not master all the attributes, particularly *spatial orientation of an agent* and *rotation on a point*. We identified four common mastery profiles of children that were associated with age. Our findings illustrate that mastering *spatial orientation* is critical to CT ability. Finally, the nuanced information about children's mastery levels has potential to provide teachers with useful information about what concepts and skills their students are struggling with so that they can adjust instruction to emphasize those concepts.

Introduction

Providing children opportunities to engage in computational thinking (CT) in early elementary school is becoming increasingly important. CT is "the thought processes involved in formulating a problem and expressing its solution" (Wing, 2014) and is often operationalized in the context of coding. Accordingly, there is a need for a better understanding of the instructional approaches, practices, and assessments that support children's development of CT in early elementary classrooms (Luo et al., 2022).

While instructional resources and assessments of CT for early elementary exist (e.g., Relkin et al., 2020), most assessments report a single total score of overall CT ability. Although these assessments are valuable, they provide an *audit* of CT learning as opposed to granular evidence of children's CT understanding that can be directly linked to classroom instruction. In order to better support the development of CT in elementary classrooms, we propose using cognitive diagnostic models (CDMs), an approach to assessment that provides fine-grained information about what skills or attributes a child has or has not yet mastered. In CDMs, multiple latent concepts and skills, referred to as attributes, are identified and linked to assessment tasks indicating which attributes are required to solve each individual task. The scored responses of the tasks are used to provide a categorical classification (i.e., mastery vs. non-mastery) of the attributes. For example, if a child correctly responds to all the tasks that are linked to the attribute *identify bugs in buggy programs*, we infer they have mastery of the attribute. But what if they only answer half of those items correctly? Or what if a task is associated with more than one attribute? Knowing which attributes students have and have not mastered allows teachers to adjust classroom instruction based on their students' needs. The purpose of this paper is to explore how we can use CDMs by conducting an analysis on existing assessment data from a study where 271 children between the ages of 4 and 8 participated in a performance assessment, *Computational and Spatial Thinking* (CaST) assessment, designed to assess CT. Given the large range in ages, we are interested in whether performance is related to age. Our analysis was guided by the following questions: (1) *How does the CDM fit the performance assessment data? (2a) What mastery profiles of CT do children exhibit? (2b) Are these profiles associated with children's age?*

Assessment of computational thinking for emerging readers

As part of a larger project, we operationalized CT for early elementary classrooms and developed curricular resources and an assessment (CaST) around coding toys and coding environments that involve programming with directional codes *forward, backwards, rotate right, and rotate left* (see Clarke-Midura et al., 2021). Figure 1a shows children working on curricular tasks (on the left) and 1b shows a child taking the assessment and the materials associated with it (on the right). The development of the assessment was connected to and dependent on the development of the CT model and curricular tasks. We engaged in iterative cycles of design-based-research (DBR) where we refined each element (CT model, curriculum, assessment) based on new information learned in the process. We identified algorithmic thinking (AT), decomposition (modularity), debugging, abstraction, and spatial thinking (ST) as developmentally appropriate components of CT. We also identified mathematical knowledge (MK) that was required to solve CT tasks such as rotation on a point, linear units, and counting on.

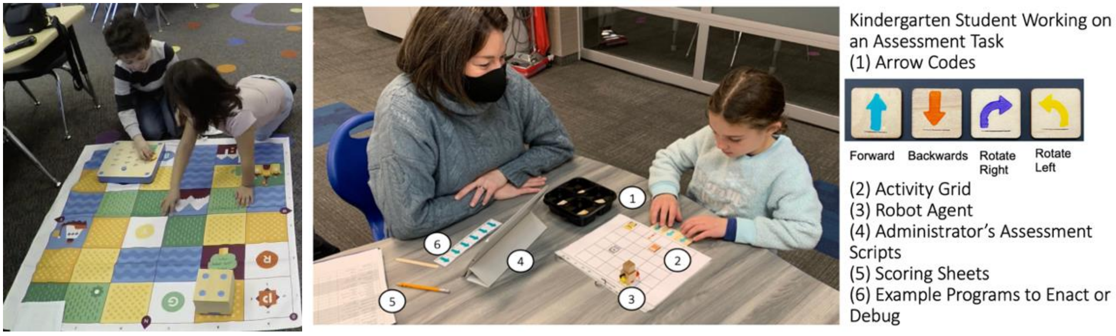
The Evidence Centered Design (ECD) framework (Mislevy & Haertel, 2006) guided the design of our CaST assessment tasks. The systematic process helped us articulate: the skills we wanted to assess, what inferences we wanted to support, what evidence we would need to support our inferences, the situations that would elicit the behaviors and observations of the skills and provide evidence, and how we would measure the skills. We used design patterns to document variable features of the tasks and the knowledge we thought each task was assessing. We specifically designed tasks to measure some of the skills we noted were necessary for CT tasks but were not part of most published CT models (e.g., rotation on a point and orientation of agent).

The CaST assessment is designed around a series of performance tasks (n = 19) that involve children either writing sequences of codes to navigate an agent from one location to another on a 6 × 6 2D grid, enacting programs by physically moving the agent on the grid, or debugging and fixing given programs using the four directional codes presented in Figure 1b (*forward, backward, rotate left, rotate right*). Given that the children we are assessing are emerging readers, the assessment is standardized and administered via a one-on-one format. The tasks are unplugged so the assessment can be used with a variety of coding toys and contexts that rely on navigational codes, which are common for pre-literate children. Some tasks have multiple correct answers, and all tasks were scored as incorrect or correct resulting in a total possible score of 19 points.

The assessment was validated in a prior study in which the items fit well to a two-parameter unidimensional Item Response Theory model (2PL IRT, see Na et al., 2023). The results of item analyses showed a high item discrimination (M = 2.26) and a moderate item difficulty (M = -.21), on average, with a high marginal reliability (r_{xx} = .87). IRT can estimate individuals' true ability score (θ) on a continuous scale, whereas CDMs classify examinees by whether or not they mastered each of the attributes that are required to successfully respond to the assessment tasks. Examinees are then classified into profiles based on the similarity of their responses. A benefit of CDM is that teachers can be provided with information on attribute mastery at both student and class levels.

Figure 1

On the Left, (a) Classroom Implementations and On the Right, (b) Assessment Administration



Methods

Sample, procedures, and data source

Our sample included 271 children (girls = 142; aged 4-8; M_{age} = 6.54) from five elementary schools in the Western United States. For the analysis, age was categorized into three groups: young (< 72 months; n = 83), middle (72 ≤ months < 84; n = 104), and old (≥ 84 months; n = 84). The assessment was administered in a one-to-one interview format, by trained researchers in a quiet area in the schools. The administration took an average of 16.4 minutes per child. All assessments were video recorded and later scored by two independent researchers. Each task was scored as correct or incorrect. The two raters had high agreement (κ = .91). Tasks where there was no agreement were reviewed by the research team.

Data analysis

Statistical analysis was a multi-step process. The first step was to map the assessment tasks to a task-by-attribute table, which is called a Q-matrix. Identifying attributes entails hypothesizing what skills are needed to answer each task. We then validated and refined the Q-matrix. Our next step was to fit the Q-Matrix to the data by using a CDM model. We fit and compared three CDMs – DINA, DINO, and G-DINA – all of which have been widely adopted in empirical studies using CDMs. As a non-compensatory model, DINA (Deterministic Input, Noisy "AND" gate model) assumes that to answer a given task, children must possess all required attributes. For example, in the case of task 18 which is linked to two attributes, *fixing a program* (A2) and *spatial orientation of* *an agent* (A3), the assumption under the DINA model is that a child must possess mastery of both attributes to successfully solve it. DINO (Deterministic Input, Noisy “OR” gate model) is a compensatory model, which assumes that if children have at least one attribute, they are likely to correctly respond to a task. In the case of task 18, if a child has mastered either *fixing a program* (A2) or *spatial orientation of an agent* (A3), they can correctly answer this task. Lastly, as a saturated model, G-DINA (Generalized Deterministic Inputs, Noisy “AND” gate model) assumes both compensatory and non-compensatory features within the test and therefore models the main effects of each attribute in conjunction with all possible interaction effects among attributes. Hence, in the example of task 18, children could have different levels of mastery probabilities depending on which attributes they have mastered or not. Both DINA and DINO are nested to G-DINA, which allows for log-likelihood test in model comparison. From the selected model, we conducted mastery profiles of each attribute, their classification accuracies, and identified mastery profiles to address our research questions. All statistical analyses were conducted in R (version 4.2.2) with *GDINA* package (Ma & de la Torre, 2020). Details of each step are described below.

Constructing, validating, and refining the q-matrix

To construct a Q-matrix, we reviewed the assessment tasks and existing test specifications. The ECD process we used to design the assessment required that we document details of the tasks, such as variable features and knowledge being assessed, that we were able to use and share for identifying the attributes. We identified four attributes that were required to solve the tasks: *sequencing codes, fixing a program, spatial orientation of an agent, and rotation on a point* (see Table 1) and then mapped them onto the items into a Q-matrix.

Table 1

Four Attributes of the CT Assessment Tasks

	Attribute	Concept	Description
A1	Sequencing codes	AT	Represents the skill of ordering and arranging codes based on knowledge of syntax and semantics
A2	Fixing a program	Debugging	Represents the skill of implementing a successful strategy to fix bugs
A3	Spatial orientation of an agent	ST	Represents the skill of knowing that the codes always produce the same movements but depend on the agent’s orientation
A4	Rotation on a point	MK	Represents the skill of knowing that a rotation occurs by rotating on a fixed point at a set angle, not translating to an adjacent point

Note. AT refers to algorithm thinking; ST refers to spatial thinking; MK refers to math knowledge.

Table 2

Refined Q-matrix for Four Attributes of CT and their PVAF values

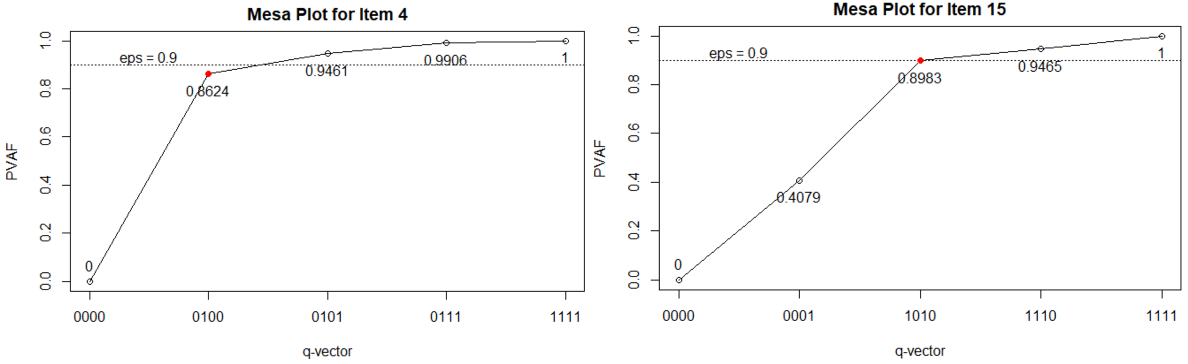
Item	Attributes				PVAF	Item	Attributes				PVAF
	A1	A2	A3	A4			A1	A2	A3	A4	
1	1	0	0	1	.941	10	0	1	0	1	.988
2	1	0	0	0	.949	11	0	1	0	1	.990
3	1	0	1	0	.994	12	0	1	1	1	.999
4	0	1	0	0	.862	13	0	1	1	1	.991
5	0	0	0	1	.966	14	1	0	1	0	.933
6	0	1	0	1	.999	15	1	0	1	0	.898
7	1	0	1	1	.984	16	1	0	1	0	.981
8	0	1	1	1	.994	17	1	0	1	0	.974
9	0	1	0	1	.997	18	0	1	1	0	.993

Note. “1” refers to required attributes to solve given items, whereas “0” indicates non-required in the attribute of each item. A1 refers to sequencing of codes, A2 refers to fixing a program, A3 refers to spatial orientation of an agent, and A4 refers to rotation on a point. PVAF refers to the proportion of variance accounted by q-vectors.

The Q-matrix was qualitatively validated by expert review of two raters (κ = .82). In order to validate the Q-matrix quantitatively, the proportion of variance of accounted (PVAF, de la Torre & Chiu, 2016) by each item-attribute specification (i.e., q-vector) was calculated and the acceptable PVAF values set to .90. We also used a mesa plot (see Figure 2), which visualized the relationship between possible q-vectors in the x-axis, and PVAF values in the y-axis to visually investigate possibilities to refine the Q-matrix. Fitting the initial Q-matrix to the assessment response data (19 tasks) did not yield acceptable model fits, so we eliminated one task and modified q-vectors of five tasks. After iterative modifications of the Q-matrix, we refitted the refined Q-matrix to the response data (18 tasks), resulting in acceptable model fits. While most tasks showed acceptable PVAF values, a mesa plot suggests that task 4 (PVAF = .862) and task 15 (PVAF = .898) need further modifications of q-vectors (see Figure 2). However, we did not modify q-vectors of these two tasks because these changes led to only minuscule increases in PVAF (less than .10 of changed PVAF) and were not aligned with what these tasks intended to measure from expert reviews. As a result, we used data from 18 of the 19 tasks with the refined Q-matrix (see Table 2) in which three tasks were assigned to one CT attribute, eleven tasks were assigned to two CT attributes, and four tasks were assigned to CT three attributes.

Figure 2

Mesa Plots of Unfitted Items (Item 4 and 15); Note. X-axis refers to item-attribute specifications (q-vectors) and Y-axis refers to PVAF refers to proportion of the variance accounted for the q-vectors. A filled dot in the mesa plot means the q-vector denoted in the Q-matrix, and black dots mean possible q-vectors in the Q-matrix. Eps (epsilon) refers to a designated threshold value of PVAF.



Selecting the appropriate CDMs

In order to select the most appropriate model, we evaluated the model fits of the three models (see Table 3). We specifically looked at the Akaike Information Criterion (AIC) and the likelihood ratio test (LRT). As shown in Table 3, G-DINA showed the lowest AIC and the LRT was significant when comparing the general model (G-DINA) to the reduced models DINA (LR: 205.11, *df* = 46, *p* <.001) and DINO (LR: 232.80, *df* = 46, *p* <.001). Thus, G-DINA was selected for the CDM model for subsequent analyses.

Table 3

Model Fit Indices for G-DINA, DINA and DINO

Model	AIC	*n*Pars	Loglik	Likelihood Ratio Test		
				LR	*df*	*p*-value
G-DINA	4635.68	97	-2220.84			
DINA	4748.79	51	-2323.40[a]	205.11	46	<.001
DINO	4674.47	51	-2337.24[b]	232.80	46	<.001

Note. AIC refers to Akaike information criterion; *n*Pars refers to number of model parameters; Loglik refers to log likelihood; LR refers to likelihood ratio; [a]G-DINA versus DINA; [b]G-DINA versus DINO.

To address RQ 1, using the G-DINA model, we estimated mastery probabilities and classification accuracies for each attribute. Using expected a posteriori (EAP, Huebner & Wang, 2011), children were classified as mastery of attributes (“1”) when their mastery probabilities of each CT attribute were above .50; otherwise, they were classified as non-mastery (“0”). For example, if a child has .373 for *sequencing of codes* (A1), .829 for *fixing a program* (A2), .992 for *spatial orientation of an agent* (A3), and .171 for *rotation on a point* (A4), their mastery status of each attribute is “0” for *sequencing of codes* (A1), “1” for *fixing a program* (A2), “1” for *spatial orientation of an agent* (A3), and “0” for *rotation on a point* (A4), resulting in a mastery profile of “0110”. Mastery proportions of each attribute – the ratio of the number of children who have mastered a given attribute to the total number of the sample - represent their relative difficulty, and their classification accuracies indicate the reliability of classifying children’s mastery status as either mastery or non-mastery.

To address RQ 2, we estimated individuals’ mastery profiles of the four CT attributes from the CDM results. For example, a mastery profile of 0100 refers to a set of children who have mastered *Fixing a program*

(A2) but have not yet mastered the other three CT attributes. We evaluated which mastery profiles were common or rare among our sample. We further conducted a chi-squared test of independence to examine the associations between identified mastery profiles and age groups. Results of this analysis are presented below.

Results

The viability of classifying children's mastery status of CT attributes

As we see in Table 4, approximately 48% of children mastered *sequencing of codes* (A1) and *fix a program* (A2), respectively. Fewer children mastered *spatial orientation of agent* (A3; 37.3%) and *rotation on a point* (A4; 40.6%). While mastery proportions of four attributes were higher for the older children (see Figure 3), we note that mastery proportions of *spatial orientation of an agent* (A3) were substantially lower (59.5%) than the other three attributes in older children. Likewise, in middle age children, *spatial orientation of an agent* (A3, 27.9%) and *rotation on a point* (A4, 26.0%) showed lower mastery proportions than the other two attributes. The estimated classification accuracies at the attribute level were high; they ranged from .90 to 97 and were .85 at the test-level. These values the G-DINA model reliably classifies children into attribute mastery. Figure 3 presents the mastery proportions of each attribute within the total sample and by each age group.

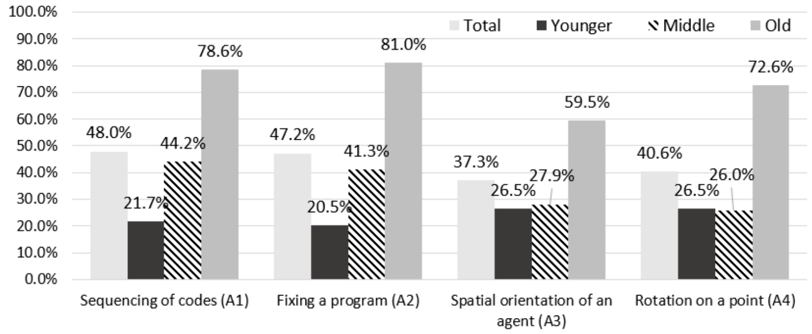
Table 4

The Proportion of Mastery of Four CT Attributes and their Classification Accuracies

	A1. Sequencing of codes	A2. Fix a program	A3. Spatial orientation of an agent	A4. Rotation on a point
Mastery proportion (%)	48.0%	47.2%	37.3%	40.6%
Classification accuracy	.96	.96	.90	.97

Figure 3

Mastery Proportions of Each Attribute in the Total Sample and Age Groups

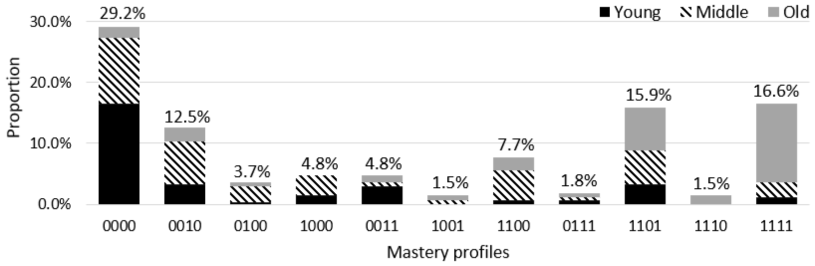


Detecting CT mastery profiles and the profiles association with children's age

CDM results yielded 11 mastery profiles out of a possible 16. Figure 4 shows the distribution of the profiles by age group where 0000 means that none of the four attributes were mastered and 1111 means that all of the four attributes were mastered. A chi-squared test of independence confirmed that the mastery profiles are statistically associated with the age groups, $\chi^2(20) = 123.83$, $n = 271$, $p < .001$, Cramer's V = .478.

Figure 4

Identified 11 Mastery Profiles of CT Components by Age Groups



We focus on the four most common profiles (those with proportions > 10%):

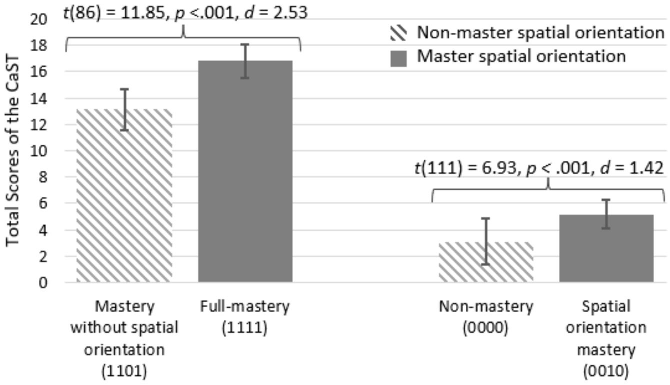
- *Non-mastery profile* (0000, *n* = 79). This profile represents children who have not mastered any of the CT attributes. It is the most common profile (29.2% of children). It is comprised of mostly young (*n* = 45) and middle (*n* = 29) children, compared to a small number of the older children (*n* = 5). This profile had the lowest total scores on CaST assessment among all 11 mastery profiles, *M* = 3.09, *SD* = 1.53.
- *Full-mastery profile* (1111, *n* = 45). This represents children who have mastered all four CT attributes. It is the second most common profile (16.6%). The group is comprised primarily of older children (*n* = 35) and some middle (*n* = 7) and younger (*n* = 3) children. This profile scored the highest CaST total score, *M* = 16.80, *SD* = 1.10.
- *Mastery without spatial orientation profile* (1101, *n* = 43). This profile represents children who mastered all of the CT attributes except *spatial orientation of an agent* (A3). It includes 15.8% of the sample and was comprised mostly of older children (*n* = 19) and middle children (*n* = 15) compared to younger children (*n* = 9). This profile had relatively high total scores on CaST assessment, *M* = 13.14, *SD* = 1.74.
- *Spatial orientation mastery profile* (0010, *n* = 34). This group only mastered *spatial orientation of an agent* (A3). It includes 12.5% of the sample. This profile was comprised of middle (*n* = 19), young (*n* = 9) and older (*n* = 6) children. This profile had relatively low total scores on CaST assessment, *M* = 5.18, *SD* = 1.29.

Importance of spatial orientation of an agent

Based on the attribute mastery results, we decided to conduct an ancillary analysis to explore the role of *mastering spatial orientation of an agent* (A3) on overall CT abilities. Using the total assessment score as a proxy of overall CT abilities, we conducted independent *t*-tests between the *full-mastery* profile (1111) and *mastery without spatial orientation* profile (1101); and between the *non-mastery* profile (0000) and s*patial orientation mastery* profile (0010) to check the role of spatial orientation in the overall CT ability. The result of the independent *t*-tests showed that the *full-mastery* profile (*M* = 16.80; *SD* = 1.10) significantly outperformed the *mastery without spatial orientation* profile (*M* = 13.14, *SD* = 1.74) on the CaST assessment, based on the CaST total score, *t*(86) = 11.85, *p* <.001, *d* = 2.53 (see Figure 5). The *spatial orientation mastery* profile (*M* = 5.18, *SD* = 1.29) had significantly higher CaST total scores than the *non-mastery* profile (*M* = 3.09, *SD* = 1.53), *t*(111) = 6.93, *p* < .001, *d* = 1.42 (see Figure 5). The results suggest that mastering *spatial orientation on an agent* (A3) played a significant role in children's overall CT abilities.

Figure 5

Mean Differences in the CaST Total Scores by whether Children Mastered Spatial Orientation



Discussion

This study explored the viability of using CDMs to diagnose mastery levels of children's CT abilities on a finer grain size by looking at four attributes: *sequencing of codes, fixing a program, spatial orientation of the agent, and rotation on a point*. We were able to fit a CDM model, G-DINA, to the CaST assessment response data and yielded information about the mastery proportions of the four attributes as well as profiles of attribute mastery in the sample, by participant's age. We conducted an additional analysis based on our results to explore the role of spatial orientation on overall CT ability using the CaST assessment total score as a proxy.

We hypothesized that knowledge of sequencing of codes, fixing a program, spatial orientation of the agent, and rotation on a point were required for children to answer the tasks on the CT assessment. Looking at just the mastery of attributes, our results indicate that higher proportions of older children mastered the four CT attributes and that the proportion of older children who mastered spatial orientation of an agent was lower than for the other three CT attributes (Figure 3). Overall, much smaller proportions of middle and younger children mastered all four attributes. Smaller proportions of middle children mastered spatial orientation of an agent and rotation on point. Yet for the younger children greater proportions showed mastery of spatial orientation of the agent and rotation on a point than the sequencing of codes and fixing a program attribute. Overall, the older children had higher proportions of mastery in the CT-related concepts than the spatial and mathematical concepts whereas the younger children had higher proportions of mastery in the spatial and mathematical related concepts. These findings align with the results of RQ 2a that show the most common mastery profile was the *Non-mastery profile*. The mastery profiles show how children's responses and attribute mastery cluster into patterns. Focusing on the four most common mastery profiles, we see that the old and middle age children were likely to be assigned to the *full-mastery* and *mastery without spatial orientation profile*, whereas the young age group were more likely to be assigned to the *non-mastery* profile. Put differently, the young children in our sample (< 72 months) have not yet mastered most of the attributes of CT, while some of the children in the middle and older age groups (≥ 72 months) either mastered all the CT attributes or needed only more experiences with spatial orientation of the agent. These findings align with Relkin et al. (2020) who in a sample of a similar age range of children found that older children performed better on measures of CT. These findings suggest that children's understanding and proficiency in CT may be associated with their age, which supports the need not only for developmentally appropriate curriculum, resources, and assessments for fostering and measuring CT in early childhood but a need to provide younger children with opportunities to engage with CT through playing with coding toys.

Perhaps the most interesting mastery profile is the *spatial orientation mastery profile* (0010, $n = 34$). This group only mastered one attribute: *spatial orientation of an agent* (A3). While it only included 12.5% of the sample, it was mostly comprised of middle age children ($n = 19$), with some young ($n = 9$) and older ($n = 6$) children. This profile had relatively low total scores on the CaST assessment ($M = 5.18$, $SD = 1.29$). We conducted additional analyses to explore the role of the spatial orientation of an agent attribute on CT knowledge, using the total CT assessment score as a proxy. The results suggest that mastering *spatial orientation on an agent* (A3) played a significant role in the overall CT abilities, as measured by the overall score on the CT assessment. Spatial thinking (ST) entails understandings of space and objects' positions in space, reasoning with objects or representations in space, and operations on spatial relationships (NRC, 2006). A component of ST, spatial orientation is the understanding of different positions in space, and children first develop spatial orientation concepts in relation to their own position in space and later develop external-based reference systems using landmarks outside themselves (Sarama & Clements, 2009). Researchers have identified a number of factors constituting spatial thinking skills; however, there is no consensus in its exact structure or consistency in measurement (Atit et al., 2020). Existing research on the relationship between CT and ST has looked at children's relation of CT skills with non-verbal visuospatial reasoning (Tsavara et al., 2022), mental rotation skills (Città et al., 2019), and spatial ability (Román-González et al., 2017) and found significant correlations between concepts of ST and CT in early childhood. Our findings further support the importance of the relationship of ST and CT and the need to better understand this relationship in early childhood.

The older and middle age group of children in our sample had higher mastery probabilities of sequencing codes and debugging programs, than spatial orientation of the agent (see Figure 3). It could be that the kinds of exposure to CT that the older children have through coding provide more experience with practices like sequencing and debugging and less with spatial orientation of agents. In the US, kindergarten standards mostly focus on applying spatial knowledge as relational from their own perspective and not from different perspectives, which means children do not get a lot of exposure to this in kindergarten. Previous research on young children playing with tangible coding toys observed children shifting back and forth between egocentric and allocentric perspectives, or reference frames, while programming robots to navigate paths on the floor. Children's inability to take on an allocentric perspective, the robot's perspective when the robot was facing a different orientation often resulted in coding errors such as selecting the wrong code (Clarke-Midura et al., 2021; Wang et al., 2021). Our findings support these findings and suggest the importance of playing with tangible coding toys at a young age to aid in the development of both ST and CT skills. Finally, research has shown that ST is a critical component of STEM learning and practices and is domain dependent (Atit et al., 2020). While ST skills are malleable and can be improved through training and instruction (Uttal et al., 2013), instead of fostering ST independently, it is more critical to situate ST into overall CT learning activities. As mentioned above, more research is needed that explores the relationship of ST and CT skills in early childhood.

Limitations and conclusion

Despite the multi-faceted nature of CT, we only selected four CT attributes due to our limited sample size. There is a need for future studies that include larger samples and more attributes, especially those related to ST and MK.

Nevertheless, identifying which CT attributes children have not mastered as well as what attributes are foundational to CT learning is an important step toward designing and implementing tailored learning experiences, and minimizing potential gaps in CT and STEM learning from an early age. Furthermore, there is a need for developmentally appropriate curricular resources and assessments of CT for early childhood. CDMs offer a potential way to provide teachers with informative information about their students' CT understanding that they can directly link to their instruction. As a field, learning scientists tend to talk about the design of assessments and learning environments separately. The present study shows the affordance of thinking about instruction, assessment, and theories of learning as an integrated system.

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Integrating Global and Science Education Perspectives on Epistemological Plurality

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Abstract: Recent conversations in learning sciences have pressed the field to attend more explicitly to multiple ways of knowing, or epistemological plurality, as a means for disrupting Northern/Western onto-epistemic supremacy (e.g., Warren et al. 2020). Similar conversations have been taking place in global education with a priority placed on elevating knowledge and ways of knowing from the Global South (de Sousa Santos, 2018). This paper works to integrate these perspectives by asking: How can critical perspectives found in global education literature inform research on student epistemological plurality during science classroom discourse? This paper integrates perspectives from global and science education to present to the field of learning sciences a new approach to considering epistemological plurality in science discourse.

Introduction

Global environmental issues like climate change currently do and are projected to continue to disproportionately impact the Global South (IPCC, 2022). Despite this, current efforts to identify and mitigate the impacts of climate change in science continue to prioritize an imposed perception that "the Eurocentric epistemological North" is "the only valid source of knowledge, no matter where, in geographic terms, that knowledge is produced" (de Sousa Santos, 2018, p. 6, see also Harding, 2008). This system of knowledge creation establishes a false separation between science and society in which scientists hold a "monopoly of authority on nature itself" (Harding, 2008, p. 56).

Meanwhile, the instantaneous movement of information and imagery in the current era has fundamentally altered our constructions of reality as the outer world of media becomes a central aspect of the "inner world of society" (Beck, 1999, p.1). In this vein, the very stuff that makes up knowledge, the basic building blocks of our cognition are also associated with and influenced by globalizations. Or as Hammer et al. (2004) might suggest, depending on the framing of a particular activity, we may now reliably activate various sets of conceptual and epistemological resources that are tied to systems of globalization and their inescapable presence. This recent shift requires us to rethink what types of knowledge we anticipate students will bring to classrooms and figure out new ways to leverage them for student sensemaking. Foundational to this shift is the importance of acknowledging and incorporating multiple ways of knowing in science classroom discourse.

The presence of the sociology of globalization as a mediating factor in student thinking presents us with an opportunity for re-imagining disciplinary practices as emergent from a vast wealth of values, cultures, and identities which have long been erased from scientific discourse (Pierson, 2022; Warren et al, 2020). Here, I explore student discourse about global environmental issues from the perspective of epistemological plurality (Andreotti, 2007; Bang & Medin, 2010; Warren et al., 2020). I have found through an examination of both global education and science education literature, that there are parallel movements taking place within both bodies of scholarship that seek to disrupt Northern/Western onto-epistemic supremacy to pursue a vision of cognitive justice as an essential part of social justice (Andreotti et al., 2011). This paper integrates perspectives from global and science education to present to the field of learning sciences a new approach to considering epistemological plurality in science discourse.

I analyzed student thinking using a multimodule interaction analysis (Erickson, 2010) to present an illustrative example of epistemological plurality during student discourse. The example presented here is taken from a larger study focused on operationalizing a framework for identifying evidence of global thinking in science classroom discourse using multimodule interaction analysis (Short, 2023).

Conceptual background

Recent research in science education has highlighted the importance of epistemological plurality in science learning as a critical step towards desettling disciplinary knowledge and practices from "colonial matrices of power" (Warren et al., p. 278). This perspective places substantial value on students' ways of knowing and making sense of the world as valid and productive cognitive processes inextricably linked to culture and identity (Pierson et al, 2022; Warren et al. 2020). Reorienting science education for multiple ways of knowing is essential for multiple reasons. First, by recognizing the socially and culturally embedded nature of knowledge construction, deconstructing epistemic hierarchies becomes a pathway for unsettling myths of science that are deeply embedded in racism, sexism, and colonialism (Harding, 2008; Medin & Bang, 2014). Second, orienting science education for epistemological plurality is essential to expanding the possibilities of human knowledge (de Sousa Santos, 2018; Warren et al., 2001).

As de Sousa Santos (2007) explained, the modernist tendency to prioritize Eurocentric ways of knowing serves to, "divide social reality into two realms, the realm of 'this side of the line' and the realm of 'the other side of the line.'" Knowledge and process for producing knowledge on the wrong side of this 'abyssal line' is "radically excluded because it lies beyond the realm of what the accepted conception of inclusion considers to be its other. What most fundamentally characterizes abyssal thinking is thus the impossibility of the copresence of the two sides of the line (de Sousa Santos, 2007, p. 47). Here, de Sousa Santos (2007) argued that scientific canon serves not only to establish whose knowledge counts, but also to establish that anything outside of those boundaries is outside the confines of reality. In doing so, Andreotti et al. (2011) argued, a vast wealth of lived experiences are wasted, as they are excluded from mainstream human endeavors to understand the universe.

In short, epistemological plurality is an indicator of a socially just approach addressing global problems (Misiaszek, 2015). Incorporating epistemological plurality in academic settings is a critical step towards transforming society away from oppressive hegemonic approaches to knowledge and progress that have led to the manufacture of the ecological calamities we find ourselves confronted with (Andreiotti, 2011, 2021; de Sousa Santos, 2018; Misiaszek, 2015).

Co-presence

Epistemological plurality in science education does not represent the end of canonical knowledge and ways of knowing; rather, it calls for the copresence of canonical and noncanonical knowledge and ways of knowing (Andreotti, 2007; de Sousa Santos, 2007, 2018). According to Andreotti et al. (2011), epistemological plurality includes "equipping students to respond and adapt to a sacred realm (of both visible and invisible realities) that is both elusive and tangible and where multiplicity and uncertainty are natural givens" (p. 47).

In learning sciences, Pierson et al. (2022) recently outlined heterogeneity in science curriculum as a pathway for centering classroom epistemic aims on students' epistemic values. At the heart of such an approach was a commitment to science that was generative but often unresolved and steeped in multiplicity (Pierson et al., 2022). A similar perspective was elucidated by Bang and Medin's (2010) accounting of how students' perspectives of sources for science knowledge included indigenous knowledge. One specific example was a sorting task in which "urban Indian middle-school children" were given "a series of 16 pictures (i.e., animals, plants, water, sun, rocks, artifacts) and asked" to consider if each would be considered alive from the perspective of a science teacher or an elder (Bang & Medin, 2010, p. 1017). In this example, students explained that an elder would say that rocks and water are alive, while a science teacher would say they are not alive. This example illustrates well the generative nature of multiplicity as an epistemic aim. Students in this example parsed the difference between canonical science knowledge (what their science teacher would answer) and noncanonical knowledge (what their elder would answer; Bang & Medin, 2010). From a pluralistic epistemological perspective, both pieces of knowledge can be true at the same time.

Similar calls for multiplicity can be found in global education research. Andreotti et al. (2011) described epistemological plurality as a copresence with Western/Northern ways of knowing, which she refers to as "unequivocal/universal knowing", and nondominant ways of knowing as "equivocal/relational knowing (p. 45). The first is characterized by a "win–lose debate of opposing ideas based on criteria of legitimacy and validity grounded on predefined parameters of empirical evidence" in which analysis reflects "neutrality, universality and objectivity" and intellectual freedom is based on the idea of "autonomous thought related to universal reason and the Cartesian subject" while the latter is characterized by uncertainty, complexity, diversity and includes space for a consideration of "visible and invisible realities" (Andreotti, 2011, p. 46).

Student resources

This work takes an ontological approach to research on epistemology that focuses on epistemological resources individuals draw on during moment-to-moment sensemaking (Russ & Luna, 2013). This resources-based perspective of student epistemology treats students' conceptualizations as dynamic and manifold (being composed of several pieces of information). From this perspective, what students "know" is dynamic and context dependent, composed of a range of cognitive resources activated during an event, interaction, or activity as the student perceives those resources to be relevant within their expectations of an interaction or activity (Hammer et al., 2004).

Interactions with students during this study sought to activate a nearly limitless range of epistemological resources by prioritizing the epistemic values students brought to the discussion. Andreotti et al. (2011) describes how instructors in higher education might go about creating discourse norms of this sort within academia. She calls for the "valorization and legitimation of suppressed or silenced knowledges" and argues that this includes supporting "student's capacity to re-situate themselves in different knowledge systems (including the experience of language/stories as metaphor), as well as re-situating themselves in their bodies, emotions and spirits" (Andreotti et al., 2011, p. 46). Thus, interactions were framed (Hammer et al., 2004) for epistemological plurality through flexible discourse to encourage contributions from students that incorporate the metaphorical, the use of story as knowledge, and the acknowledgement of affect and spirituality all as valid and productive intellectual resources (Andreotti et al., 2011).

Research context, data, and analysis

Data collection took place within an interdisciplinary and international project focused on urban sustainability in the Arctic. During the project participants from Anchorage developed 60-second digital environmental stories about an environmental problem that was important to them. Interview data selected for analysis in this study are from a single site located in Anchorage, Alaska. The participating classroom was a small private school in Anchorage. The school has a long history of student-centered teaching and learning. Participants were fourth, fifth, sixth, seventh, and eighth graders, many of whom participated in the project for 3 consecutive years, during which time data was collected. An important note is that while several students participated in the project for multiple years, not all of the students completed all three prompts all 3 years. Additionally, while several students participated in the project multiple times, quite a few completed videos only once. Semi-structured video-elicitation interviews were framed around the digital stories created by students. Video elicitation interviews took place in groups of three to four students and lasted approximately 45 minutes each. During the interviews, the students watched videos created by their classmates as well as students of a similar age from a major metropolitan area in the Southeastern United States. Interviews were video recorded using the same laptop on which students watched digital stories.

Data analysis

Data transcription processes reflect Erickson's (1992) *microanalysis*. First, video and audio recordings were listened to thoroughly. Illustrative events were identified and tagged based on the framework for epistemological plurality described here. During that process I was cognizant that limiting the data transcribed limited my ability to recognize important patterns present within the complex interrelations that make up the social ecology of students' experiences (Ratcliff, 2003). To mitigate this limitation, the corpus of data was revisited iteratively. Next, continuing to use the process described in Erickson (2004), I watched each video in its entirety again, this time stopping and replaying at the boundaries that were noted earlier. During this viewing I also looked for sustained topical conversation from or between individuals, as well as sustained posture or listening behavior. Again, timestamp data was recorded to denote the start or end of an episode of talk.

The episode presented here was selected out of the corpus of 34 events that were initially tagged as salient for illustrating evidence from a broader global thinking framework. I followed a process described by Erickson (2004). I began by reviewing the corpus of video data at regular speed without stopping. As I watched, I took notes, similar to field notes, when I noticed student utterances or segments of the interview that were consistent with the codes for global thinking as well as verbal and nonverbal cues to indicate the end of a topic of conversation. Most often these cues included a long pause, looking around, or adjusting their seated positions to indicate a transition in the activity. I watched each video in its entirety again, this time stopping and replaying at the boundaries that were noted earlier. During this viewing I also looked for sustained topical conversation from or between individuals, as well as sustained posture or listening behavior. Again, timestamp data was recorded to denote the start or end of an episode of talk. During this second pass, I began to establish specific episodes of student talk. Episodes often included several events, or moments in which student talk was consistent with my codes. Episodes were established when there was a topical shift in the conversation, or students' nonverbal behavior indicated a shift based on their posture, gaze, or proximity to peers (Erickson, 2004).

Transcriptions included all student dialogue, word for word, including annotations for pauses and phrase stops, laughing, and other verbal behavior not defined as "talk." Nonverbal transcription was created with the use of screenshots from the video along with accompanying notes to clarify exactly which words accompanied which gestures. Also, in that column were notes about voice quality (tone, prosody, and pace), consistent with Norris (2016).

As Ochs (1979) pointed out, segments of video or audio data selected reflects "the particular interests, the hypothesis, examined of the researcher" (p. 44). To be clear, this does not mean that non-salient events were not treated as important for shedding light on the types of talk moves that were effective in framing for global thinking; this is discussed in more depth in the next section. This data, including student videos, classroom observations, and teacher interviews, offered important clues to indicate underlying cognitive processes at play for individual students during the interviews, in ways similar to Russ et al. (2012). I relied on interactive analysis

(Jordan & Henderson, 1995) to systematically identify evidence of epistemological plurality. Student interactions were analyzed with attention to multiple modes of communication. The approach taken here is similar to Norris (2004), in which I rely on annotated video stills to attend to nonverbal modes and the ways they appear to contribute to students' perceptions about the nature of the interview, what was expected of them, and dynamic construction of the purpose of each conversation as it progressed.

I relied on gesture to shed light on ideas and utterances shared by students that were supported and sometimes completed through gesture (Johnson, 2017). Verbal aspects of communication beyond words were also examined as I analyzed each of the interviews. This includes attention to pauses, self-interruptions, and restarts and the ways interlocutors respond to them in interaction (Erickson, 1992; Goodwin, 2018).

Epistemological plurality

Throughout the analysis, I used the coding scheme developed through my larger conceptual framework which included indicators for epistemological plurality as it is presented here. Codes were applied line by line to indicate how they are tagged in relation to each individual speaker, which is consistent with a resources-based ontological perspective which asserts that students experience activities in individually subjective ways. This provides a more robust view of the myriad ways individual students drew on their lived experiences and existing epistemological resources when discussing global environmental issues. The description for the epistemological plurality code is included in Table 1.

Table 1

Description of Code for Epistemological Plurality

Code	Description	Salient Examples
Epistemological plurality (EP)	Students draw on canonical and noncanonical knowledge while working to understand global environmental issues. Examples of types of knowledge include religious beliefs, held values, and intuitive knowledge as well as school-based science content. Ways of knowing include community-based ways of knowing, traditional ways of knowing, ethical and moral frameworks, as well as more conventional claim/evidence-based reasoning reflective of canonical habits of mind.	Um // Well / there are / uh / the / uh / the leaves with the photosynthesis / right // And um / I don't know / I just think that / um / if we planted more trees // well and there's also a a difference / like here we have / we don't have / like smog / or anything like that / um / and / and we have more trees / […] I think a place is more healthy when it has more.

Illustrative episode: Respect our elder species

Epistemological plurality is not contingent on students drawing on an epistemological resource other than those associated with canonical science. Rather, I use it here in ways consistent with Andreotti (2011) and de Sousa Santos (2007) in which epistemological plurality is defined as the copresence of canonical and noncanonical knowledge and ways of knowing while seeking to develop understanding. This pluralistic approach to epistemology is reflective of what Misiaszek (2015) described as knowledge approaches from below, or which de Sousa Santos (2007) referred to as post-abyssal thinking, in which boundaries around what constitutes valid forms of reasoning are moved to include a broader range of lived experiences. Importantly, as Beck (1999) and Harding (2008) pointed out, modernist Western/Northern approaches to epistemology, or epistemology from above, are globally pervasive to such a degree that they often saturate the cognitive realm. As Andreotti et al. (2011) pointed out, they are always present in academic settings. Therefore, evidence of nondominant forms of epistemology that are treated as equally valid to dominant Western/Northern approaches indicate the copresence of canonical and noncanonical knowledge and ways of knowing.

Epistemological plurality includes the use of everyday intuitive knowledge, indigenous knowledge, spiritual knowledge, and ethical/moral beliefs, as well as intellectual resources typically associated with more Western/Northern science perspectives and knowledge. It may also include community-based ways of knowing, home-based ways of knowing, and ways of knowing that are drawn from the spiritual realm alongside Western/Northern approaches to constructing knowledge. The following excerpt offers a salient example of how students may establish a copresence of canonical and noncanonical knowledge and ways of knowing by incorporating nondominant forms in discourse while making sense of a particular issue. In the transcript excerpt Ashley has been asked about a video she created that focused on keeping moose safe from automobiles. In response, Ashley explains in Lines 1–3 that all of the videos she has created focus on protecting animals: "I actually think that the last / like / three videos I've done are / have been about animals / um / animal awareness //."

1	Ashley	I actually think that the last / like / three	
2		videos I've done are / have been about	
3		animals / um / animal awareness //	
4		and I think the main reasons is / um / we	
5		as humans / um / our tendency is that we	
6		respect someone who's older than we	*EP*
7		are // And when you look at our species /	*EP*
8		our species is very young compared to	*EP*
9		some other species // turtles and other	*EP*
10		animals / um / even chimpanzees they	*EP*
11		come before us so / like we respect people	*EP*
12		who are older than us and our elders / we	*EP*
13		should respect species that are older than	*EP*
14		us / and help keep them alive //	*EP*

As Ashley continues, she draws on her everyday knowledge, adding a value-laden statement that people tend to respect their elders. In Lines 4–7 Ashley says, "We as humans / um / our tendency is that we respect someone who's older than we are //." Next, Ashley continues to make the case for respecting nonhumans in the same way we do our elders, by drawing on more traditional science content knowledge. Specifically, she uses knowledge about evolution and she begins listing animals that evolved prior to humans. In Lines 7–11, Ashley says, "when you look at our species / our species is very young compared to some other species // turtles and other animals / um / even chimpanzees they come before us." Thus, Ashley is integrating her everyday knowledge about how she has been taught to treat her elders with school science knowledge about when different species evolved on Earth. Furthermore, Ashley's description of nonhumans as "elders" is reminiscent of findings from Bang and Medin (2009) in which participants treat nonhumans as relatives with something to teach humans. Similarly, respecting elder species suggests that having existed longer, the animals at the center of Ashley's video have a greater sense of living on planet Earth that should be treated as intrinsically of value.

15	Interviewer	So when you say respect can you / you	
16		mean / can you say more about that //	
17		What do you mean by respect // like	
18	Ashley	Well / um / if we're respecting our animals	EP

19	making sure it’s not us who kills them // it’s	EP
20	not our fault // because just doing what	EP
21	they’re doing / like moose right now	EP
22	they’re not trying to kill the world / not	EP
23	trying to end the world // They’re not going	EP
24	end another species / but um / humans /	EP
25	we’ve already killed so many species //	EP

In Lines 15–17, the interviewer presses Ashley to expand on the term “respect.” I asked, “So when you say respect can you…you mean? can you say more about that? What do you mean by respect?” Ashley’s response to this question appears to draw on yet another set of epistemological resources. Specifically, she appears to draw on her personal sense of ethics and moralism Lines 20–24 when she says, “because just doing what they’re doing, like moose right now, they’re not trying to kill the world, not trying to end the world, they’re not going to end another species.” In essence, Ashley appears to be making the case that because moose are not a threat to the existence of humans, that we are obligated to avoid harming them. This point is further supported in Lines 24–25, when she follows up with “but, um, humans, we’ve already killed so many species .” Here Ashley is comparing human impacts, and specifically human-caused extinction, to the potential threat nonhumans have to humans. She considers those impacts to be unbalanced, in which humans “kill so many species,” as opposed to moose who are “not trying to kill the world.”

Similar accounts of students attempting to balance the needs of humans and the needs of nonhumans fairly are found in Koprina (2019), in which students were assigned a specific position for a classroom debate. The position included placing the needs of humans on equal standing as those with nonhumans as a means to think beyond androcentrism. While the essays discussed in Koprina (2019) are taken from university students, the underlining sentiment is similar. Like Ashley above, Marina compared and contrasted human and nonhuman destructiveness in making the case for eccentric approaches to development. The student wrote: “After all, we should not forget that we are the most destructive species in terms of our unsustainable practices and lifestyle” (Koprina, 2019, p. 13).

This event is salient for illustrating epistemological plurality because Ashley is intermingling canonical and noncanonical knowledge and ways of knowing that she perceives to be relevant to the issue that is being discussed. She does this while situated in school, an environment in which the abyssal line described by de Sousa Santos (2007) is firmly in place to prioritize canonical knowledge and ways of knowing while treating alternatives as nonexistent. But Ashley uses knowledge and reasoning that moves beyond those limitations, thus *establishing a copresence* of canonical and noncanonical knowledge and ways of knowing through discourse.

In other episodes, epistemological plurality often took the form of integrating information obtained through media, or in conversations with parents, and students’ sense of care and empathy for nonhumans. In one segment, for example, another student, Allison, explained that she chose to film her digital environmental video about the palm oil industry to raise awareness about habitat destruction and its impact on orangutangs. Allison begins by describing the reasoning behind her choice to focus on palm oil as the subject of her video. She says she wants people to “know what they are doing” when they buy products with palm oil in them. Up until then, her tone had remained flat, until it shifted with the phrase “what they’re doing.” When she is asked a follow-up question, “what *are* they doing?” Allison says ,“they’re KILLING another species,” her pitch increases through the entire phrase, peaking on the word “killing” until dropping again to the flat tone she began with when she says “sorry, um, I don’t know, I just think it’s sad”.

Implications

In considering important implications for research and practice, this paper offers several. First, the framework from which the epistemological codes used in this paper were drawn needs to be shared and evaluated by people from a diverse range of cultures and backgrounds to reveal areas I was not able to anticipate from my own sociocultural perspective. Likewise, additional studies using the coding system are needed to determine the ease with which the codes may be transferable to other researchers. Therefore, it is my hope is that this work will be taken up by others who have different backgrounds, are of different generations or races/ethnicities, and speak languages other than English. For this work to reflect a truly globally situated perspective on epistemological plurality, it needs to be built on by people from across the globe to address ethno-political considerations that I may not be able to anticipate (Raveendran, 2018).

There have been times when students have contributed conceptual resources that I was unable to recognize as epistemology. For example, Connor, one of the students from Anchorage, created a video that was, essentially, filming his backyard. He aimed the camera at the trees and asked viewers to listen. When I first watched the video, I was confused. What I was watching did not immediately register as knowledge sharing. It was later, after reading Bang and Marin (2015) in which they discussed Indigenous ways of knowing, that I began to acknowledge that Connor's video was sharing epistemological resources that were reflective of his Alaska Native upbringing. Connor did not need to tell me about the trees and the wind. The trees and the wind could speak for themselves. I needed to learn to hear their language (Bang & Marin, 2015). Sharing this work with people from other cultures may reveal other areas I am not able to anticipate. This is a critical next step for this work if it is to be taken up and used in learning sciences.

Concluding thoughts

Throughout this paper I have suggested and subsequently shown that it is possible for researchers and educators to explicitly attend to the epistemological plurality during science teaching and learning. To do so, I argue, creates opportunities to activate epistemological resources students possess but may otherwise overlook based on perceived expectations during instruction. More firmly conceptualizing epistemological plurality within learning sciences as productive to science learning serves a broader goal to reimagine epistemological disciplinary activities as dynamic, emergent, and intrinsically linked to culture and values (Warren et al., 2020).).

Currently, attending to epistemological plurality is a challenge to science classroom teachers, especially within the era of the *Next Generation Science Standards* (NGSS), which places significant value on teaching disciplinary practices (NGSS Lead States, 2013) and the development of canon consistent knowledge products (Pierson et al., 2022). There is a potential disharmony between this work and the pressure science classroom teachers face to meet educational standards like the NGSS. To have any chance of success, widespread attention to epistemological plurality in classrooms requires co-presence (Andreotti et al., 2011). Co-presence requires us to make space for the epistemic aims of participants at all levels. For many teachers this includes epistemic aims imposed from above by powerful external forces, such as federal, state, and local policies including educational standards. For students it may be a range of epistemic aims from external forces as well as those from below, which are grounded more locally and tied to students' everyday experiences both in and out of school. These may include diverse linguistic resources, and community and cultural values students carry with them as they navigate the complex web of expectations that characterize students' experiences in school. The potential copresence offers the field is one in which epistemic aims from above in science education become entangled with those from below to bridge the abyssal line between Western/Northern onto-epistemic supremacy and the vast wealth of knowledge that falls beyond (de Sousa Santos, 2007).

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Being a Good Student: Risks and Reactive Coping Strategies Encountered in a Summer STEM Makerspace for Black Youth

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Abstract: There has been a large push over the last decade to drive STEM interest during the formative years of adolescence through computer science related initiatives such as computational makerspaces that allow students to design and build personally connected artifacts. However, these programs are not often designed to be culturally relevant to the students they aim to motivate. This paper presents a case study of one student who participated in the first iteration of a summer makerspace camp for Black youth ages 12-16. The design principles guiding this STEM camp adapted pedagogies for computational making for belonging and becoming (Escude et al., 2020) with a goal of fostering culturally relevant STEM identity development. Using the phenomenological variant of ecological systems theory (PVEST; Wigfield et al., 2007) as a theoretical and analytical lens, we present three phenomenological episodes representing an overview of the student's arc from Days 1-8 of the 12- day camp. Over time we see the student extend the boundaries and objects of their coping strategies, moving from just utilizing the resources in front of him to thinking more flexibly about where help can be found. We argue that this student is an ideal case for refining design principles and providing insights into supporting belonging and becoming in the context of computational making.

Introduction

Students of color and girls have historically been underrepresented in STEM, and even after recent upticks in CS enrollment and federally funded programs like CS4All, Black students especially still lag well behind their contemporary counterparts in the increase of enrollment in STEM fields (Brown et al., 2013; Boroush, 2020).

As one potential solution, educators have leveraged informal learning environments to offer engaging computer science-related programming in hyper-locally relevant ways. Makerspaces are one such format. Makerspaces promise to bring together the worlds of "creativity and curricular content" in STEM, especially for students that previously found themselves at odds with traditional schooling (Hughes et al., 2018). In makerspaces, students can design and build projects of their interests using equipment and materials of their own choosing. The design process is typically driven by "ill-structured problems" solvable in numerous ways allowing for a wide range of unique and personal outcomes (Dousay, 2017). The constructivist and constructionist principles guiding the design of such spaces have been termed *computational making pedagogies* (e.g., Dousay, 2017; Hughes et al., 2018; Lee et al., 2020).

However, makerspaces have largely not delivered on the promise of fostering a new industrial revolution for all (Anderson, 2012; Blikstein, 2014). Makers are largely white, college-educated men, and the makerspaces themselves tend to reflect this by continuing "tensions and contradictions present that can give rise to inequalities that further suppress meaningful engagement from women and people of color" (Martin et al., 2018, p. 36). Without adopting critical lenses, computational making pedagogies remain neutral to the sociopolitical forces present in the communities they offer to serve. Such neutrality (unintentionally) perpetuates the status quo of makerspace environments.

This paper presents a case study of one student who participated in a summer makerspace camp for Black youth ages 12-16. This design guiding this STEM camp adapted pedagogies for computational making in order to design for belonging and becoming (Escude et al., 2020; Tissenbaum et al., 2021) with a goal of fostering culturally relevant STEM identity development. Using the phenomenological variant of ecological systems theory (PVEST; Wigfield et al., 2007) as a theoretical and analytical lens, this study examines the vulnerabilities that one student faced and the adaptive coping strategies they used to ultimately complete a computational making project. We argue that this student is an ideal case for providing insights into how to support belonging and becoming in the context of computational making.

Background: Adolescence and STEM identity development

Much of the decision-making around STEM identity is formed well before college, starting even before students make it to high school. Adolescence serves as a critical time of identity formation, and it is often here that students think most deeply about who they are and where they fit into society. Even when students of color express an interest in science at a young age, this interest can be lost in a short time, often due to students developing an image of doing science that seems incongruent with who they, or the world, see themselves as (Carlone et al., 2014). There is also a negative trend in student engagement and motivation between elementary and secondary school, specifically in math and science (Carlone et al., 2014). While this is not a trend specific to Black students, students of color are often viewed negatively regarding their STEM abilities, including by teachers (Carlone, 2014). This ever-increasing understanding that the world views them in a specific way is rarely experienced as a protective factor regarding STEM identity development in students of color or girls (Brown et al., 2013; Carlone, 2014). Black students become hyper-aware that they are not often represented or wanted in STEM fields and that technology can act in racist ways (Benjamin, 2019).

Theoretical framework: understanding culturally relevant identity development using the phenomenological variant of ecological systems theory (PVEST)

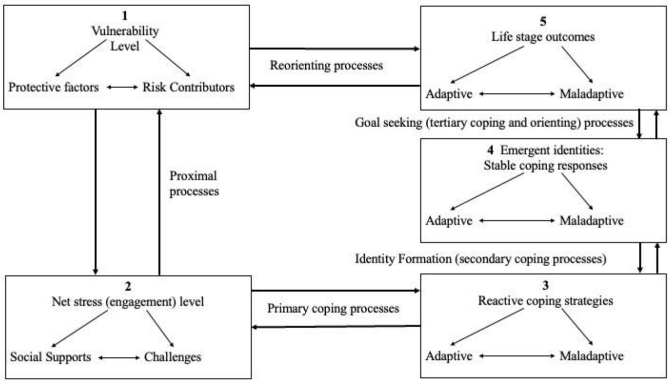
Identity development is a situated phenomenon that involves the dynamic interaction between an individual and their environment(s). Ecological systems theory (EST) is an ecological model that captures these interactions to describe an individual's identity development as being affected by systems outside of and including the self (Bronfenbrenner, 1977). Identity development, therefore, is the "outcome of an individual's interaction with their environment, including the people and physical objects within" (Ozaki et al., 2020 p. 256). These interactions, over time, affect the development of the individual's beliefs about themselves and who they are concerning these environments and other connected environments.

The Phenomenological Variant of Ecological Systems Theory (PVEST) introduced by Spencer et al. (1997) expands on EST by describing more clearly the mechanism by which individuals' interactions with their proximal processes (see Figure 1), moments, where net vulnerability interacts with net stress level, over time, can result in students drawing conclusions as to "who they are, with the goal of responding to negative feedback" (Wigfield et al., 2007). PVEST takes a magnifying lens to proximal processes and looks more specifically at student and environmental assets and how they might interact with each other during points of friction.

We will walk through this model using an example of one familiar type of friction a student might encounter in schooling: being called on out of the blue to answer a question by their teacher. Different students will react differently to this situation. For some, it may be inconsequential. PVEST describes these students as having low net vulnerability in this situation (see Figure 1, Box 1). One's net vulnerability is the outcome of particular individual-level risks and protective factors at play at that moment, such as race, gender, or social stereotypes. For others, however, it may be perceived as a challenge: they may perceive it as a test of themselves as an intelligent individual, a good student, or a myriad of other perceived beliefs about self. For these students with a higher degree of net vulnerability, this perceived challenge may raise their net stress (Box 2).

People respond to stress with reactive coping processes (Box 3). These coping processes can either be maladaptive or adaptive. For instance, the uncertain student, may attempt to answer the question, or they might avoid answering altogether by saying, "I don't know," or staying silent. Their decision about coping processes will depend largely on their past experiences and the perceived effectiveness of similar strategies in similar situations. Over time, these coping processes become part of who they are and how they respond to similar situations throughout life: in other words, one of a student's emergent identities (Box 4).

Figure 1
Phenomenological Variant of Ecological Systems Theory, reprinted from Wigfield et al., 2007, p.708.



Inherent in this model is the assumption that microsystems are not neutral grounds. Rather, they bring challenges and supports that compose an individual's net stress, and, if high enough, may challenge the student's perception of self. By the same token, if higher levels of support exist, the situation will elicit less net stress. Based on what we see of Black STEM students, it is plausible that lowering the challenges of a specific microsystem could reduce their net stress. For example, a Black student who perceives themselves as a good student receiving critical feedback from an instructor may respond differently depending on how they experience this in relation to their racial identity within the institution (Cohen & Garcia, 2008). In other words, different microsystems influence what counts as a risk and for whom.

Importantly, PVEST also explains how students develop productive identities and coping outcomes while navigating risks, stresses, and vulnerabilities. All humans experience some level of vulnerability, and net stress in itself is also not necessarily a negative. In fact, overcoming challenges is an integral part of "positive growth and development" (Wigfield et al., 2007). Students may develop numerous strategies for engaging and succeeding in stressful environments, and over time, could transform these risks into support. As such, this model is helpful for understanding the mechanisms of resilience while simultaneously acknowledging the environmental, sociological, and systemic influences requiring that resilience.

Aims of the paper and research questions

This paper presents a micro-analysis of one student's (Jordan – pseudonym) participation in a 6-week summer maker camp to illuminate the tensions and proximal processes that Jordan encountered. In analyzing his specific reactive coping processes as well as how we as facilitators responded to these coping processes, we aim to address:

1. What aspects of the designed environment did Jordan experience as risks?
2. What kinds of reacting coping processes did he demonstrate?
3. How did those reactive coping processes evolve over the course of his interaction in the makerspace, including continued interactions with both facilitators and materials?

Methods

Study context and participants

During the summer of 2021, we (the first (Black male) and third (White male) authors) implemented a 6-week summer camp in an informal community center setting in the Midwest. The summer camp focused on computational making that aimed to foster and positively support the emerging identities of Black middle school boys. These goals were in alignment with those of the local community center, which had a mission of promoting college and career readiness as well as providing social and emotional support for Black boys and men between the ages of 3 and 24. Our camp focused on middle school boys and met twice a week for two hours each meeting period, for a total of approximately 24 hours of contact time. Participants were 12 middle school boys that were in the broader summer camp program at the community center. All except two students identified as Black. On any given day, the number of students in attendance ranged between 6 - 12. While they had all signed up for the broader summer camp, they had not specifically signed up for the makerspace camp. Students had little to no prior in-depth experience with physical computing.

Program design

Our overall program design was driven by twin commitments to supporting belonging and becoming (Escude et al., 2020; Tissenbaum et al., 2021). Central to these commitments were principles for reflexively supporting student agency. Inspired by Escude et al.'s (2020) metaphor of stretching and releasing a rubber band, we tried to "open up" as much of the curriculum as possible, both in material usage as well how we as facilitators responded to student tensions in the moment. More specifically, three key design principles guiding this "opening up" included (1) *Maintaining curricular and pedagogical elasticity* - allowing for flexibility in student expectations and being responsive when they appear; (2*) Practicing transformative inclusion* - changing the space for the student instead of expecting the student to change; and (3) *Balancing organizational and structural priorities* - thinking more deeply about imbalances in expectations brought about by the organizations involved. Ideally, students would learn some basic skills in the use of microcontrollers that would then allow them to explore and build their own personal projects during the second three weeks of the implementation, followed by a symposium where they would share their projects with other tribes and community members. Over the course of three weeks, students built and modified artifacts that contained LEDs, motors, and a variety of onboard and external sensors, before following a design process to create their **own** personal or community-based project.

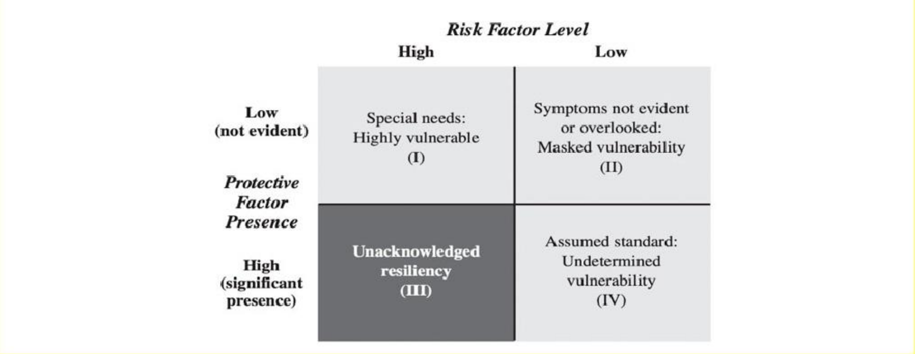
We utilized the BBC Micro:bit microcontroller due to its approachable nature and being purpose-built for education. For example, the numerous physical connection pins that one normally sees when looking at microcontrollers, have been abstracted away and are replaced with circular spaces where wires can be connected to by alligator clips or even screws. We also chose to initially expose them to a limited but useful array of electrical components such as LEDs, motors, and several useful onboard or external sensors.

Data collection, case selection, and analysis

Data included audio recorders at each table in the camp (often just two) and two cameras, one at the front and one at the back of the room, positioned to capture the students as they worked and their movement through the room. In total, approximately 24 hours of video and audio were captured across all the devices. Field observations were also captured, and the facilitators did daily debriefs on the days' activities to adapt the curriculum to student needs or other emergent factors.

Figure 2

Spencer's dual axis coping formulation of PVEST reprinted from Wigfield et al., 2007, p.731.



Video clip segments were stitched together for each hour of the 24-hours recorded and imported into MAXQDA software for analysis. We utilized content-logging (Jordan & Henderson, 1995) of student interactions with each other and with materials of all the videos, close microanalysis of key moments, and interactions of the students throughout the process (Jordan & Henderson, 1995). This content-logging process led to the selection of a single student, Jordan, whose low literacy would be viewed as a large educational risk factor that would mark him as a quadrant I (see Figure 2) "highly vulnerable" student in Spencer's Dual Axis Coping Formulation (DACF) of PVEST (Wigfield et al., 2007). Jordan's reactive coping processes often mitigated this risk factor. We looked at this as an opportunity to look at his strategy selection, which could offer insight into his identity development and foreground possible areas of challenge or support for other students. Based on our repeated viewings, we began to identify sources of "unacknowledged resilience" in Jordan's interactions. This "unacknowledged resilience" that Spencer describes as individuals falling into quadrant III (Q3) of the DACF. Spencer describes these Q3 individuals as being often overlooked in research while also describing their importance in informing the design of programs and policy:

> "The group is also important for careful study since the unpacking of their experiences allows one to determine how much risk is facilitative…and how much risk…undermines positive health and development (i.e., pushing individuals from functioning as Quadrant III members and, instead, deteriorate into Quadrant I level of high vulnerability) (Wigfield et al., 2007, p. 733)."

We identified moments where Jordan was mentioned in the video content logs and re-watched those clips, generating more detailed logs. We began to identify emerging themes about Jordan's interactions and progression through the summer based on these detailed logs. These themes were related to Jordan's experiences of "friction" and his help-seeking strategies. We then identified four distinct moments that captured pivotal moments of "friction" for Jordan's trajectory and conducted close microanalysis of those four moments (Jordan & Henderson, 1995). The four identified moments represent *phenomenological episodes:* tensions that required Jordan to utilize a reactive coping strategy and could have been facilitative or undermined his protective factors. We documented Jordan's reactive coping strategies, as well as how we, as facilitators, responded to these coping strategies. We then examined how Jordan leveraged them differentially over time to (ultimately) successfully navigate his own path through the program. In the interest of space, three of those four moments are presented here.

Findings

We present three phenomenological episodes that represent Jordan's arc from Days 1-8 of the 12-day camp.

Across these three episodes, he shifted from passive reactive coping strategies to more active mechanisms by identifying and taking advantage of available supports. Across all three episodes, we provide in-text the connected strategies (S1, S2, etc.) that we saw Jordan use during the camp as revealed by our thematic analysis.

Phenomenological episode 1: Passive signals for help

Jordan's first phenomenological episode occurred during the initial task of the camp: messing around with a micro:bit and following some basic instructions to get it set up. Throughout this episode, Jordan's body language signaled that he was uncertain about how to proceed. He also utilized three distinct reactive coping strategies in response to this uncertainty: (S1) Sending silent signals while waiting for help to come; (S2) Shifting focus to others and the environment when "stuck" - what are other people doing?; (S3) Asking questions of available resources; and (S4) Attempting to figure things out on his own. The following vignette illustrates how Jordan utilized these coping strategies throughout the initial micro:bit activity, which lasted a total of 16 minutes.

After students completed a pre-survey, the instructors passed out the micro:bits and instructed students to "mess around" with them. Jordan's micro:bit can be seen sitting, wrapped, in the corner of his table. After sitting, arms folded, waiting (S1) He began to look around, saw others interacting with their micro:bits, before finally reached for his own. (S2). He picked it up, a gave it a quick turn in his hand, looking at it for 20 seconds before putting it back down and glancing around the room again (S4). He looked towards F1 for 2 seconds before verbally calling over for help and sat with his hands folded in front of him making small glances around the room (S4). As F1 arrived. Jordan held up the USB cable and asked something about it (S3). F1 told him he could plug in the micro:bit, to which he asked another inaudible question while holding up the USB cable. F1 held up his micro:bit and said that he can plug the USB cable into the micro:bit and then walked away (S3). He immediately reached for the micro:bit and struggled to unwrap it for 30 seconds before looking at Garfield, the student at the same table who had already plugged his in (S2).

At this point, Garfield finally succeeded in getting his micro:bit powered up, causing it to go through a sequence of flashing lights. This caught Jordan's attention, and after observing Garfield's micro:bit, Jordan connected his USB cable to his laptop (keeping it rolled up in the same way as Garfield), but struggled to plug it into his micro:bit. Jordan glanced around almost nervously, then tapped Garfield on the arm and asked for help (S3). Garfield helped Jordan get his micro:bit powered up, but Jordan sat there, looking around, not knowing what to do next (S4). Jordan continued this cycle of being shown what to do but not knowing how to proceed, moving between Strategies 3 and 4. F1 then told the class that he had handed out sheets with additional support, which Jordan picked up and turned right way up (S2). Jordan briefly glanced at the sheet before once again looking over at Garfield (S2). After several minutes F2 came over and helped Jordan use the document to go to the needed URL, including helping correct Jordan's typing.

Throughout this episode, Jordan encountered friction at nearly every encounter with materials and his coping strategies were incredibly passive. When he did leverage more active strategies, such as asking Garfield for help, it was coupled with a nervous look that suggested he may have felt that he was cheating. In addition, when I (F1) responded to Jordan's question, I did so operating under the principle of "student agency": wanting students to be able to "mess around" and manipulate things on their own without relying on a facilitator to do it for them. Upon reviewing the data, it's clear that this choice may have served to reduce belonging and prohibit opportunities for becoming, in that they essentially rendered Jordan's initial reactive coping strategies ineffective.

Phenomenological episode 2: Jordan's wheel-spinning cycle

This episode occurred on the second day of the first week of the program, where we wanted students to use their understanding of "addressing" LEDs to make a digital design on a larger 8x8 grid LED matrix. To help facilitate this, F1 coded a design of the Jamaican flag and used that as an example for them to think with. Our scaffolding required students to start by following a URL to get to (https://craftdesignonline.com/pattern-grid/) to develop their design using the interactive grid tool. After coming up with their design, we then asked them to transfer the design to paper, which would then later allow them to input these colors into MakeCode for use on the micro:bit.

The design document gave a basic set of directions for completion as well as abbreviations to use to denote what color the specific LED should be set to when they set it up. It is easy to overlook the tensions faced by Jordan during the episode. At first glance, each cell in his worksheet looked filled in, but on closer inspection, we noticed that Jordan had erased everything he had originally written in the grid. He originally seemed to be trying to number his grid with a one in the 63rd cell and count to 64 by the time he got to the last cell. It is unclear truly why or what he was doing with these numbers, but numbering the grid was his takeaway from this portion of the design process.

Jordan faced the first of a chain of challenges immediately while trying to log in to the laptop with the password on the board. Jordan glanced around and noticed that others had opened their laptops and were typing. He, too, opened his laptop (S2). Jordan then focused on his laptop and began typing something. When F2 was close to Jordan, Jordan raised his hand (S3). This portion of the overall episode shows one of Jordan's consistent coping responses: "reading the room," collecting information from what others are saying or doing.

Throughout this interaction, F2 seemed to recognize that Jordan was having some trouble following the spelling of the URL and could be seen pointing to each letter as he said each out loud, even slowing down in his spelling of the URL. When they completed the URL, F2 took charge of the laptop to point out to Jordan what he needed to do before moving on to help another student.

After the facilitator left, Jordan entered what we refer to as the "wheel-spinning cycle" (WSC). The WSC loops Jordan's coping strategies endlessly until a source of external input arrives. For example, when the F2 moved away, Jordan's gaze followed his movement (S3). Jordan continued to glance around until F1 passed by. Jordan engaged him with a question: "What are these?" F1 responded that they were the different colors that he could use to design, then asked, "Does that make sense?" Jordan took the opportunity to ask a follow-up question about the paper. F1 again replied that "the screen is the place where you can do it and then transfer it to the paper." Jordan nodded his head, and F1 walked away to help another student.

F2 then walked by and said to the student sitting next to Jordan, "Cool checkerboard pattern!" Jordan craned his neck towards the student's screen before returning focus to his laptop (S2).

When Jordan engaged with his laptop on this occasion, he did not exhibit wheel spinning, rather, he continued to engage with his trackpad for the next ten minutes with all attention focused on his screen. After ten minutes, Jordan glanced over at the F2, who was helping another student, and raised his hand. F2 acknowledged Jordan but continued working with the student first. As he waited, Jordan sat back in his chair for several seconds before he got the attention of Garfield and Amari across the table from him. He turned his laptop screen around to them, and to the camera for the first time. He broke out into a wide smile and asked them to "check it out." Jordan had completed his design of a four-color checkerboard pattern that he was clearly happy with. Amari responds, "that's better than mine." In this episode, we saw Jordan break out of his WSC by utilizing a risk strategy (S2) to achieve a successful making outcome, promoting positive identity development.

Phenomenological episode 3: Jordan uses his laptop to help him complete a sentence

On the eighth day, students were completing a design planning document and being introduced to the materials and components to start building their personal projects. Here we saw Jordan using a different form of his strategies, as he needed to write sentences on the planning document. He moved to sit right next to Garfield. He glanced down at his planning document, on which he should have been working on a basketball game. F1 mentioned Jordan's basketball hoop and how he could use the design of the first one to make an improved version. He is attentive throughout F1's instructions, as well as when F2 begins to also give directions for the day, his gaze focused on the speaker with his hands clasped.

F2 asked if the directions made sense before looking directly at Jordan, who gave a small nod of yes. Jordan glanced down at the design document in front of him but still did not move it (S1). Jordan spent some time rubbing his eyes while he glanced around and looked over at the table where F2 was helping another student (S2). Jordan then pushed back from the table as he moved his hands away from the laptop (S1). Seemingly without conversation, Garfield reached over the table and picked up Jordan's paper, turning it to the correct page before placing it back in front of him. Jordan then looked at his paper but still seemed stuck. He looked at F2 and continued to wait (S2). After a moment, Garfield got up to get something to write with and Jordan also immediately followed, coming back with a pen before going back and replacing it with a pencil (S2). After coming back, his glances followed F2 until F2 sat down with another student. Jordan then looked down at his paper and began WSC, looking from F1 to F2 to the paper in front of him. After 3 minutes of holding the pen and staring at the page and the front of the room, Jordan turned to Garfield and asked, "What am I supposed to do?" (S3). Inaudibly Garfield explained something to him, after which he seemed to show more interest in interacting with the page. Jordan wrote on the paper off and on for the next 3 minutes before asking Garfield something again. Garfield looked at Jordan's paper and responded again (S3).

A minute later, Jordan got up again and went back to the materials table, coming back with a laptop. This time Jordan seemed to enter the password for the laptop correctly from the board. Two minutes later, Jordan started using the laptop as a reference (S3 + S4): he had typed something in and was now writing on his paper while glancing back and forth to the laptop. This behavior went on for seven minutes, at which point he turned around to F2, raised his hands, and called for his help (S3). F2 acknowledged Jordan but was trying to finish something with another student, and Jordan began to wait. He did no more writing while waiting (S1).

Discussion

We presented a close analysis of three instances in Jordan's trajectory that allows us to see both how our design principles unintentionally functioned as risks for Jordan, as well as the reactive coping strategies that were more or less effective in this context. Looking across these episodes, it seems that Jordan's most persistent challenge was one of uncertainty, which then elicited a Responses Arc (RA): (RA1) Silent call for help (sitting away from the laptop with his arms folded). (RA2) Reading the room (Where are facilitators, what are they saying to others, are they close by? What are other students doing? What counts as good work?) (RA3) Public call for help (raising hands when a facilitator entered in proximity). (RA4) Where is help located in the room? (Going to look over someone's shoulder, asking student directly for help). (RA5) What can I figure out on my own? (Reading of board, looking at the instruction sheet) Throughout the camp, Jordan would enter this arc if it seemed that help was going to take too long for him to proceed or if he had just received help and was still uncertain as to how to proceed. By episode three, we can see that Jordan has started being more active in solving some of the problems that he runs into. Instead of waiting for the facilitators to make it to him, he instead breaks out of the wheel-spinning cycle by both specifically asking Garfield direct questions, as well as utilizing the laptop to help him spell out a sentence. This problem could have been solved by waiting for facilitators, but instead of waiting for direct assistance Jordan formulated alternative ways. In this case Jordan was able to leverage a computational resource to help get him past the friction brought about by his uncertainty. Over time we began trying to do more checking to see if Jordan understood what we explained, as seen in episodes 2 and 3, but these attempts did not always help.

These re-orientations seem to reflect the movement from a formal classroom to an informal learning environment: Jordan's initial responses were ones that would have been supported, even praised, in formal education settings. In addition, a teacher in a formal education setting would have had more information about Jordan's reading abilities than we did. Jordan's vulnerabilities were most exposed when he was asked to read and write, especially without the aid of the laptop. His silent bids for help when instructions were available and readable (e.g., on worksheets) were often overlooked. His main question was always, "What should I be doing?" While a knowing teacher would have immediately leveraged at-level literacy strategies, we most often simply redirected him to the written instructions. Still, Jordan was one of the few students that were consistently present throughout the camp, and he also started and completed a personal project by the last week of the camp. Jordan showed persistence in both his attendance and in his desire to complete what was asked of him.

Although Jordan was often more focused on completion than creation due to having to deal with consistent uncertainty, he was able to build off examples that he knew to be exemplars, including his final project. One of the problems with Jordan's reactive coping, especially for educators that are not his formal educators, is an ability to overlook both his efforts and subsequent achievements. Jordan's project, while being a remix of an earlier one, showed the ability to reason by working with the modular nature of the electronic components. His project utilized an infrared sensor that sensed when a ball went into a cup, sending a signal to his micro:bit, replicating an automated basketball hoop. With his understanding of these components, he was able to come up with a design that merged skills learned from separate projects by making the external LED strip light up when the infrared sensor was triggered. The basketball court that he built looked identical to the court that he drew on his design document, and the sentence that he wrote to describe it on his design sheet, while very rudimentary, is exactly what he ended up doing.

Jordan is more than a Black middle school boy. He is an intersection of so much more, and aspects of those intersections were overlooked during design. While trying to focus on a portion of his identity, we overlooked others. The scaffolds that we offered him were largely literacy based. This was exacerbated by Jordan's seeming belief that he needed to work largely as an individual. While Jordan found many of the holes present in our design, he also serves as a resource for improving future iterations of improved design. These responses also seemed to evolve over the course of the summer camp and moved from passive reactive coping to more active processes.

Conclusion

This paper explored the complexities of designing computational making curricula in a culturally supportive and responsive manner by closely following the experiences of Jordan, a Black student, during the first iteration of a makerspace summer camp. To better design future spaces that facilitate resilience in students like Jordan, we propose the following strategies: (1) *Maintaining curricular and pedagogical elasticity* – Our focus on flexibility to allow personal choices in projects could be enhanced by considering elasticity in the context of instructional scaffolding. Jordan would have benefited more from exemplars, collaborative grouping, and one-on-one conversations rather than the numerous paper-based handouts provided. (2*) Practicing transformative inclusion* - the program would have benefitted from us as facilitators being more direct about recognizing and supporting students' individual coping skills, especially since our overall goal was supporting their emergent maker identities. (3) *Balancing organizational and structural priorities* – While community center members knew more about each participant student, the structure of our communication did not effectively support the exchange of personal student information. In subsequent iterations, we engaged more directly with staff members and parents to better understand the intricacies of each student. Jordan as a model is helpful in understanding the mechanisms of resilience while simultaneously acknowledging the environmental, sociological, and systemic influences requiring that resilience. Overall, this case study provides valuable insights for refining design principles and supporting belonging and becoming in the context of computational making for students similar to Jordan.

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Dialogues Without Words: Multispecies and Multimattered Creativity in Maker Education

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Abstract: In response to the tendency of making to control and harness the material world, we propose the ‘creative pluriverse,’ which can fit many worlds, as a framework to design and study the possibility of multispecies and multimattered creativity. We ground this concept in process philosophies, theories of embodied cognition, and ecological materialism to advance a posthumanist conception of creative making. Using a design-based research approach, we reimagine making, particularly biomaking with fungi, as a ‘dialogue without words’ that nurtures didactic tensions and relations between learners and other-than-human entities and elements. By examining a series of dialogues–between a boy, a tree, clay, and fungi–we observe instances of learning through multispecies creative production and discuss implications for learning design in hybrid pluriverse worlds.

“Queremos un mundo donde quepan muchos mundos.”
[We want a world where many worlds fit]. (Zapatista Movement, in Escobar, 2018, p. xvi)

Introduction: Makers, not masters

In the past few years, we have learned that viruses can jump from corralled animals into human bodies, that wildfires and rising seas know nothing about urban boundaries, and that human-made stuff now weighs more than all remaining living biomass (Elhacham et al., 2020). As the tensions between social, environmental, and technological forces grow and manifest at all scales, we wonder *what counts* as making and *who counts* as a maker in a world that seems to be making and unmaking itself. In times of human-nature fragmentation and reconfiguration, we explore how posthumanist and embodied lenses can help us make sense of maker education as a practice situated within the creative ebbs and flows of the earth.

Informed by constructionist pedagogies, we have explored how constructionist maker education provides students with opportunities to critically engage with social and environmental challenges in personally meaningful ways while gaining valuable knowledge and skills (Holbert, Dando, & Correa, 2020). Still, we are becoming increasingly aware of the subtle ways maker education reproduces the rhetoric of mastery and control that leads us to the same crisis we aim to confront. Contemporary maker education remains situated mainly in the modern imaginary of progress, growth, and innovation. The environmental crisis is acknowledged but framed as yet another technoscientific challenge for young minds in preparation for their future ahead (Kohtala & Hyysalo, 2015). Methodologically, most maker education initiatives leverage human-centered design and problem-solving frameworks for students to produce innovations that respond to immediate problems without questioning their root causes. In the meantime, the planet can barely keep up with the pace of human-centered innovation and its associated patterns of linear extraction, production, consumption, and disposal.

Although practices of recycling, upcycling, and repair are increasingly encouraged (Dew & Rosner, 2019), it is commonplace to give students open access to tools and materials to generate prototypes and artifacts that tend to be discarded as fast as they are produced (Song et al., 2019). It can be argued that the main purpose of rapid prototyping and tinkering with materials extend far beyond the innovation itself through the long-lasting learning gained in the process (Ratto, 2011). However, learning in these terms ignores planetary boundaries and reinforces anthropocentrism. Learners are situated at the center of the material world and in a position of relative power. This leads to a fundamental contradiction: We actively seek students’ empowerment; we ask them to problem-solve, figure-something-out, put-it-together. Yet, we feel increasingly powerless amid the magnitude of more-than-human forces disrupting everyday life. Are we unintendedly asking students to be masters knowing that humans can only be makers? How can we expect them to *harness* the material world when the most we can do is to humbly join its untamed flows of matter?

The narrative of the master is not unique to the social trend branded ‘maker movement’ and its patriarchal imaginary of the maker (Buechley, 2013; Vossoughi et al., 2016). Even in well-intended educational research, maker and master tend to get muddled when learners are seen above the rest of the world. Students are undoubtedly relevant, but they exist only in relation to a larger complex socio-ecological system, and the condition of this system will inevitably shape learning. Socio-cultural frames of constructionism call us to look beyond the learner and consider learning as a “bidirectional” dialogue with artifacts, materials, spaces, and communities (Holbert, Berland, & Kafai, 2020, p. 9). The question then is how to credit all parts in this dialogue without resorting to listening only to the human voice. Posthumanist scholars argue that the problem of socio-constructivist paradigms is that, by assuming human-meaning making and discourse as the starting point of the construction of reality, we inevitably get caught in an *anthropocentric gaze* that obscures the active participation of other-than-human entities and elements (Alaimo & Hekman, 2008; Hultman & Lenz Taguchi, 2010). Rousell and colleagues (2022) note that the participation of materials gets constrained to the role of *resources* as they hold no value aside from imposed socio-cultural meanings. Furthermore, the participation of other living beings, and their idiosyncratic ways of meaning-making, are often ignored, silenced, or relegated as resources alongside other materials.

To make sense of our hybrid socio-techno-ecological world, several scholars in maker education (Keune & Peppler, 2019; Lemieux & Rowsell, 2020; Sheridan et al., 2020) and creativity (Chappell, 2018; 2022; Rousell et al., 2022) are looking into posthumanist frameworks. These perspectives emphasize how creativity and learning emerge from the enmeshment of people, materials, and artifacts through what Chappell (2018) describes as an “embodied dialogue” in which people and things are continuously “making and being made” (p. 282). Whereas most research has focused on foregrounding the participation of materials, objects, and technologies in making, we investigate the participation of other living beings in making with biology, also known as biomaking (Lui et al., 2019). We embrace a radical ontological and epistemological pluralism where humans and other-than-humans can coexist and create meaningfully through embodied dialogue.

In his book “Designs for the Pluriverse: Radical Interdependence, Autonomy, and the Making of Worlds,” Escobar (2018) proposes an inclusive conception of design as world-making, a practice devoted to the creation of multiple ways of being and doing in attunement with the earth based on the radical interdependence of all beings. With the concept of pluriverse creativity, we aim to advance a multimattered and multispecies understanding of creative production that encompasses the unique ways in which all biotic and abiotic entities, in their different ways of being and doing, actively participate in the ongoing production of new worlds.

Creativity in the pluriverse shifts away from innovation and mobilize making towards lost meanings of creativity. To that end, we draw a theoretical framework from process philosophies, theories of embodied cognition, posthumanism, and ecological materialism. We then apply this framework to designing and implementing a biomaking program described as a “dialogue without words” in the methods section. Finally, we examine a series of dialogues–between a boy, a tree, clay, and fungi. We use this case to discuss instances of emerging learning through multispecies creative production and outline preliminary directions for a renewed understanding of creativity in maker education.

Theoretical framework: Reclaiming pluriverse creativities

To move away from anthropocentric conceptions of maker education, we consider it necessary to reorient our practices toward creativity instead of innovation. However, as Rousell and colleagues (2022) observe, creativity and innovation are often treated as interchangeable concepts in education, emphasizing the latter. Except for recent deviations towards distributed (Glăveanu, 2014) and participatory (Clapp, 2016) models, the primary concern of creative research in education has been restricted to exceptional individuals and remarkable products. Research on individual subjects focuses mainly on psychometrics (Feldhusen & Goh, 1995) and giftedness (Howe, 1999) while research on final products evaluates them in terms of novelty and social value (Amabile, 2018). What is mainly absent is the study of creative processes. Sawyer (1998) noted that creativity research has “separated ideation, divergent thought, and insight on the one hand and execution, implementation, and performance on the other” (p. 11). The problem with this dualism, Ingold (2013) notes, is that creation is not the sudden actualization of preconceived ideas but the actual making of them.

Rather than proposing a new definition for creativity, some scholars propose a return to the word’s etymological roots and its original meaning in process philosophies (Ingold, 2013; Rousell et al., 2022). According to Meyer (2005), it was Whitehead, the 20th century philosopher and mathematician, who first introduced the noun ‘creativity’ as derived from the Latin verb *creare* meaning to bring forth, to produce, to grow. Although Whitehead (1978) avoided defining creativity directly stating that “there is no meaning to ‘creativity’ apart from its ‘creatures’” (p. 344), he referred to it as the principle of *becoming*, the “temporal passage to novelty” by which many disjunctive entities move towards unity or what he called the “production of novel togetherness” (p. 21). In his view, creativity is universal, embodied, procedural, and collective. Such perspective contrasts sharply with contemporary notions of creativity as an internal human trait or a property of socially acclaimed masterpieces. For Whitehead (1978), creativity is not about *who* produces or *what* is produced but about production and movement because there are no products but only moments, occasions, or creatures. A creature we see at any given moment, he argues, is just a moment in the flows of material circulations. In Whitehead’s process philosophy, creativity, as well as thinking and becoming, are inherently productive processes that emerge not from individuals but from their relations in the ongoing reconfiguration of reality (Pickering, 2005).

Similarly, theories of the embodied mind see cognition not as an internal operational process but rather as a relational domain that emerges *between* the mind, the body, and the environment (Maturana & Varela, 1992). Thompson (2007) argues that cognition emerges from this interrelated system and defines it as "the exercise of skillful know-how in situated and embodied action" (p. 13). Cognition is not an exclusively human property but transversal to all adaptive life. From apes to amoebas, all living organisms are cognizant and autonomous, given their capacity to purposely regulate the flow of matter and energy through them to generate themselves, sustain their identity, and avoid dissolution (Thompson, 2007). Maturana and Varela (1992) coined the term "autopoiesis" (from Greek αὐτο- [auto-] 'self,' and ποίησις [poiesis] 'creation, production') to describe the recursive process by which a system produces and maintains itself by creating its own parts. In the words of Weber and Varela (2002), "[f]orm, then, is not just an abstract goal in a genetic program, but a material task to fulfill from moment to moment" (p. 117). Biological forms crystallize the active role of the organism in its morphogenesis and its species' evolution in the long term. While genes set the parameters for development, the actual form of each living being emerges from ongoing *sense-making* of the environment through situated and embodied action (Weber and Varela, 2002). Thompson and Stapleton (2009) add that sense-making involves not just cognition but also emotion because, in making sense of its surroundings in relation to its current bodily state, the organism determines their value or relevance in the degree it feels attracted or repelled. In the words of Fuchs and Koch (2014), emotion emerges "from the circular interaction between affective qualities or affordances in the environment and the subject's bodily resonance," which suggest a correspondence between motion and emotion (p. 1).

In anthropology, ecological materialism brings these ideas together to discern the relations between making and growing. Ingold (2013) argues for an understanding of creativity not divorced from the material unfolding of the living world. Like other creatures, he observes, humans gather materials from a world already going on and redirect material flows in anticipation of what may emerge. Ingold and Hallam (2016) observe that the designs of both natural and human worlds are the outcomes of skilled response to a mutually responsive material environment; skilled makers know their materials and work *along* them to keep creation going; likewise, thriving organisms know their medium to keep life or self-creation going. Notably, what is fabricated does not escape the flows of life–artifacts do not transcend nature by the imprint of culture–but remain as material gatherings prone to dissolution, corrosion, wear, and breakdown (Ingold, 2013).

The concept of pluriverse creativity assembles these ideas to enable the possibility of multispecies and multimattered creativity as a form of embodied dialogue. We wonder what forms of sustainable and fertile living result when flattening hierarchies and allowing creativity to emerge from the enmeshment between living beings, materials, technologies, and humans. Pluriverse creativity aims to hold a dialectic and didactic space to consider multiple ways of being and their idiosyncratic ways of moving the world towards novel togetherness.

Methodology and research design

Building on the theoretical framework, we designed an implementation to support pluriverse creativity. We invited middle-school students to build creative relationships with the living world and each other through hands-on biomaking with fungi. An online invitation called youth to join a different story of the environmental crisis: 'Sometimes, climate change can feel overwhelming. Especially if you are young and surrounded by adults who think *you* are the future and need to find solutions to literally save the planet! What if rather than trying to fix it, we join the creative and regenerative power of the earth?'

We recruited twelve participants, seven girls and five boys, aged 11-12 from two public schools in a heavily developed American city. Students did not have previous experience with biomaking and had little exposure to outdoor landscapes beyond urban parks and playgrounds. Divided into two groups, we met after school for three hours a day, once a week for a six-week period. In total, participants dedicated 18 hours to the workshop. The activities were evenly distributed into two settings: A local urban park and a maker lab on a university campus. At the park, students could wander independently within 6.5 acres of woods labeled as wild but relatively managed. The makerspace was adapted as a biomaking lab that more closely resembled an apothecary. It mixed technological tools and gadgets with all sorts of gathered materials displayed in jars and boxes labeled as fungi food, biomaterial ingredients, stones, twigs, dried mushrooms, etc. By bringing elements from the park into the lab and vice versa, we wanted to intentionally blur the boundaries between indoor and outdoor settings. The aim was to introduce a persistent presence of more-than-human elements and entities–such as fungi, mosquitoes, trees, worms, logs, moths, spiders, and even bacteria and mold–into the making process.

The central non-human participant of the workshop was fungal mycelium. In previous work, we have detailed the properties that make fungi a suitable organism to facilitate interspecies creativity (Correa & Holbert, 2021). Mycelium is a multicellular organism that grows as a white meshwork of threadlike tissues. It lives underground or beneath decaying wood or leaves. Under certain conditions, it produces the fruiting body we know as mushrooms. It can be cultivated relatively easily by inoculating a carbon-rich substrate (e.g., woodchips, grains, cardboard, etc.) and providing certain temperature and humidity conditions. Broadly speaking, building with mycelium involves leveraging the organism's capacity to fuse pieces of organic matter by allowing the organism to grow through a substrate inside of a mold which is subsequently released after several days of growth.

Workshop activities were facilitated by two or three facilitators (first, third, and fourth authors) and documented by one or two research assistants. All workshop sessions were audio and video recorded through a rich tapestry of equipment, each with its own affordances and constraints. We used 360-degree cameras to record group activities in the park and lab and chest-mounted action cameras for students' solo work at the park. Action cameras allowed a (relatively) less invasive capture of participants' intimate work (remote from the researchers) at the park and aimed at capturing their embodied sense-making. We held two group interviews and had individual walking conversational interviews. We also took media videos and photographs of the maker activities, drawings, and in-process creations. The first and fourth authors also took observational notes about participants' behavior and the fluctuating state of the park and its creatures.

As design-based research, the workshop's aim was to both be informed and inform our theoretical and practical understanding of making as a multispecies and multimattered practice. Iterative cycles between theoretical and practical development are characteristic of design-based research (Wang & Hannafin, 2005). We designed a program that reimagined biomaking to afford mindful interspecies creativity. By implementing and analyzing the program in two iterations (with the two different groups), the aim was to refine existent theory and incrementally advance practical applications of creativity beyond humans in education.

To leverage pluriverse creativity, we centered the body as an interface between human and non-human participants. Drawing from Chappell's (2018) notion of creativity as embodied dialogue, we framed making as a *dialogue without words* by which multiple entities and elements can gather to make something together. Learners were invited to practice different ways of establishing wordless conversations with other bodies. This involved tuning into non-human ways of being in the world and responding through making while also attending to other beings' ways of making. Some design decisions we took to support dialogue without words were:

- Listening to other non-human bodies: We asked students to find a personal place in the park they felt drawn to while exploring the area. We let students move freely around the park and be moved emotionally and physically by other bodies. We facilitated activities to heighten students' reception of the movement of the forest in order to build awareness of other creatures' ways of perceiving the world.
- Allowing non-human bodies to have the first word: Instead of asking students to problem-solve, ideate, and project ideas on materials, we framed making as a response to a living world that is already going on. Specifically, we asked them to focus on one specific feature of their personal place–a crack in the soil, the twisted way of a trunk, the sound of leaves–as a starting point for making.
- Responding through making: After allowing enough space and time for something to call students' attention, we invited them to use clay and later mycelium to respond to the specific feature–by extending it, disrupting it, or repeating it–just as they would do in a conversation with a friend.
- Listening to their human bodies: Rather than providing recipes or techniques, as is often the case in biomaking, we leveraged students' intuition and sense-making to guide the creative dialogue. For example, instead of telling students exactly how much water mycelium needs, we invited them to recall their experiences of seeing mycelium growing in moist places in the park. This was facilitated with the prompt what do you feel? (Rather than what do you think?).
- Assembling bodily rhythms: Human and non-human bodies transform matter at different paces; while students are able to build a mold and fill it with an inoculated substrate in a couple of hours, mycelium can take three to five days to completely colonize the substrate and be ready to unmold. As facilitators, we had to coordinate activities accordingly to allow human and non-human parts to express themselves fully while being open to integrating unpredictable human and non-human responses.
- Allowing non-human bodies to have the last word: Instead of dehydrating the resulting mycelium pieces for students to take them home, we brought them alive to the park, where they were shared with families and friends on the last day of the workshop. We chose to work with a strand that was endemic to the area and beneficial to the forest ecology so that the organism could continue to live beyond the duration of the workshop and grow publicly at the park as a statement of interspecies possibility.

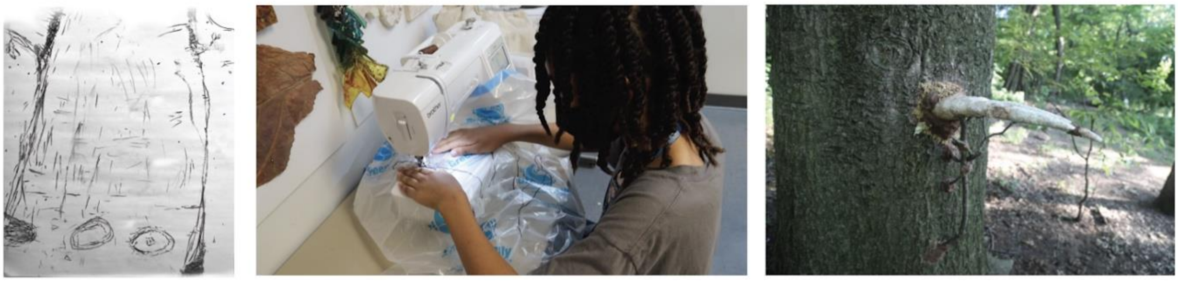
Guided by Tsing's "arts of noticing" (2015, p. 37), the analysis gave attention to multispecies relations often ignored or bypassed in traditional qualitative research. Tsing asks us to "look around rather than ahead" (p. 22) to make room for possibilities in "latent commons" (p. 135). We attempted to look at entities and matter around students as much as we looked at them and tried to make sense of events through the theoretical framework. Whereas process philosophy drew our attention to material transformations occurring between bodies, embodied cognition led us to interpret the behavior of organisms without anthropomorphizing by considering their role in driving material flows and their diverse forms of making sense of the world. These insights were assembled through multispecies storytelling (Tsing, 2015), which uses lively writing strategies (see also Blaise & Hamm, 2019; Goebel, 2022) to convey immersion in a multispecies world.

Findings: Dialogues without words

First dialogue

The slender red oak and its ancestors had felt human dwellings grow heavy over their roots. Yet, the tree knows the river keeps flowing nearby; every autumn, it counts on its breeze to spread leaves over its acorns and protect them from the coming snow. After the winter, bright green buds are slowly uncoiling from the tree's bare branches. A pack of young and noisy humans pass next to its trunk layered in warm clothes and carrying heavy backpacks [as described in notes]. The oak was there when one of them decisively walked towards it, sat over its roots, and pressed his back against a cavity on its bark that 'felt like somebody sat there before' [as shared in group interview]. The roughness of the northern side of the trunk captures his attention [as captured by action camera]. He never looks up at the branches or peers around the trunk but focuses on the crevices and foldings of its darker side. He is particularly drawn to a circular mark the size of a fist [noted in individual interview, student's drawing (Figure 1a), and captured by action camera]. When prompted about how the bark came to be that way, he points to the mark: 'there used to be a branch over here … hmmm maybe I can make another branch for it.'

Figure 1
Student's drawing of the tree and the circular marks on its bark (a), sewing bags to make a branch-shaped mold (b), and the 'prosthetic branch' installed on the tree with the support of clay and twigs (c)


(a) *(b)* *(c)*

Second dialogue

Mycelium threads unfolding and branching outwards through an intricate world of hardwood chips, exploring all crevices, filling every corner, breaking down everything on their path until reaching an inscrutable plastic membrane that refuses to break down. Moving sugars and oxygen through a tangled body and releasing carbon dioxide until the air around feels stale and thin. Suddenly, a stream of fresh and dry air wraps the newly formed body of mycelium. Using scissors, the kid carefully begins to tear apart the plastic mold and release what he called 'the prosthetic branch.' He had made the branch-shaped mold at the lab by sewing together two layers of compostable plastic bags (Figure 1b). Later he had filled the mold with loose hardwood chips inoculated with mycelium so it could grow in that shape. Three days later, the kid is back at the tree [captured by action camera], sitting cross-legged on the ground, finally opening the mold: 'I feel like a mad scientist, buah ha ha.' Yet, his human hands do not seem to know how to harness the odd body of mycelium. Not knowing how much pressure it can handle, the mycelium branch breaks once 'crap!' and twice 'creep!' The dismembered mycelium branch lays in front of him next to a block of clay that seems to suggest a way forward. He grabs a chunk of clay and connects the broken pieces back: 'clay is so heavy…I hope mycelium can grow through clay…cause if it can't then this part never grows again…I hope you can grow through clay dude.'

Third dialogue

Despite the kid's efforts, the clay refuses to hold the broken mycelium branch together, 'don't die on me,' he whispers. As he tries to save his mycelium branch, other creatures come by [captured by his action camera]. A white moth finds on his fingers a good place to land but, after realizing they are moving, launches off to the ground only to be chased after. ‘Do you wanna die?’ asked the kid while firmly holding the scissors. The moth tries to open its white wings to fly away, but they are broken and useless. The boy grabs a stick from the ground whispering, ‘yes you do, yes you do.’ The white moth attempts a final jump before disappearing under the stick. ‘The dude was done.’ Soon after, a mosquito finds the boy’s warm skin while he was wrestling with the clay. ‘Aaaaghh bugs, nature,’ claimed the boy with a contemptuous tone that was immediately followed by a new exclamation in a high-pitched voice: ‘I love nature, but I just don’t like bugs […] when I have a kid he is going to be partly made of glass.’ Finally, a second boy arrives to the tree screaming and running from a hive of bees that does not seem interested in him [as captured by his action camera]; breathing heavily, he exclaims: ‘am I the only one scared of all these animals?’ A brown squirrel passing by hears the kid's heavy steps and freezes staring at him. ‘Aaaahhh! There is a squirrel! The squirrel is looking at me!’

Fourth dialogue

The harsh bark of the tree refuses the clay and the prosthetic branch altogether. Six tangled human arms wrestle with the branch and clay against gravity. Together, all bodies–hands, tree trunk, clay, mycelium branch, and sticks–finally suspend the prosthetic branch in a delicate and almost impossible balance (Figure 1c). A human group of friends and relatives gather around the tree and look puzzled at the branch. Holding a pencil in his hand, the boy shares proudly about the prosthetic branch and his hopes for it: ‘it’ll stay on here and mushrooms will grow. It can be like a patio for squirrels […] if we get lucky this might actually grow into the tree so it can stay there without the clay.’ His voice spreads through the forest and a thick layer of fully-grown leaves dresses the canopy, cycling matter, crafting atmosphere, and giving breath to all bodies under its shadow.

Discussion: Making sense of creativity in the pluriverse

Dialogues without words are lively, messy, and prone to misunderstandings, contradictions, and discomfort. Instead of bringing students back to pure nature ecologies that no longer exist or asking them to dream distant techno-utopian futures, we choose with Haraway (2016) to “stay with the trouble” and give space for learners to craft ways forward from the midst of our hybrid, odd, messy, and unraveling pluriverse worlds.

The first dialogue positions maker activities within a larger hybrid ecology. Not a wild and innocent landscape but a place of resistance; a seemingly wild but managed patch of woods in a city of manicured parks and playgrounds. The dialogue was initiated by the encounter between the kid’s back and the tree’s bark pressing against each other and, later on, by the circular mark that captured his attention. His reading of the mark as a trace of a fallen branch suggests an incipient understanding of the tree not as a finished and static object but as an unfolding body. Giving living beings the chance – space and time – for learners to notice them and giving learners cognitive tools for noticing is a necessary first step to acknowledging creativity in the world. It is worth considering how this incipient noticing could have been nurtured further, through prompts or discussion, for the student to consider something as still as a tree as an unfolding creature that is in movement within itself despite its solid appearance. Subtly, this was suggested by the practice of making itself through which the student entered into conversation and joined the tree on its becoming.

The second dialogue presents a series of embodied conversations that gave rise to the ‘prosthetic branch.’ The actual form of the branch emerged from the relational engagement of mycelium growing outwards through the wood chips and against the surrounding plastic mold. The mold’s shape, in turn, emerged from the dialogue between the sewing machine, the boy, and the plastic bags. Later on, at the park, the student, the mold, and the branch wrestled with mutually responding forces until the final shape was released. In the process, his unskilled bodily movements, not knowing the body of mycelium well enough, broke its delicate fibers apart. When looking for a way forward, the student demonstrated both thinking like the organism and thinking through clay in an embodied manner. The myceliated substrate, which is as light as styrofoam, contrasted with the weight of the clay. When holding the clay in his hands, the question of mycelium’s ability to grow through clay emerged from his embodied understanding of density and his past experiences growing mycelium at the lab.

The third dialogue shows how the students’ presence in the forest was not without friction. Despite our efforts to build awareness of their bodies and other fragile non-human bodies around them, they inadvertently and, at times, intentionally smashed seedlings, made trails, and displaced or killed critters. When learning occurs outdoors, Pacini-Ketchabaw (2013) suggests important questions: “Who lives and who dies with children's visits to the forest? What worlds are created? What futures are generated and regenerated in these visits?” (p. 356). The boy’s care for mycelium contrasted with his reaction toward other creatures that interrupted his work. Non-human bodies moved the students’ bodies–emotionally and physically–and awakened visceral reactions that they attempted to tame rationally, perhaps given the presence of the chest camera. In these intimate yet uncomfortable encounters, human-nature boundaries dissipated, allowing for what Taylor and Pacini-Ketchabaw (2015) describe as the “mutual vulnerability” inherent to everyday interspecies encounters. Being observed by piercing non-human eyes, feeling the fragile body of a moth breaking down, becoming porous and edible for mosquitoes, having a skin that is not 'made of glass.'

Finally, the fourth dialogue illustrates the student's emerging understanding of making within a larger scheme of multispecies events. For him, the branch is not finished; mushrooms will grow, squirrels will play, and mycelium may even continue to grow toward the tree. An understanding of making in continuity with the ongoing transformations of the earth facilitates a mindful consideration of its implications. Creativity in the pluriverse demands responsibility for the "creatures" (Whitehead, 1978) that we make and the traces we leave behind. Thinking of making as growing offers paths to re-weave human threads into the fabric of life.

The presented dialogues without words describe how a multiplicity of beings accommodate to each other in their discordant ways of being. Every-body–children, facilitators, mycelium, clay, bugs–was doing its own thing, immersed in embodied sense-making. Yet, when intentionally assembled, collective sense-making can bring forth novel togetherness. As primary steps in the path of re-thinking making in the pluriverse, we highlight the importance of giving space for learners and other beings to notice each other and discern shared participation in the creative reconfiguration of the earth. Whereas this research focused on biomaking, its principles extend towards all making practices considering the active participation of materials and technologies in the collective making and remaking of the earth.

Conclusion

We explored the pluriverse creativities as a space to study making as an embodied process by which a multiplicity of entities and elements give rise to the forms and features of the world. By recognizing the intricate ways natural and artificial forces build and grow upon each other, we aim to advance understandings of making in which humans are not in a position of management and control but instead immersed in a complex socio-ecological world in ongoing material reconfiguration. This way, rather than trying to save the planet through making, we invite makers to join the earth in its creative dynamics and regenerative capacity. Recognizing the challenges ahead, we look forward to new paths in maker education where students and other beings can learn from each other through productive differences, create collective sense-making, and move towards novel togetherness.

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Three Chronotopes for Humanizing the Language of Mathematics

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Abstract: This paper explores how discourse practices in advanced mathematics can center, rather than obscure, the human role and experience in the discipline. Inspired by renewed calls to humanize mathematics (R. Gutiérrez, 2018), I draw on Bakhtin's (1981, 2010) notion of chronotope (space-time configuration), to conceptualize three types of moves that humanize mathematical discourse. The humanizing moves are characterized by the space-time scales of human activity they evoke: (1) here-and-now experience doing math, (2) social-historical context of math activity, and (3) cultural-discursive hybridity. I illustrate the three categories with excerpts from Real Analysis lectures. While the illustrative data are from a proof-based university math course, the intended contribution of the paper is theoretical and the categories are applicable to other contexts and modality of math communication as well.

Introduction

Math, and in particular, contemporary academic math (i.e. the discursive practice of research mathematicians), is often experienced as alienating and decontextualized from human issues and experiences (Davis & Hersh, 1981; Schoenfeld, 1994), especially among students who are already underrepresented and marginalized in the discipline (R. Gutiérrez, 2018; Herzig, 2004). One aspect of practice that contributes to such feelings of alienation are the discipline's norms of talking and writing (Lemke, 1990). Language practices in contemporary academic mathematics are centered on the register of the formal text, which is known to obfuscate human agency, e.g. through linguistic devices such as passive verbs and nominalization (Burton & Morgan, 2000). These dehumanizing features are pervasive in part because they help constitute the community's epistemic goals of creating abstract, indubitable, objective and universal knowledge (Hersh, 1991). Language choices, however, are not set in stone. In communication contexts such as lectures, instructors can embellish the textual register with movement, speech and inscription that put "humanity in the machine" (Shaw, 2001, p. 27) and have the potential to cultivate a feeling of disciplinary belonging for students (Rodd, 2003).

The term humanizing has been gaining popularity in mathematics education in recent years, following R. Gutiérrez's (2018) call to shift away from mainstream equity discourses, which are obsessed with "fixing" students' (perceived) deficits and hence counterproductive (Adiredja, 2019; R. Gutiérrez, 2018), to a conversation that focuses instead on how classroom mathematics itself can be reconfigured to better reflect the human beings it lives through and serves. Yet, despite the increased popularity of the term, there is no clear agreement on what humanizing actually means or looks like in concrete mathematical interactions. In this paper, I aim to unpack what humanizing can mean for communication in contemporary academic mathematics. I propose a framework for thinking about this issue and illustrate how lecturers' small discursive moves in advanced math courses can contribute to a more humanizing experience and image of the discipline.

What about mathematical language and interactions can be humanized?

What might we mean by *humanizing* mathematical language? R. Gutiérrez (2018), for example, listed eight (non-exhaustive) dimensions along which math classrooms can be rehumanized for "students and teachers who are Latinx, Black and Indigenous… They include (1) participation/positioning, (2) cultures/histories, (3) windows/mirrors, (4) living practice, (5) creation, (6) broadening mathematics, (7) body/emotion, and (8) ownerships." (p. 4) This list casts a wide net. Other scholarship focuses more specifically on one or two of these issues, and does not necessarily frame them under a single umbrella term such as humanization. Also, in contrast to R. Gutiérrez's work, the starting point for other research is not necessarily the concerns and experiences of marginalized students. Nevertheless, similar aspects of discourse are taken up. For example, in the embodied cognition tradition, researchers attend to how mainstream math teaching discourse, seeped in Cartesian dualism, can devalue and make invisible important affective and embodied resources by focusing primarily on seemingly 'mental' processes, abstraction and formalism (e.g. J. Gutiérrez, 2018; Núñez et al., 1999). In the social-semiotics tradition, researchers studied the linguistic features of written mathematics, such as academic research articles and textbooks, to highlight how pervasive practices such as nominalization (turning verbs into nouns; e.g. "I counted" to "counting" to "a count") and the use of passive voice (e.g. "as shown by the count in theorem 2.7") contribute to the obfuscation of human agency in the creation of mathematics (Burton & Morgan, 2000). Rotman (1988), building on Pierce's semiotic theory, observed that mathematical texts make extensive use of inclusive imperatives such as "formalize" "define" and "let", and suggested that these are instructions for an abstract semiotic agent he called "Subject". The Subject is an idealized reader and writer of the text, a decontextualized scribbler that does the epistemic work of mathematics. Importantly, this idealized writer-reader has no social identity, nor is it situated in any cultural-historical context. It does not have preferences, goals, nor does it get excited or scared. There is nothing besides text and cognition in the universe the formal text evokes.

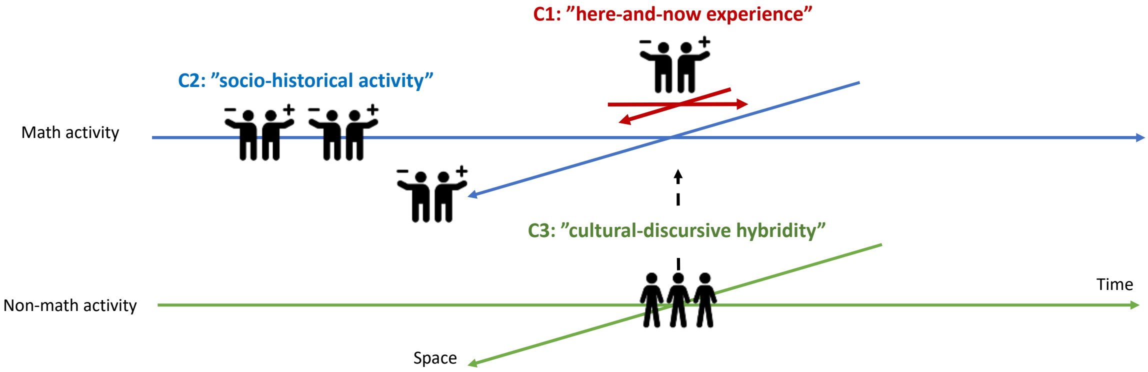
Humanizing mathematical language through three space-time scales

To provide room for human experience, mathematical texts need to construct a world in which human beings can be situated. Bakhtin's (1981, 2010) concept of chronotope is a useful tool for thinking about how this can be accomplished through language. In his study of the evolution of the novel as a literary genre, Bakhtin coined the term chronotope (in Greek, "time-space") to refer to "the intrinsic connectedness of temporal and spatial relationships that are artistically expressed in literature." (p. 84). This construct allowed Bakhtin to effectively contrast and characterize different novel types (e.g. adventure, metamorphosis, biographical novel), which in turn allowed him to track the historical evolution of the genre through concrete examples of texts. Important for my purpose here is that a text's chronotope "determines to a significant degree the image of man… The image of man is always intrinsically chronotopic." (Bakhtin, 1981, p. 85)

In this paper, I use the concept on a much smaller scale of speech genres (Bakhtin, 2010) to characterize three broad types of mathematical utterances that can be humanizing. I propose that human experience in mathematics can be discursively situated in three time-space arenas: (1) the here-and-now experience doing math, (2) the social-historical context of math activity, and (3) cultural-discursive hybridity. Figure 1 illustrates these three chronotopes within a single space-time diagram. The first chronotope (in red) is about the in-the-moment experience, the micro-genesis of doing math. The second chronotope (in blue) expands both the space and time scales, attending to the synchronic and diachronic dimensions of activity; it invites us to look at how math is a collective cultural practice, spanned across historical time and across socio-geographic space. The third choronotope (in green) entails a further expansion of space-time, inviting us to consider other discourses and cultural-historical activity systems that are parallel, interwoven, and seep to and from the social history of what we typically label as "mathematical".

Figure 1

A chronotopic framework for situating the human in mathematical discourse



This conceptual framework was developed in the context of a video based micro-ethnographic study (Derry et al., 2010; Erickson, 1992) of language practices and ideologies in an advanced math university course called Real Analysis. The data corpus consists of video recordings of lectures and auxiliary documents (e.g. lecture notes) from Real Analysis courses taught in a large research-oriented university in the United States. The study's participants are five research mathematicians who taught the observed lecture-courses. Data was obtained in two rounds of data collection: one course in Spring 2015 (taught by Henry, in person), and four courses in Fall 2020 (taught online by Alex, Cai, David and Emmett). In this paper, for coherence, I only use data from Henry's lectures. These data were analyzed first and feature a large amount and variety of moves that can be humanizing.

The framework emerged through inductive coding of transcripts and document data (Saldaña, 2021). The focal question orienting analysis was: What aspects of advanced math lecture discourse may contribute to a more humanizing experience and image of the discipline? In an initial round of coding, I flagged and labeled lecturers' discursive moves that I broadly interpreted as humanizing. This process generated a long list of codes such as "performed affect", "personification" and "out-of-math metaphors". I then synthesized the codes into broad categories. Bakhtin's chronotope construct was then brought in to help characterize the categories and situate them within a single coherent theory. The resulting framework, of three chronotopic scales for humanizing mathematical discourse, is operationalized and exemplified in the sections below.

An important caveat is in order. I do not claim that the examples provided below were indeed experienced as humanizing by the students attending those lectures. Nor that these moves should or are likely to result in a humanizing reaction for most readers. How utterances are responded to is a function of context and of the interpretive repertoire that each individual addressee draws on. This is always true, but particularly salient for the third chronotope, as different experiences with 'out of math' discourses and activities shape how such references are taken up. My initial flagging of episodes as potentially humanizing certainly involved subjective judgement. When making these determinations, I drew on my experience as a student in advanced mathematics courses (in both my undergraduate and graduate education), and my ongoing work as a university math instructor. My experience and positionality as a white immigrant woman in the US have no doubt influenced these interpretations as well. Thus, rather than claim a definite humanizing effect, my intention is to convince the reader that certain *types* of discursive moves are worth considering to humanize math talk. Ultimately, the efficacy of deploying any such move in interactions rests upon deep familiarity with the background and perspectives of one's interlocutors.

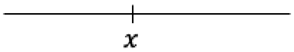
Chronotope 1: Multidimensional here-and-now experience doing math

How do we talk about and enact the in-the-moment experience of doing math; how does mathematical activity *feel like* to the person doing it? If we look at the formal register, the language of formal mathematical texts, the vast majority of actions are attributed to an abstract agent (Rotman, 1988) and are cognitive and epistemic in nature. But when actual people engage with math, they do more than "consider", "assume" or "know". They also have affective experiences such as excitement and fear, they imagine pictures and motion, and they have bodily experiences moving in and around inscriptions and virtual mathematical landscapes (Ochs et al., 1996). These experiences are rarely reported on in writing, in part because that would jeopardize the epistemic goal of the text by making the mathematical ideas bound to the concrete human body. An abstract free-floating cognitive agency "assumes," but *a person* also feels, imagines, and moves.

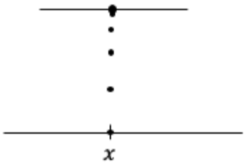
Example 1.1: Embodied interpretation

When math is done by humans, it is always done with bodies and material artifacts (Núñez et al., 1999). Mainstream discourse about math, seeped in traditions of mind-body dualism, tends to erase or at least decenter the material and bodily aspects of math activity (J. Gutiérrez, 2018). Bodies either do not exist at all, or are inconsequential. One way to humanize math, to frame math as done by actual human beings, is to explicitly talk about and enact the body in mathematical activity. The example below illustrates how attending to the body can be done in lectures within the specific context of "interpreting formal definitions", a discursive practice central to academic math. The episode begins after Henry finished writing the formal definitions for pointwise and uniform continuity. Actions are described in double brackets (( )). Inscriptions are reproduced within the transcript as well.

1 The question is what image do I get in my mind. So, let's try to see this one here
2 ((points at 'pointwise' convergence condition, sketches a diagram)). My image of it is



3 It says. For every x in S. OK. So, let me stand on x. What does it then say? It says that
4 fn of x minus f of x should be less than epsilon. That means that the fn of x <u>converges</u>
6 to f of x. So, that simply means going up going up going up and converging to a point



7 over there. I have (been)- ((stomps feet)) I stand on a point ((pulls fists down)) and
8 then I look (at) ((raises hands up)) fn going up to the point that's sitting up there.
9 That's my feeling of it.

The interpretation is personal. Henry speaks with the voice of an "I" when he says "what image do *I get in my* mind*"* (line 1), "*my* image of it is" (line 2) and "that's *my* feeling of it" (line 9). He also inserts himself into the graph: “let me stand on x” (line 3), “I stand on a point” (line 7), and “I look at” (line 8). Henry constructs a subjectivity that imagines (lines 1 and 2) and feels (line 9). This subject imagines moving in and around the world of inscriptions (Ochs et al., 1996); he “stands” on a point and looks at function values “going up going up going up” to a point above. But this is not just visual imagery. It is a full body experience. To “stand on x” Henry firmly stomps his feet on the ground and holds his hands tight to stay put (lines 8-9). Looking up involves raising his hands and pointing up in the graph (line 9). The subjectivity Henry enacts is vastly different than the one in the formal math text (in fact, the definition text Henry wrote does not refer to a human subject at all). Henry’s “I” is one that imagines and feels, not just “considers” and “defines.” And it does this imagining with a body.

In this episode, Henry enacted interpretations of the pointwise convergence definition using language and gestures that depict an embodied experience. These interpretations explicitly evoked and mobilized the whole body, and in so doing, conveyed the idea that math is felt and that we do it with our whole body.

Example 1.2: Emotional reactions and stances

Discourse about math and math learning often describes “cold” cognition (Pintrich et al., 1993). However, whenever people do math, they do not cease to have feelings. Emotions and emotional stances toward the objects of activity are not only part of mathematical experience, but also central to it. It is often the very emotions bundled up with the math that propel our mathematical activity forward (Jaber & Hammer, 2016). Thus, one way to more accurately and expansively depict what math *feels like* in the moment, is to explicitly center emotional reactions and stances in our discourse in and about math.

In the observed lectures, there were many instances of instructors displaying affective reactions to the math they were talking about. At times, affective stances were labeled explicitly (e.g. “I’m scared” or “I’m excited”). Most often, however, affect is conveyed through describing the object of focus and through other modalities such as prosody and gestures. The excerpt below illustrates this latter type of “performed affect.” In this episode, Henry discussed errors in recalling the radius of convergence formula ($\mathcal{R} = \frac{1}{\overline{\lim}\sqrt[n]{|a_n|}}$):

1 Some people were confused about $\mathcal{R} = \overline{\lim}\sqrt[n]{|a_n|}$. That’s of course wrong.
2 [should be] one divided by it $\mathcal{R} = \frac{1}{\overline{\lim}\sqrt[n]{|a_n|}}$. That’s why it’s a bad way of remembering it.
3 In some sense, the best way of remembering it is $\overline{\lim}\sqrt[n]{|a_n||x|^n} < 1$. Right?
4 That’s a lim sup. That’s maybe the most natural way of remembering it.
5 I know this is this horrible beta ( ) instead of 1 over R

The episode ends with a display of an affective stance (Ochs, 1996) toward a “horrible beta” (line 7). The word “beta” refers to terminology introduced in the textbook $\beta = \lim\sup|a_n|^{\frac{1}{n}}$. What I wish to call attention to is Henry’s use of the the adjective “horrible”, which enacts an affective stance toward the mathematical signifier. What makes the beta horrible? And importantly, to whom? The beta is not “horrible” in a platonic mathematical universe. It is horrible to Henry (and possibly students) in the here-and-now and perhaps also in past experiences of encountering the signifier (e.g. when reading the textbook). Thus, this affective stance marker centers the here-and-now experience of people doing math. The overt affective display constructs engagement with math not as an unemotional view from nowhere, but as a person that can get intimidated by the presence of symbols.

Chronotope 2: Socio-historical context of math activity

The first chronotope entailed zooming in on how it *feels* to do math *in-the-moment*, attending to how mathematical experience is, like any other human experience, multidimensional. In particular, doing math is not purely a cognitive and epistemic experience; it involves affective, somatic, and aesthetic dimensions as well. In the second chronotope, we zoom out and look at the broader socio-historical context of mathematical activity.

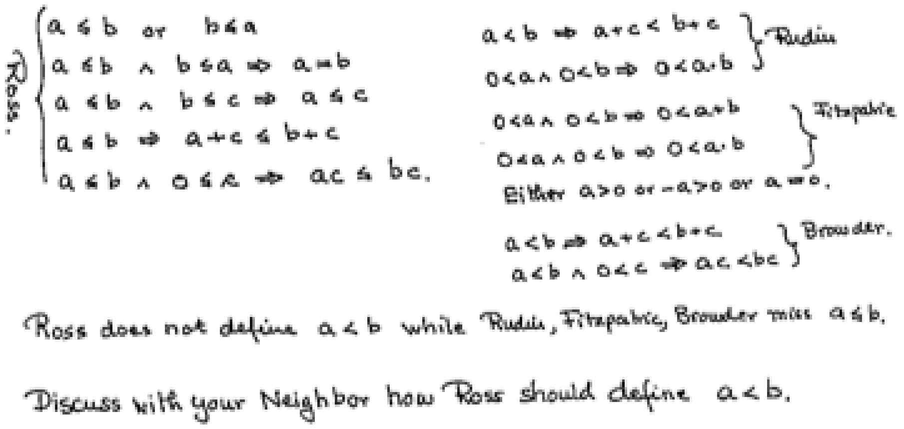
Doing math is not just a random experience that people come to have. Mathematical activity is a *social* practice (Schoenfeld, 2016); it has a history and it is shared by a community of other people who “do math”, past, present and future. That is, mathematical experience is part of a cultural-historical activity system (Cole, 1998). The socio-historical context of mathematical activity is not typically centered in disciplinary discourse, with the formal register often avoiding it altogether. The history of mathematics – the fact that mathematical texts such as definitions and theorems were and continue to be *written by people*, based on decisions, errors, circumstances, purposes and preferences – is rarely discussed in official texts. Likewise, the fact that mathematical texts are not decontextualized archives of truths but rather artifacts that people use (today and in the past) for different kinds of purposes and in different kinds of ways is not emphasized. If mathematical texts were to be historically contextualized, they run the risk of being seen as historically contingent, of being one of many possible alternatives, and thus lose their status of universality and objectivity.

Example 2.1: Authorship, social persona and choice

One way to portray mathematical activity as situated in socio-historical context is to explicitly attribute authorship to mathematical text units (e.g. theorems, definitions and proofs). In the formal register, mathematical text units often come from "nowhere". Definitions are "defined" by abstract semiotic agents (e.g. "we define a metric …") or there is no agent at all (e.g. "a metric is defined…"). In contexts of practice, however, definitions are always written by people. These people have names, purposes, and preferences. Classroom discourse can highlight that. As an example, consider the following excerpt from Henry's lecture notes (shown in Figure 2 below).

Figure 2

Lecture notes excerpt inviting students to compare definitions in four textbooks



Ross.
$a \le b$ or $b \le a$
$a \le b \wedge b \le a \Rightarrow a = b$
$a \le b \wedge b \le c \Rightarrow a \le c$
$a \le b \Rightarrow a + c \le b + c$
$a \le b \wedge 0 \le c \Rightarrow ac \le bc.$

$a < b \Rightarrow a + c < b + c$
$0 < a \wedge 0 < b \Rightarrow 0 < a \cdot b$
Rudin

$0 < a \wedge 0 < b \Rightarrow 0 < a + b$
$0 < a \wedge 0 < b \Rightarrow 0 < a \cdot b$
Either $a > 0$ or $-a > 0$ or $a = 0$.
Fitzpatric

$a < b \Rightarrow a + c < b + c$
$a < b \wedge 0 < c \Rightarrow ac < bc$
Browder.

Ross does not define $a < b$ while Rudin, Fitzpatric, Browder miss $a \le b$.

Discuss with your Neighbor how Ross should define $a < b$.

In the above notes, Henry presents excerpts of definitions from four different textbooks, one for the sign (top left, labeled "Ross") and three others for the sign (top right, labeled "Rudin", "Fitzpatric" and "Browder"). Presenting these definitions side-by-side invites students to engage in a mathematical practice that is ubiquitous in mathematicians' day-to-day work, yet not often centered in pedagogy: comparing and contrasting alternative definition formulations for "the same" (or similar) mathematical object. Designing a classroom task that mimics this practice is an interesting pedagogical move in and of itself, but what I wish to highlight for the purpose of the discussion on humanization is that Henry does not "just" ask students to compare features of different definitions. By labeling each definition by its respective textbook author Henry associates them to people. This does not only raise the consideration of alternatives but further suggests that these definitions were chosen and written by specific people, identifiable by their last name.

Furthermore, the verbs in the next sentence in the notes ("Ross does not define $a < b$" and "Rudin, Fitzpatric, Browder miss $a \leq b$") explicitly attribute definition formulation as an action by the mentioned authors. Ross, Rudin, Fitzpatric and Browder are presented here as agentic mathematical actors that choose between alternatives (even if not knowingly, as suggested by the verb "miss"). Such a formulation promotes an image of mathematics as a living practice (R. Gutiérrez, 2018), one that "… underscores mathematics as something in motion. When students can see mathematics as full of not just culture and history, but power dynamics, debates, divergent answers, and rule breaking, it highlights the human element and helps promote a vision that is a verb rather than a noun" (p. 5). While this excerpt from Henry's notes does not go as far as revealing "behind the scenes" power dynamics, it does suggest at least the possibility of debate. What we see in this example from Henry's notes is more than just attaching a name to a mathematical text unit (a common practice in math texts, e.g. "Cauchy's theorem"). Here, the names are positioned as agents. They perform actions such as "define" and "miss" and students are invited engage in mathematical activity from these agents' perspectives

Chronotope 3: Discursive hybridity

In the first two chronotopes we looked at the human experience in mathematical activity on different time scales; the micro (chronotope 1), and meso and macro (chronotope 2). Each dimension further involved an expansion of features and contexts under consideration. From a cognitive micro experience, to one that is also affective and multimodal. From decontextualized abstract math, to one that incorporates various mathematical histories and futures. So far, we stayed within contexts that are traditionally considered mathematical. However, mathematical activity is just a small fraction of the human experience. For people to feel fully human in math classrooms, to be reflected in mathematical interactions, non-mathematical discourses and activities should permeate too (R. Gutiérrez, 2018). Such a hybridization of math language does not only affirm students; it can also expand the mathematical meaning potential to new contexts, thus enriching mathematics itself (Adiredja & Zandieh, 2020).

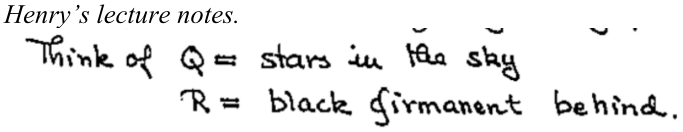
Looking at the textual register and many math classrooms, one may have the impression that other human activities and discourses do not exist. Written texts will sometimes reference "applications" in other STEM fields, but that is as far off from "pure" math that the text would stir from. But no activity is ever in isolation, and no discourse is ever entirely separated from other voices. Hybridity is an inherent feature of all languages (Bakhtin, 1981), and so too in math, other voices seep through. This chronotope invites us to celeberate this feature of language, and strategically furnish math talk with voices that index other spheres of social activity, those typically considered outside of the discipline. Rather than demarcating disciplinary boundaries (e.g. "now we are talking 'off topic'"), it highlights discursive moves that enact mathematics as blended, permeable and truly diverse.

Example 3.1: Out of math context as a metaphorical resource for mathematical concepts

One way to hybridize the discourse in math classrooms is to use out-of-math contexts or situations to make sense of mathematical concepts. Everyday experiences are a powerful resource for making sense of mathematical ideas, and also used by experts (Sfard, 1994). Yet, the role of out-of-math experiences in mathematical understandings are rarely discussed out in the open. In advanced math courses such as Real Analysis, even when "informal" interpretations are allowed, the evoked context (e.g. physical-dynamical models such as moving graphs) still tends to be removed from the everyday world. The example below (Figure 3), taken from Henry's lecture notes, illustrates how the everyday activity of "looking up at the night sky" can be leveraged to make sense of the relationship between the sets of real and rational numbers.

Figure 3

The night sky context as the sets of Real and Rational numbers, Henry's lecture notes.



Think of $\mathbb{Q}$ = stars in the sky
$\mathbb{R}$ = black firmament behind.

In this excerpt, Henry invites students to think about $\mathbb{Q}$ (the set of all rational numbers) and $\mathbb{R}$ (the set of all real numbers) in terms of two parts of the night sky: the stars and black background "behind" them. The metaphor helps highlight important properties of these two sets: the set inclusion relationships $\mathbb{Q} \subset \mathbb{R}$, and the density of $\mathbb{Q}$ in $\mathbb{R}$. It illustrates the crucial and complex idea of different types of infinity. Of course, the metaphor has limitations. Because the stars and the black firmament are distinct entities in the metaphor, it may suggest that $\mathbb{Q}$ is not contained in $\mathbb{R}$ (which is wrong per normative usage of the terms). But metaphors are not powerful because they are absolutely correct. When mathematicians leverage metaphors as tactical tools of sense making in local contexts, they capitalize on their affordances all the while acknowledging their limitations.

It is important to exploit metaphors, not only because they buttress the mathematical sense-making of experts (Sfard, 1994), but because they are humanizing. They provide important spaces for intersection between official mathematical texts and students' lived experience (Adiredja & Zandieh, 2020). In this example, Henry's invocation of the night sky context may provide students with opportunities to connect everyday experience with mathematical ideas. A student can recall or imagine themselves looking up at the night sky, and use that rich and imaginative experience as a sensemaking resource in the classroom. And perhaps more importantly, by explicitly referencing this metaphor in the notes, Henry does not only invite students to make sense of numbers in terms of the night sky. This move implicitly sanctions the practice of leveraging everyday experiences for mathematical sense making as a legitimate resource in advanced mathematics. It makes drawing on everyday experiences not only "allowed," but encouraged.

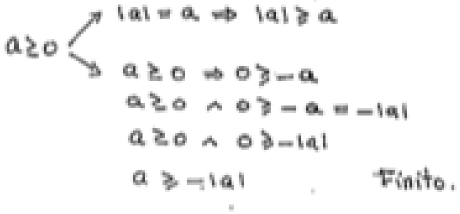
Example 3.2: Using language resources not typically associated with math

In the previous example, we looked at how an everyday situation ("looking up at the night sky") can be evoked to make sense of mathematical ideas. Next, I would like to examine how math lectures can use various types of language resources from spheres of human activity not commonly associated with math (e.g. MEMEs, slang words, everyday forms of speech, etc.). Why is seeing social diversity in the language of mathematical activity important? This goes back to R. Gutiérrez's (2018) idea of Mirrors/Windows and to a general call for more diverse representation in mathematics. Bringing in out-of-math language forms can help youth see themselves reflected in the activity. The more we diversify the language practice, the more diverse forms of self can be reflected in "official classroom discourse," the more inviting the space becomes. By using particular words, phrases, even intonations, a speaker can invoke out-of-math voices that make the activity feel a bit more familiar. What's humanizing about it is the idea that as people doing math, we are also always embedded in other discourses, and bringing resources from those other discourses acknowledges that aspect of our humanity. As with out-of-math metaphors and contexts, out-of-math language resources is not only *for students*. Rather, making disciplinary boundaries more permeable has the potential to enrich mathematics itself.

The example below (Figure 4) can serve as a small illustration of this. In the third lecture in the semester, Henry wrote a proof of the $a \geq 0$ case of the inequality $-|a| \leq a \leq |a|$ in the following way:

Figure 4

Lecture notes excerpt: Finito in place of Q.E.D.



$$a \geq 0 \begin{cases} |a| = a \Rightarrow |a| \geq a \\ a \geq 0 \Rightarrow 0 \geq -a \end{cases}$$

$$a \geq 0 \wedge 0 \geq -a = -|a|$$

$$a \geq 0 \wedge 0 \geq -|a|$$

$$a \geq -|a|$$

Finito.

What stands about this example in terms of discursive hybridity is the use of the word "finito" at the end of the proof. It is common to mark the end of mathematical proofs. Two commonly used signifiers to mark ends of proofs in math are: "Q.E.D.", which initializes quod erat demonstrandum (in Latin "which was to be demonstrated"), and the tombstone symbol , imported into mathematical usage by Paul Halmos. In contrast to these two standard forms, Herny's use of 'finito' is idiosyncratic. The word is borrowed from Spanish and Italian, where it means "finished" or "finite". In English, it might evoke a playful connotation. Thus, using the word "finito" instead of the more traditional or Q.E.D can lighten, or signal a feeling of relief (though an addressee's actual take-up such connotations dependents on their familiarity with and acceptance of the word's playful usage). Finally, as with the above example of using an out-of-math metaphor, using such a word in the notes can sanction similar kinds of language-blending for students too, using terms and references they are more familiar with.

Discussion and conclusions

In this paper, I argued that Bakhtin's (1981, 2010) chronotopes are a useful tool for conceptualizing the discursive construction of human-math relations. I proposed three mathematical chronotopes – (1) here-and-now experience of doing math, (2) social-historical context of math activity, and (3) cultural-discursive hybridity – as concrete arenas for situating the human in mathematical discourse. I provided illustrations of small discursive moves in advanced math lectures that can be considered humanizing in terms of these three broad categories.

The proposed framework can be used to humanize advanced mathematical language in two ways. On one hand, it can help scholars and university math educators who routinely observe talk in advanced math courses notice humanizing discursive moves lecturers make. This includes researchers who use lecture discourse as data, practitioners who observe lectures for the purposes of peer-evaluation and feedback, and instructors, who may reflect on how they themselves talk and routinely evaluate the talk and writing of students. I suggest that the moves I highlighted are helpful for humanizing, and thus critically important to note in the talk of both instructors and students. Second, I aim the framework to be helpful to instructors who want to humanize their lectures but are not sure where to start in tackling this broad and perhaps vague objective. What I offer is three dimensions to think with, and some examples of things one might try in classroom talk or writing. This is not a one size fits all recommendation of "pedagogical tricks." I provided examples of one lecturer's moves, and hope these can function as a springboard for new ideas about how advanced math discourse can be humanized.

There is no intention or presumption that this study gives a definitive answer to what humanizing math lecture discourse is or can be. Such an objective is neither feasible nor desirable. Arguably, any researcher's attempt to give a definitive answer in a top-down manner is in itself dehumanizing (Vossoughi & Gutierrez, 2016). Rather, I aimed to provide an initial conceptual framework and empirically grounded taxonomy of discursive phenomena that can be considered humanizing in advanced mathematics lectures. This objective – of descriptive detail and theoretical grounding – is motivated by the assumption that the resulting language can help practitioners talk about "teaching math in a humanizing way" in ways that will better support us to consciously and collaboratively work toward this goal. Simply agreeing to "teach math in a humanizing way", or tell others to do so, without agreeing on what that means in the micro-detail of classroom practice is not sufficiently specific as a description of practice to be actionable (Erickson, 1992).

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Literacy for Knowledge Building in Two Partnering Science Classrooms

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Abstract: Using an interactional ethnography approach, this study analyzes student literacy practices in two Grade 5/6 classrooms that engaged in a science inquiry organized based on the Knowledge Building pedagogy. Students studied human body systems for 10 weeks with the support of Knowledge Forum. While students conducted collaborative inquiry in each classroom, a shared meta-space was available for cross-classroom collaboration. Analysis of classroom observations, interviews, and online discourse elaborated five core features of literacy for knowledge generation, which integrates reading, writing, and dialogue across multiple inquiry forms, media, and discourse spaces for sustained knowledge building.

Introduction

In an open informational world with constant changes, education needs to prepare students as critical knowledge consumers as well as knowledge generators, who can work with multiple sources of information to develop creative solutions to challenging problems. As a specific change, the pervasive use of digital technologies has transformed traditional reading and writing, changing from reading single source documents for comprehension to reading across sources, forms, and media platforms for creative problem solving (Leu et al., 2004; Liu, 2014; Goldman & Scardamalia, 2013). In reflection of these changes, education reforms call for efforts to develop productive literacy that supports knowledge generation in different subject areas (Council of Chief State School Officers, 2010; National Council for the Social Studies, 2013; NGSS Lead States 2013; Ontario Ministry of Education, 2013; Wright & Domke, 2019). To meet this demand, educators need to better understand what such new literacy looks like in practice and how to support students of various age groups in literacy engagement.

Content literacy teaching used to focus on supporting students' role as knowledge consumers; literacy to support authentic disciplinary practices needs to additionally support student knowledge generation. What does such literacy for authentic disciplinary practices look like? Goldman and colleagues (2016) identified literacy related to five core constructs of disciplinary practices: epistemology (beliefs about the nature of knowledge and knowing); inquiry practices and reasoning strategies; overarching concepts and principles; types of texts and media in which information is represented and expressed; and discourse and language structures essential to the disciplinary practices. As literacy for science practices, students engage in close reading of science information to construct knowledge that involves multiple representations, synthesize information from multiple sources, construct explanations of various phenomena, justify and critique explanations using science principles and evidence, and understand the nature of scientific discourse. These core constructs represent key features of "reading for understanding" that supports evidence-based argumentation using multiple information sources.

Complementing the above framework that focuses more on reading, researchers underline writing and dialogue as tools of disciplinary inquiry (Applebee et al., 2003). Reflecting on how technology transforms reading and writing, Bereiter and Scardamalia (2005) proposed the concept of *dialogic literacy* as an alternative to print literacy. Dialogic literacy refers to "the ability to engage productively in discourse whose purpose is to generate new knowledge and understanding." (Bereiter & Scardamalia, 2005, p. 758) Such discourse involves careful and genuine listening, understanding different perspectives, building on others' ideas, developing common ground, and negotiating new ideas and challenges beyond the status quo. Researchers further emphasize the shift of reading, writing, and sensemaking in networked environments. A group of researchers (Liu, 2014; Thomas et al., 2007) developed the concept of *trans-literacy*: the ability to read, write and interact across a range of platforms, tools and media from signing and orality through handwriting, print, to digital media and social networks (Thomas et al., 2007). Given the pervasive use of digital and interactive environments, researchers call for efforts to incorporate trans-literacy as an important part of disciplinary literacy (Goldman & Scardamalia, 2013). Such high-level literacy is essential to scientific sensemaking in which students not only comprehend given information but also continually identify problems of understanding, search for and work on potential ideas, and develop coherent explanations that make sense (Odden & Russ, 2019).

This study investigates disciplinary literacy in a student-driven, open-ended inquiry organized based on the Knowledge Building (KB) pedagogy. KB aims to transform classrooms into knowledge-building communities in line with how knowledge creation takes place in the real world (Scardamalia & Bereiter, 2006). Students not only work on pre-defined problems and tasks, but also identify new and deeper problems based on their interests and needs. The space of problems continues to evolve as student understandings advance, driving ever-deepening inquiry processes. Networked environments, such as Knowledge Forum (KF) (Scardamalia & Bereiter, 2006), are used to support knowledge building discourse and processes. KF provides a collective knowledge space that gives student ideas a public permanent representation. Students contribute to ongoing conversations by sharing and building on each other's ideas. They continually identify new/deeper problems while their understanding deepens. Recent research further expands student interaction and collaboration to a larger social context. Students not only collaborate with their own classmates but also share their knowledge advances in a meta-space accessible to a network of classrooms (Laferrière, Law, & Montané, 2012; Zhang et al., 2020). They engage in collaborative inquiry as members of a community who also learn from and reference the works of other communities.

Several studies have examined student literacy practices in knowledge building communities. Sun and colleagues investigated how students engaged in productive writing and reading as an integral part of their knowledge building in science and social studies (Sun et al., 2010; Zhang & Sun, 2011). Their reading practices demonstrate new features: reading for advancing the knowledge of their classroom community; reading for continual problem finding and solving; reading embedded in ongoing knowledge building discourse, both online and offline; and connecting student knowledge with knowledge built by others in the larger world (Zhang & Sun, 2011). A two-year study traced students' online discourse during Grades 3-4 to examine vocabulary growth. Knowledge building discourse served as an authentic context for students to use and expand productive vocabulary, including academic vocabulary and domain-specific words. Their use of high-order vocabulary positively correlates with their participation rate in collaborative knowledge building (Sun et al., 2010). In a more recent study, Hong and colleagues (2020) found that children who engaged in knowledge-building inquiry outperformed those receiving traditional instruction in an assessment of reading. Beyond reading and writing of text, students also incorporated rich graphic representations in their online discourse (Gan et al., 2021).

Building on the above studies, the current study aims to depict a more comprehensive picture of disciplinary literacy for knowledge generation. Our conceptual lens integrates the above-reviewed concepts of disciplinary literacy (Goldman et al., 2016), dialogic literacy (Bereiter & Scardamalia, 2005) and trans-literacy (Liu, 2014; Thomas et al., 2007). Through the analysis of rich classroom data, we hope to capture how students read, write and interact across multiple sources, forms and spaces to advance their knowledge. As an expanded context for knowledge building, the current study included a cluster of classrooms that conducted collaborative inquiry supported by an online environment. Students engaged in cross-classroom interaction organized using a multi-layer model (Zhang et al., 2020). While members of each individual classroom pursued collaborative inquiry and discourse to deepen their understandings in a domain area, they had access to a cross-community space ("meta-space") where they shared their knowledge advances and challenges with other classrooms that studied the same curriculum area. As a common structure for synthesizing and sharing knowledge advances, students working on a shared problem or topic co-authored a "super note" that included three sections: Questions explored, "big ideas" learned (framed as "We used to think…now we understand…") and deeper research needed. The super notes were shared in the meta-space, as boundary objects (Star & Griesemer, 1989), to support cross-classroom discourse. In this context, our data analyses address an overarching question: What characterizes student literacy practices essential to their collaborative knowledge building? As part of this question, we were also interested in the teachers' role in supporting student engagement of disciplinary literacy.

Classroom context

This study analyzed student literacy practices in two Grade 5/6 classrooms based on the dataset generated in our research project focused on cross-classroom collaboration for knowledge building (Zhang et al., 2020). Two teachers taught science in the two classrooms: Mr. B and Mr. M. Both teachers had multiple years of teaching experience; Mr. B was more experienced with teaching science using the KB pedagogy and technology. There were 24 students in Mr. M's room and 23 students in Mr. B's room.

The two classrooms studied human body systems for 10 weeks with the support of Knowledge Forum (KF) (Scardamalia & Bereiter, 2006). On an ongoing basis, students in each classroom contributed and built on each other's ideas. With their teacher's support, students in each classroom generated questions about the human body that stemmed out of students' interests, put forth initial ideas, and then subjected these ideas to testing through observations, experiments, and peer discussion to improve them. They read books and online materials and conducted knowledge building talks in small groups and as a whole class to share and build on one another's ideas. They further continued their discourse and interaction online in KF. Students in each classroom worked in their home class views (workspaces), where they read and built on peers' ideas in the online discourse. At the same time, they had access to the "Super View" that was shared between the two classrooms. A visual was added to the Super View consisting of two trees with a number of branches where super notes about various inquiry topics could be placed (see Figure 1). As they made progress in various lines of inquiry, students created syntheses of their journey of thinking, which were called "super notes." Each super note was structured using the following scaffolds*: Our research topic and problems…, We used to think…Now we understand…, We need deeper research*. Prior to this study, several classrooms from two schools had studied human body systems and created super notes. These achieved super notes were also shared in the Super View.

Figure 1

The "Super View" for sharing super notes (Journey of Thinking syntheses) across classrooms.

Super Note about the Nervous System and the Spinal Cord (Ideas from Ben's Grade 5/6 Class)

[redacted]
2016-05-02
14:16

We used to think - that the nervous system didn't have to do anything with the spinal cord. Also, we used to think that the brain was the only part of the nervous system. -

Now we understand - That the spinal cord is actually the main part of the nervous system, and that the nervous system works by sending messages from the reaction nerves to the brain by traveling through the spinal cord to the brain. The spinal cord travels through the spine, so the spine has a very important role in the nervous system (Even though it isn't part of the nervous system). -

We need deeper research - On what the nerves are actually doing when they react and how do they determine the intensity of the reaction. -

The teacher in each classroom first introduced the Super View in the third week of the inquiry when their students had generated their own questions and conducted initial research about the various topics related to the human body. Students read the Super Notes from the previous classes and reflected on what they could learn from the questions and ideas. Once students conducted deeper research in each classroom in the next two to three weeks, students working on various themes started to create super notes to summarize their progress for sharing with their own classmates as well as with the other classroom. Students from the two classrooms read each other's super notes and discussed insights gained.

Data sources and analyses

This study analyzed student literacy practices in the human body inquiry as a telling case. Our data sources included classroom observations of the science lessons (11 from Mr. B and 8 from Mr. M), video recordings of whole-class discussions and small-group work, records of online discourse (146 notes from Mr. B's classroom, and 243 from the class of Mr. M), 16 super notes shared between the two classrooms, and student and teacher interviews. A researcher interviewed 13 students from the two classrooms focusing on how they pursued their inquiry, created super notes, and read and learned from the super notes of the partner classroom.

Our data analysis used an interactional ethnography approach, which offers a logic of inquiry for investigating what learners do and construct in a temporal sequence of events as viewed through multiple levels of analysis (Green & Bridges, 2018). As the main data sources, we analyzed the classroom observations and video recordings in relation to student notes written on KF. A researcher observed each science lesson and created a rich documentation of the classroom events, which were indexed and mapped based on time. The data organization provided contextual information about each major classroom event observed, time and topic of the inquiry activities, highlights of student and teacher participation, and sources of data recorded. As a visual representation of what happened in student inquiry, we constructed a timeline-based map (Green & Bridges, 2018) of the learning events identified from the observation sheets of each classroom. Each learning event was then analyzed focusing on the literacy practices reflected in student work as individuals, groups, and interacting classrooms. Specifically, we used a grounded theory method (Strauss & Corbin, 1998) to code the specific forms of inquiry which students carried out, involving reading, writing, and interacting for knowledge generation. Each inquiry event was tagged based on its prevalence in the whole lesson period, ranging from a major episode (#3) to a small moment/branch of work (#2), to brief occurrence embedded in the whole classroom process (#1). We further traced backward and forward to search for empirically grounded connections between the current event and what happened before and after. Through reviewing the various forms of inquiry and discourse in the historical context of the whole human body inquiry, we identified compelling patterns (themes) that characterize how students wrote, read, and interacted during knowledge building (see Results).

Additionally, focusing on features of dialogic and trans-literacy, we conducted social network analysis to examine students' online peer responses within each classroom (i.e., who had built on whose ideas on KF) and used content analysis to examine the quality of student super notes shared between the two classrooms. Drawing upon our prior study (Zhang et al., 2020), the analysis coded each super note based on students' questions investigated and the complexity level of their knowledge syntheses. We also analyzed student interviews to understand how they generated super notes for cross-classroom sharing. Two researchers read and re-read the interview transcriptions, created open codes, and identified compelling themes representing various notions of super notes.

Results

Tracing diverse forms of inquiry and discourse over time

The analysis of classroom observations traced students' engagement in various forms of inquiry and discourse that involved reading, writing, and interacting with one another for knowledge building. Due to space limit, we provide the timeline-based mapping of inquiry events in one classroom only (see Figure 2). Major activity episodes (tagged with three stars in coding) are highlighted green with three stars. Small branches of work are tagged with two stars, and very brief occurrences are marked with one star. The upper section shows the various forms of inquiry. The lower section traces the different forms of social discourse.

Figure 2

Tracing of various forms of inquiry and discourse in Mr. B's classroom

	28-Mar	7-Apr	11-Apr	14-Apr	18-Apr	21-Apr	25-Apr	28-Apr	2-May	9-May	19-May	6-Jun
read books	•	•	•	••		•••	••					
websites		•	••	••						•••	••	
watch video			•	•••						•••		
image/visual			•		•••		••					
note-taking	•••	•	•		••							
source to post		•••	•••	•••			••				•••	
create video											•••	
question	•••	•••	•	•						•		
connect					•••			•	••		•••	
drama							•••					
role play/game					•••	•••					••	
past work			•	•	•	•	•		•	•	••	
group talk	••						•••	•••	•••	•••		
group experiment	•		•••		•••							
class talk	•		••		•••							
metatalk	••	•••	•••	•••		•••	•••	•••			•••	•••
write KF notes		•••	•••	•••						•••		
co-author KF notes			••						•••	•••		
read KF notes		•				•••				•••		
talk about KF notes		•••		•								
write super notes								•••	•••	•••	•••	
read super notes				•				••	•••		•••	
talk about super notes				•				••	•••		•••	

As the tracing of inquiry practices (upper section of Figure 2) reveals, students carried out diverse forms of inquiry to understand core issues and concepts related to human body systems, supported by rich information resources in different media and forms. Specifically, they read print materials related to their research topics as individuals or groups; searched and read information on various science websites; watched online videos; observed and analyzed visuals including 2D images, 3D models, X-ray images, and cartoons. While they made close reading and analysis, students engaged in generative processes such as taking notes of important information, ideas, and questions; generating and sharing questions as directions of inquiry; building connection across different topics and sources; using the sources to write and refine their online posts; creating personal videos to share knowledge; and playing dramas (skits) or participatory games to show how different body systems work. Over time, students continually referenced their prior works and ideas as they carried out new and deeper inquiry.

Over the course of the human body inquiry, students interacted with peers in flexible groups to discuss ideas and conduct experiments and observations. They participated in whole class knowledge-building talks to build on one another's ideas and investigate specific questions. As an important form of classroom discussions, the teacher facilitated meta-talk: metacognitive conversations in which students shared reflections on their online discourse or face-to-face inquiry focusing on metacognitive issues, including inquiry directions and questions, progress, plans, and ways to organize and enhance their online discourse. Drawing upon the information, ideas, and questions generated in the face-to-face activities, students wrote individual and co-authored notes on KF to have online discussions with their own classmates. Each major time slot for writing KF notes involved reading and building on peers' notes. Additionally, special time was scheduled for students to make extensive reading of their peer notes. Beyond the regular online discourse with each classroom, students engaged in cross-classroom sharing in the later part of the inquiry through writing and reading super notes in the meta-space (Super View) shared between the two classrooms. Both regular and super notes became objects of discussion when students read and referenced specific notes and super notes in face-to-face classroom talks.

Compelling patterns of how students wrote, read, and interacted for KB

On the basis of the holistic tracking, our analysis further investigated the temporal connections among the diverse forms of inquiry and discourse, with information generated in one activity feeding to what students inquired in the next activity. A set of compelling patterns (themes) emerged characterizing how students wrote, read, and interacted for continual knowledge building.

Working across multiple sources/media of information to solve problems and deepen understanding

Connecting multiple sources and forms of information to build progressive understandings was a key aspect of student literacy practices. The observation notes documented students' practices of using multiple sources of information such as books, online resources, videos, and images. For example, on April 7 in Mr. B's room, "Some students are copying text from their previous Word documents. Some are using their paper notes. Some are looking into books laying around. Some are going online to find information." On the same day, students engaged in generative activities along with their reading, including taking personal notes, generating questions, and drawing upon the sources to write KF notes (see Apr 7 in Figure 2). Their selection of reading was driven by the questions they had generated about the human body. As they read for understanding, they generated further questions. Students took notes of the information from the readings, personal understandings and questions in personal notebooks. They further reviewed their personal notes to consider what might be worthwhile to share on KF. "To write the notes, some students are using books (2 students are looking at Genes and DNA, 5 students on digestive system –> see the note on how food is processed"). One student is looking at her own notes in the binder." The observational notes also point to teacher's encouragement to use resources with proper practices of citing them: "The teacher is helping students to focus and enrich their ideas; he is encouraging them to use authoritative sources and reference them." Another observational note mentions how the teacher showed students how to use videos. The needs to contribute to the community's knowledge drove students to think further, read more closely across sources, discuss with peers, and reflect on what they had known as well as what they needed to better understand.

Integrating multiple forms of inquiry to advance knowledge

Students integrated multiple forms of inquiry and thinking, ranging from concrete experiences to personal questions, theories/explanations, video presentations, participatory games, and role play. Each form of inquiry was often embedded in the context of other inquiry activities supported by multiple sources of information. Personal experiences (e.g., dreams, injuries) were shared in the classroom talks and online discourse, feeding to student question generation and explanation/theory building. Conceptual explanations of how the body systems work were further elaborated, demonstrated, and applied through role-playing games. For example, on April 18, the teacher built on student interests to introduce a role play: "Last time you were interested in medical problems. Today, I have some medical activities for you: to do what doctors may do." With different X-rays of the bones (and other body parts) hanging on walls around the room, students acted like doctors to figure out if the bone is broken or not. Students were given a blank form for patient notes. This form had three columns: 1 - patient's name, 2 - injury (yes or not), 3 – name of the bone displayed on the X-ray. To support their diagnose, students could use iPads to view virtual 3D images of the human skeleton or observe skeleton models in the room. Rich conversations took place in the role-play groups and later on KF.

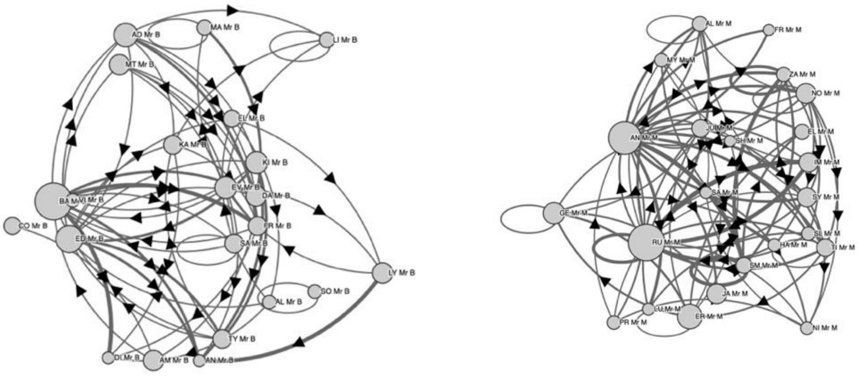
Navigating multiple discourse spaces for ongoing knowledge sharing and mutual build-on

The members of each class navigated multiple spaces of discourse over time, including personal notebooks, small group talks, whole class meetings, online discourse in the regular KF views of each classroom, and the Super View that served as a meta-space shared across classrooms. The teachers worked with students to develop a reflective sense of how the difference spaces could be used productively: Using personal notetaking to keep track of quick thoughts, questions, and information collected; bouncing ideas during small group and whole class meetings; writing "worthy" notes on KF focusing on meaningful ideas and questions; and writing super notes to synthesize "big ideas" of value to broader peers. For example, on April 7, Mr. B facilitated the following meta-talk on what is "note worthy."

> Mr. B: What makes a note worthy for grade 5/6?
> S1: More details and deeper questions you can research into.
> S2: Don't just say "I agree", instead explain why you agree or disagree.
> Mr. B: Do not forget to support your reasoning.
> S3: Give reasoning and explain why.
> S4: Add theories to your questions to explain why.
> Mr. B: If you add links or pictures, describe them, explain why you put them in there. Do not forget the title of the note.

Students wrote KF notes to share their ideas, questions, and information from various sources. Their online contributions were often rooted in the various types of activities that students engaged in face-to-face, such as whole class discussions, small group talks, and experiments. They read and built on (responded to) one another's notes for continual online discourse, which enabled ongoing idea sharing and build-on based on student need. A total of 146 notes were written by students in Mr. B's classroom and 243 by Mr. M's students. Figure 3 shows the sociogram of mutual build-on among students in each classroom. Each node represents a student, and each line a build-on relationship. The extensive build-on links show dialogic interactions among students in each class with everyone included.

Figure 3
Social network analysis of who built onto whose notes on KF in each classroom



Meta-talk to reflect on the history of ideas, from the past to the present and to future inquiries

As noted above, students engaged in meta-talk (metadiscourse) to reflect on and structure their ongoing inquiry and discourse. They shared reflections on their "juicy" questions generated by themselves and their peers; planned how they could collaborate in groups to investigate these questions, and made input on how their KF views should be organized, used and linked. As a central feature of cross-classroom collaboration, students worked in groups to co-author super notes to reflect on their journey of thinking in each line of inquiry, which were shared in the Super View. Writing and sharing super notes functioned as a specific form of metadiscourse by which students reviewed knowledge progress achieved through their online and face-to-face discourse. In the final interview, students reflected upon how they approached super note writing and reading. As the themes emerged, students considered super notes as a way to capture and share their journeys of inquiry: "It's like one huge note that reflects on all of your ideas, and what you used to think and what you now know." Students commented that super notes should focus on the "big ideas" they had developed, as "a summary of the big idea and knowledge basis." As a student said, "I think it is to focus on the entire idea of the topic you are focusing on and not just the tiny details you wanna share with the whole class." Students recognized the need to share accountable and valuable knowledge through super notes: "Well, we definitely did not include like the information that we did not know much about, because that would mean that… like if you were not sure if that was right or not, then it would not be good to include it." They further commented that the super notes should be well-phrased and accessible: "When you look at normal notes… there maybe some spelling errors, and maybe some like grammar errors… If you look at super notes that are amazingly written and they are really simple and they help people understand what is the main focus of this super note." Our content analysis examined the questions and ideas summarized in the super notes. In the 16 super notes generated, students identified 32 questions for deeper inquiry, mostly searching for reasons, mechanisms, and connections. Students' summaries of knowledge advances show a high level of scientific quality focused on offering elaborated explanations of how things work (see Zhang et al., 2020).

Working across communities to advance personal and collective understanding

Students read the super notes from their own and the partner classroom, reflected on the different perspectives, and identified knowledge connections and gaps. For example, Mr. B asked: "What was the idea that came from the super notes that you hadn't thought before and that pushed your thinking further?" A student shared the following reflection on a super note she read about the brain: "Well I never really thought about what side of the brain controls what side of the body… but it turns out that your left side of the brain controls the right side of your body." Similarly, Mr. M facilitated a discussion of the super notes among his students, asking: "What topic either strikes you as new information or something that you'd like to pick up as a thread and go deeper into?" Two students responded that they had learned something interesting about allergies, a topic they did not study in their home class. Students also reflected on how the super notes of Mr. B's class related to their own work: "Me and J are doing the immune system… and we saw these notes about white blood cells, and that was really cool 'cause white blood cells were part of your immune system. We don't really know about them… it was really helpful for us…" Key ideas and questions picked up from the super notes of their partner classroom became the focus of deeper inquiry and dialogues.

Discussion

This study contributes a deeper view of student literacy practices that take place in elementary classrooms engaging in scientific sensemaking and knowledge building supported by digitally mediated environments. The findings identified five core features of reading, writing and interacting for knowledge generation. These features are characteristic of the new dimensions of literacy proposed by researchers such as dialogic and trans-literacy for authentic disciplinary inquiry (Bereiter & Scardamalia, 2005; Goldman et al., 2016; Liu, 2014; Thomas et al., 2007). As a key aspect of such literacy for knowledge generation, students *work across multiple forms and sources of knowledge* to make meaning and develop new understandings. Students may use a variety of sources such as books, websites, videos, and models to support their problem solving. Sometimes, when the resources are beyond their reading level, the teacher may provide help accessing them. While working with the information resources, students further generate personal ideas, questions, and narratives that build on their own life experiences and carry out experiments and investigations. What they think and encounter in each moment successively triggers deeper questions and new ideas, driving sustained cycles of sensemaking and idea improvement (Odden & Russ, 2019; Zhang & Sun, 2011).

Students engage in *dialogic literacy* as a social practice that supports dynamic networking of people and ideas in technology-augmented communication. Students participate in whole class discussions, form and work in interest-based groups, and continue their interactive discourse in an online environment. Ideas developed by some of the participants in any of these dialogic settings can be carried over to other dialogic settings that involve the same or different participants. Through the extended interaction, high-potential ideas may be further improved and diffused among the broader participants. Interrelated ideas may be combined and synthesized to develop coherent and complex ideas. New problems and challenges emerge from ongoing dialogues, informing directions of deeper inquiry.

Such literacy practices involve *boundary-crossing* between social groups and across different time periods. Ideas are continually developed on the basis of their intertextual past and further project into future contexts of inquiry and discourse. Specifically, students pay sustained attention (Liu, 2014) to ideas and information generated/encountered in various time-bound interactions, selectively revisit and build on the prior ideas as they pursue new/deeper inquiry. With the support of online environments that archive students' knowledge artifacts, students have the chance to access and build on the knowledge generated by a network of classrooms, including previous student cohort groups who had studied the same (or related) topics. Generating knowledge artifacts that will be continually used by future students gives students an authentic purpose for productive inquiry and writing (Zhang et al., 2020).

We are conducting deeper analyses of the teachers' role in scaffolding the key aspects of disciplinary literacy for knowledge generation. Future studies may design a reflective framework to guide teachers' scaffolding of student literacy engagement in science inquiry. Analytics tools may be designed to help students monitor and improve their literacy practices as part of their knowledge building across disciplines.

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Analyzing Teacher Epistemic Moves in Science Classrooms

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Abstract: Science education needs to be transformed to meet the needs of the current "post-truth" era. One way to face these challenges is for science educators to promote apt epistemic performance in classrooms. In this paper, we use Barzilai & Chinn's (2018) Apt-AIR framework to analyze teacher instructional moves as they work to encourage apt epistemic performance in their science classrooms. Findings present a portrait of teacher moves directed at epistemic performance. Specifically, we highlight teacher epistemic moves that emerged from our analysis. We discuss trends in teachers' moves and implications of these for improving classroom epistemic discourse, and we discuss the potential to develop epistemic routines that coordinate productive sequences of moves. We conclude with the affordances and implications of our analysis for science education.

Introduction and theoretical background

As science denialism and the spread of misinformation become ever more rampant (Cooke, 2018), there is a widespread rejection of well-justified scientific consensus on matters such as COVID- 19, vaccination safety, and climate change. Current science education has failed to meet the growing challenges of this "post truth" world (Chinn et al., 2021). Thus, there is an urgent need for teachers to develop and implement instructional strategies that enable students to accurately appraise scientific information (Barzilai & Chinn, 2018; Chinn et al., 2020; Duncan et al., 2018). One way to address these concerns is to develop science instruction to promote *apt epistemic performance* that can extend to thinking about scientific issues outside of school (Chinn et al., 2020; Gorman & Gorman, 2021; Hussain-Abidi, et al., 2022).

Apt epistemic performance is successful epistemic performance (e.g., developing a good understanding of climate change) achieved through competence (e.g., skillful appraisal of scientific expert consensus on the topic and consideration of the many lines of supporting evidence) (Barzilai & Chinn, 2018). Apt epistemic performance is further unpacked along two dimensions that define the *Apt-AIR framework* (Barzilai & Chinn, 2018). The first dimension specifies three components of epistemic thinking: (a) Aims, or goals (e.g., aiming to reach an accurate conclusion), (b) Ideals, or standards for evaluating whether an aim has been achieved (e.g., fit with relevant evidence and the consensus of experts as ideals for determining whether an accurate conclusion has been reached), and (c) Reliable processes (RPs) that are used to achieve the aims with a good likelihood of success (e.g., evaluating multiple sources of information, evaluating the expertise of sources, determining the degree of scientific consensus, and so on). Current science education has often not explicitly addressed all these components (see Chinn et al., 2021, for arguments). Therefore, there is a need to support students' development and use of appropriate aims, ideals, and reliable processes to evaluate scientific information.

The second dimension of apt epistemic performance in the Apt-AIR framework consists of five aspects of engagement with aims, ideals, and processes (Barzilai & Chinn, 2018). These include a *cognitive* aspect, involving the use of reliable cognitive processes to achieve valuable epistemic aims that meet appropriate ideals (e.g., testing a toy car to determine how it works and ensuring that the resulting explanation fits the evidence gathered); a *metacognitive* aspect, encompassing metacognitive skills and metacognitive understanding of appropriate aims, ideals, and reliable processes (e.g., reflecting on what the best methods are for testing the car to see how it works); a *social* aspect, including working effectively with others along with an awareness of the role of social processes in producing knowledge (e.g., working in groups, receiving and responding to critiques from others, and using these critiques to improve one's explanation); a *caring* aspect, which involves positive affect and dispositions towards pursuing and achieving apt epistemic performance (e.g., being deeply committed to making sure the explanations fit the evidence); and an *adaptive* aspect, which includes adjusting aims, ideals, and reliable processes to meet the demands of diverse contexts (e.g., considering how the best investigative methods might differ between trying to figure out how a toaster works, and trying to figure out how a toy car works).

The crossing of the 3 components and the 5 aspects of Apt-AIR yields 15 cells in a 3x5 table; apt epistemic performance involves coordinating adept engagement across all of these cells (see Table 2). For science instruction to successfully promote students' apt epistemic performance, instruction needs to encourage adept engagement in all 15 cells. One way to encourage such engagement is through *teacher epistemic moves* in classroom discourse, which we define as discourse-based moves that aim to support apt epistemic performance in students. To do this, teachers might call attention to, or prompt engagement with the components and aspects of Apt-AIR. This raises the question of how often teachers *do* employ moves that engage students with each of the components and aspects, as well as what kinds of moves they make. The purpose of this study is to investigate these questions. To facilitate this, we have performed an initial analysis of teacher moves using the 3x5 Apt-AIR framework.

Recent scholarship has made great progress in developing frameworks for categorizing teacher moves in different contexts, including within discourse-based science instruction (e.g., Soysal & Yilmaz-Tuzun, 2021; Wei et. al., 2018). We consider our approach as complementary to this work. What distinguishes our approach is that we have organized our analysis around a comprehensive evaluation of apt epistemic performance. Accordingly, our goal is to develop a portrait of a range of teacher epistemic moves when there is a focus on student apt epistemic performance.

More specifically, the objective of this study is to examine the variety of teacher epistemic moves employed by three high school science teachers in order to analyze how they encourage apt epistemic performance. Understanding how these teachers implement a unit focused on epistemic performance in science classrooms allows us to identify excellent practices as well as to spot areas in which improvement is possible. This in turn will ensure that students learn to engage with all of the aspects and components needed to achieve apt epistemic performance. Thus, in this preliminary analysis, we seek investigate: (1) How often do teachers address each aspect and component of apt epistemic performance? (2) What kinds of teacher epistemic moves do teachers use to address each aspect and component of apt epistemic performance? (3) What particular aims, ideals, and processes do teachers address? (4) How do teachers use sequences of epistemic moves to promote apt epistemic performance?

Method

Context

In July 2022, researchers and teachers collaborated to create an inquiry unit focusing on epidemics and the nature of science, largely within the context of a fictional viral outbreak. This unit was created with a deliberate focus on developing apt epistemic performance incorporating all five aspects discussed above. The epidemic unit featured a game-like, agent-based epidemic simulation that combines graphical blocks-based StarLogo programming with a 3-D game-like interface (see Figure 1) (Yoon et al., 2016; 2017). Students engaged with the epidemic unit while working in groups of 2-5 as they tried to control an outbreak by running experiments and gathering data in order to find which mitigation strategies they would recommend for their town in the simulation. Although the unit was constructed to span eight class periods, teachers tended to run the unit over four to six periods to fit scheduling and curriculum constraints.

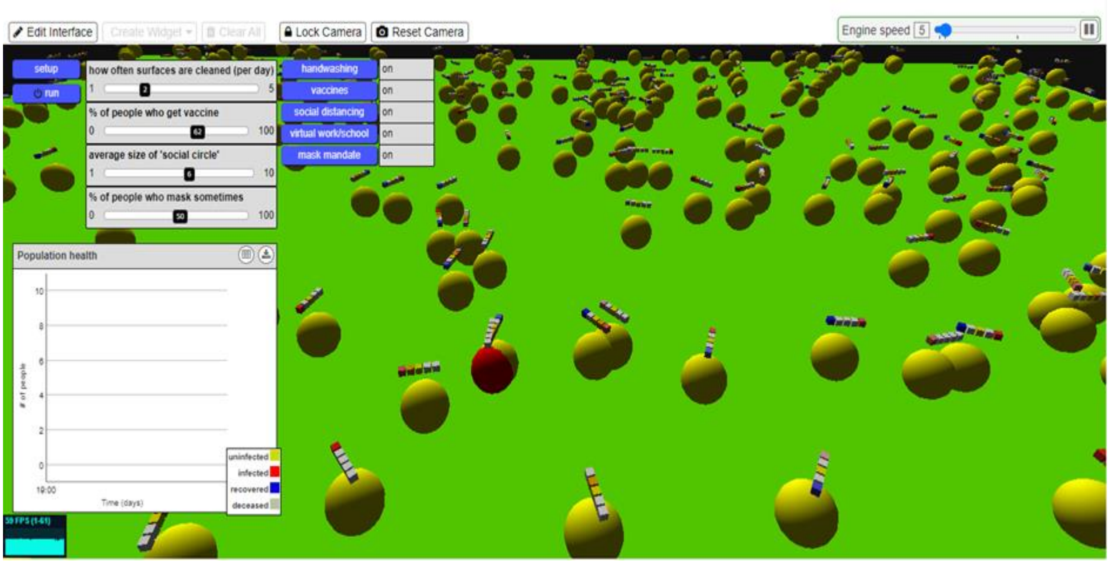
For the present study, a particularly important characteristic of this unit is the focus on teacher epistemic moves. The unit aimed to accomplish this by including activities that directly focus on aims, ideals, and reliable processes across the five aspects of apt epistemic performance. Further, teacher reminders called "epistemic callouts" were embedded within the teacher guide of the unit to remind teachers of opportunities within the lessons to highlight apt epistemic performance. Examples of activities within the unit include co-creating class criteria of the characteristics of good scientific models and practices (metacognitive engagement with ideals), peer review and iterative revision of student models (reliable social processes), and reflection on applications of classroom activities to science practices encountered out of school (adaptive engagement with aims, ideals, and processes). An example of an epistemic callout while students peer reviewed models is a reminder to encourage students to justify why particular criteria are important (metacognitive/caring engagement with ideals) and explain why particular criteria are or are not found in different models that they looked at (metacognitive/adaptive engagement with ideals).

Participants

In order to develop a preliminary method of analysis, we started with three of the five high school science teachers who taught the epidemic unit. We selected these teachers due to their rather different pedagogical styles, allowing the method of analysis to be tested on a wider array of styles. Two of the teachers, whom we call Catherine and Aaliyah, taught ninth grade biology. The third teacher, whom we call Rohini, taught tenth grade chemistry.

Catherine taught at a private boarding school, Aaliyah taught at a charter school in an urban district, and Rohini taught at a public high school in a suburban district. All schools were in the northeastern United States. All teachers spent time during summer professional development familiarizing themselves with the curriculum and the simulation (see Figure 1).

Figure 1
Game-like interface of the BioGraph Modeling Epidemic Unit



how often surfaces are cleaned (per day): 2
% of people who get vaccine: 62
average size of 'social circle': 6
% of people who mask sometimes: 50
handwashing: on
vaccines: on
social distancing: on
virtual work/school: on
mask mandate: on

Data sources and analysis

Implementations of the unit were recorded through Zoom meetings, which were active through the teachers' computers during their in-person classes. From these recordings, we analyzed the teacher epistemic moves that were employed in the classroom and classified these moves within the 3x5 Apt-AIR framework. That is, as shown in Table 2, we examined whether teacher moves addressed aims, ideals, and/or reliable processes within each of the five aspects (cognitive, metacognitive, social, caring, and adaptive). In Table 1, we show four general types of moves used by teachers when addressing aims, ideals, and/or reliable processes, which were determined through bottom-up and top-down coding methods during data analysis.

Table 1
Types of teacher epistemic moves used to promote epistemic performance

Type	Definition	Examples
Describe	The teacher directly describes or explains an epistemic aim, ideal, or process	"One way that scientists can test something is by running multiple trials."
Label	The teacher attributes value or clarity to an epistemic aim, ideal, or process	"It's better to say 'make accurate measurements' instead of just 'make measurements'."
Justify	The teacher provides a reason or argument for an epistemic aim, ideal, or process, sometimes justifying it with another aim, ideal, or process	"They need to run multiple trials because there can be variation in each trial, and error in each measurement."
Prompt	The teacher prompts students to use, describe, evaluate, or justify an epistemic aim, ideal, or process.	"What are some good processes to follow to make sure that we test things thoroughly?"

Results

In Table 2, we present the Apt-AIR framework, along with the specific teacher epistemic moves that are being described. We also include examples of teacher epistemic moves for 13 of the 15 cells (we found no instances of teacher moves addressing the adaptivity of aims or ideals). Note that most teacher moves can be coded into multiple aspects. For example, "Let's put together a list of criteria for good scientific models" is a statement about an epistemic aim that is both social (collaboration with peers) and metacognitive (planning and evaluating epistemic performance).

Table 2
Examples of teacher epistemic moves analyzed within the Apt-AIR framework

	Aims	Ideals	Reliable processes
Cognitive	Describing **cognitive aims**	Describing **cognitive ideals**	Prompting justification of **reliable cognitive processes**
	"And so you're going to **make a model** that is going to explain how **the cars** work."	"So, this is an example of a model that a student has for their car to see how it works, right? **That explains their car's internal mechanisms** to determine how this car is working. Okay? And then, in addition to that, they have an explanation."	"The sugar pill didn't do anything. So, let's talk about that sugar pill, does anyone know why **they would give them a sugar pill**? That's not just a random detail, that's something scientists do."
Metacognitive	Describing **metacognitive aims**	Prompting description of **metacognitive ideals**	Describing and labeling **unreliable metacognitive processes**
	"So your goal with your partner or your group, are to now **come up with one characteristic of good scientific methods** with your partner, and referencing part two of the homework if needed, initial your idea with both of your initials, and try not to repeat something that's already written."	"Alright, so, I want us to think about what would be some great criteria for our, for a model. So, thinking about what you have actually reviewed, right? Let us come up with **a list that we all agree upon that would be great criteria**."	"Now sometimes when we write a prediction, we become very biased in collecting the data, because we only look in one direction. We have to prove our hypothesis, **let's just cherry-pick the data that we like, and let's write it down**. And let's say it proves our hypothesis. We tend to do that, it's very common, but that is incorrect science."
Social	Labeling **social aims**	Justifying **social ideals**	Describing and prompting justification of **reliable social processes**
	"Why do we need to critique each other's work?" [student says, "So that everyone can improve?"] "**So that everyone can improve**. What else could be the reason?" [student says, "So we can get other people's perspectives?"] "Why is it important for us to know other people's thoughts and perspectives?"	"We are trying to read what is written, we don't go around and explain our process. I should not be hearing, oh, this is how you should be reading my process, or my step-by-step procedure that is written there. No. We don't get to do that in real science. When someone publishes it we get to read their thought process. That's why **it has to make sense to everyone**."	"You are critiquing, nothing personal is happening here. It's what we do in science, we **critique each other's work**. Why is it needed in science? Why do we need to **critique each other's work**?"
Caring	Labeling and describing **caring aims**	Prompting justification of **caring ideals**	Justifying reliable metacognitive processes with a **reliable caring process**
	"Very good, very good, if we're not **following good scientific methods**, we	"Why do we need to critique each other's work?" [student says, "So that everyone can	"Even if you're like our prediction was totally wrong, I want you to still put it here,

	might give out false information, and then	improve?"] "So that everyone can improve. What else could	because **it's important for us to see where we started**."
	someone will start believing the false information."	be the reason?" [student says "So we can get other people's perspectives?"] "Why is it **important for us to know** other people's thoughts and perspectives?"	
Adaptivity			Describing and justifying **reliable adaptive processes**
			"So when we just did our model, the car, you couldn't take the car apart. Because **scientists can't always take something apart** in order to determine if something is working. **Scientists have to, sometimes, test things out**. Because, can you take a cell apart?" [inaudible response] "Why?" [inaudible response] "It's too small, it's microscopic."

From this initial analysis, several trends stand out that highlight some of the affordances provided by the use of our Apt-AIR 3x5 analysis, which we discuss below.

Identifying coverage of components and aspects

The analysis readily points to components, aspects, and their intersections that are addressed more frequently, less frequently, or not at all. For example, we found a very small number of teacher epistemic moves addressing the aspect of caring, and even fewer moves addressing adaptive engagement. In contrast, there were more moves that involved engagement with the cognitive, metacognitive, and social aspects. Indeed, we found no moves addressing adaptive engagement with aims or ideals. What follows are some examples of prompts that teachers could conceivably use to ask students to engage adaptively with aims or ideals in the epidemic unit:

Example of adapting an aim: "How do you think that our goals relate to what the goals of scientists studying COVID are?"

Example of adapting an ideal: "Are there situations when a smaller sample would be OK?"

The aspect of adaptivity may be especially important in encouraging students to connect what they are doing in class with the scientific issues they encounter out of school. Teachers could encourage students, for example, to contrast the processes they are using to conduct research (e.g., careful control of variables within their simulation environment) to what scientists do (e.g., controlling variables in real-world research settings).

Identifying patterns of moves across components and aspects

The analysis also enables us to observe patterns of the types of teacher epistemic moves used across and within cells. For example, although there were many epistemic moves that addressed aims (typically, teachers described the epistemic aim of the activity), there were very few that explicitly prompted students to evaluate their quality (is this aim a valuable one?) or to justify them (why should we try to accomplish this aim?).

Furthermore, there were few justifications or prompts for justifications of metacognitive aims, ideals, and processes outside of the activities in which classes developed lists of criteria for good models or good methods. When students give justifications, they are providing reasons for why the aims or ideals they are advocating are valuable, and why the processes are reliable. These justifications help the students understand the aims, ideals, and processes, as well as to care about their use. For example, a prompt asking students whether evidence is good or not (evaluation) and to explain why (justification) supports them in developing an understanding of what counts as good evidence and why good evidence is valuable.

In addition to identifying significant trends in how teachers' epistemic moves contributed to students' thinking across the five aspects of engagement with aims, ideals, and processes, our classification provides insights into longer sequences of teachers' interactions with students. We provide examples below.

Identifying particular aims, ideals, and processes

A third affordance of the Apt-AIR analysis is that it enables educators to identify the particular aims, ideals, and processes that are the focus of discussion. It is possible then to consider whether these are productive components to focus on, whether alternatives might be better to introduce, or whether some might be problematized. For instance, in one of the examples in Table 2, a teacher asks, "Why do we need to critique each other's work?" This prompt asks students to justify the value of critiquing in science, which could help students appreciate the role of the process of critique. Critique in science is a core reliable process that is well worth pursuing. On the other hand, the teacher's remark "we are trying to read what was written; we don't go around and explain our process" describes a process of scientific communication that relies exclusively on written work. This is not compatible with what is known about scientific communication, in which interpersonal and other oral interactions are often important for scientists to understand each other's work (Collins, 2014). Rather than endorsing the process of relying on written documents alone, teachers might consider problematizing this process in discussions with students, perhaps considering a fuller range of scientific communication.

The Apt-AIR analysis thus enables us to provide, for any teacher at any time, a portrait of the particular aims, ideals, and processes that are the focus of the community's work, as well as how those components shift over time. This analysis then allows teachers and analysts to reflect on which aims, ideals, and processes are currently the focus, and whether it might be good to consider alternatives.

Sequences of teachers' epistemic moves

Our analysis also provides a lens to examine sequences of teachers' epistemic moves, and how well these are orchestrated to promote better student thinking. Teachers could use productive sequences of discourse repeatedly to promote advances in students' thinking—we refer to such sequences as *epistemic routines*.

In the analyses below, we discuss epistemic routines used by two teachers, Catherine and Rohini, as they led their students' in generating criteria lists for good scientific methods. In presenting these moves, we highlight their classification in terms of our Apt-AIR analysis and note what insights are provided by this analysis.

Catherine starts this activity by pointing the students to open a shared slide in Google Slides on their computers, where each student can see and edit the text on the slide at the same time. The slide has eight blank lines where students can type in responses. Around the classroom, students are seated in small groups of two to three each. Catherine asks that each group of students come up with one characteristic of a good scientific method, or in other words, a criterion that a scientific method should have to meet in order to be considered to be good. She asks each group to type their characteristic into the shared slide, and to make sure that the characteristic they enter is not the same as another groups. Catherine also mentions that, after all of the groups have entered a characteristic, she will ask each group one at a time to clarify the meaning of what they typed and to provide justifications of why they chose that characteristic. What follows is an excerpt from this clarification process.

- "So, first group, having measurable evidence without having to worry about people's opinions, can you tell me a little bit about why you put that?" *Catherine first describes a metacognitive ideal by restating the characteristic that the first group of students typed. This is metacognitive since the characteristic is a criterion for evaluating, and possibly planning, other cognitive or metacognitive performances (scientific methods). Catherine then prompts the students to justify this metacognitive ideal.*
- [student says, "How you measure your evidence is also part of how you support your hypothesis or the claim you're making, and while if you use that evidence people's opinion might not really matter, you still have to deal with it because sometimes if people are fighting it still effects things."] "Mmm. Ok. So can you give an example using our drug experiment of what measurable evidence would be, and what not measurable evidence would be?" *After the justification, Catherine responds by labeling the clarity of the student's metacognitive ideal, though only partially. She then prompts the student to further justify their metacognitive ideal with an additional metacognitive ideal (what makes evidence measurable).*
- [student says, "Like their fevers?"] "Ok, so like, a numerical, your fever is 101. And what's non-numerical evidence? Or like vague evidence?" *Catherine again responds by labeling the student's metacognitive ideal (though this time it is a different ideal), and then follows up by repeating the second part of her previous prompt for justification.*
- [student says, "Some person saying they feel better."] "Ok so I'll agree with that, so having measurable evidence, I'm going to add a little bit, like a fever measurement versus just "I feel better." Because that

kind of gets away from people's opinions, right? So maybe if I'm in the hospital I don't feel better, I still feel bad even if objectively, I'm healthier." *This time, Catherine responds by labeling the value of the student's metacognitive ideal, and further describes that ideal herself before moving on to the next group.*

This excerpt shows a relatively simple epistemic routine that may be useful for expanding students' responses and getting a clearer picture of the student's metacognitive understanding. The routine takes the following form: (1) the teacher prompts for a description of metacognitive ideals (2) a student describes an ideal, and the teacher prompts for justification of the same metacognitive ideal (3) the student justifies, and the teacher labels the clarity of the student's justification before prompting for justification of the same metacognitive ideal with an example of other metacognitive ideals (4) the student justifies with an example, and the teacher endorses the value of the student's metacognitive ideals, and further describes those ideals before moving on.

Rohini begins the activity by opening a slide that is projected to the front of the room. The slide has multiple empty lines, and she describes to the students that they are going to make a class list of good scientific methods. She then immediately prompts the class for what they think one good method would be. Below is the fourth time she prompts this during the activity.

- "Okay, moving on to four, yes?" *Her statement here of "moving on to four" serves as a prompt for a description of metacognitive ideals, as it is a continuation of her initial prompt for such descriptions.*
- [student says, "A control group?"] "A control group. Why do we need a control group?" *Rohini gives an implied label of some amount of clarity of the metacognitive ideal when she restates the student's response. She then prompts for a justification of that metacognitive ideal.*
- [student says, "You need something to compare it to?"] "Okay, we need to include comparisons. Very good." *Restating the student's response, Rohini then labels the correctness of the metacognitive ideal.*

This excerpt shows a routine similar to, but simpler than Catherine's. The structure of this routine is: (1) the teacher prompts for a description of metacognitive ideals (2) the student describes, then the teacher labels the clarity of the student's description of a metacognitive ideal and prompts for justification of the same metacognitive ideal (3) the student justifies, and then the teacher labels the correctness of the justification before moving on.

Something seen in both teachers' routines is evaluation of the value of the student's response at the end, which could lower students' agency and personal investment in the class list. This is especially the case with Rohini's routine, where the assertion of correctness likely directs the students away from further discourse, and towards searching for an answer deemed to be correct. One benefit of our analysis could be the identification of how and when teachers evaluate student responses, and how these routines may affect student outcomes compared to routines that lead the class to evaluate ideals themselves. Otherwise, these two routines are mostly centered around a single component—students' description of metacognitive ideals. However, as Catherine's routine shows, additional components (aims, ideals, reliable processes) can be brought in, and maybe also additional aspects (cognitive, social, etc.) as suggested by some entries in Table 2 (see the example for social aims). Being able to analyze how such sequences of moves shift between the cells of Apt-AIR allows for comparison between the usage of different sequences and student outcomes, enabling the identification and creation of robust routines that can best promote a full coverage of apt epistemic performance.

Discussion

The results of this preliminary analysis present a new way of analyzing teacher moves that aims to promote students' thinking. The Apt-AIR 3x5 analysis yielded a portrait of the range of teacher epistemic moves that were used by the three teachers as they taught a lesson designed to foster apt epistemic performance. Below we discuss our four main findings to date and the affordances of each.

1. Teacher epistemic moves provided little to no coverage of some aspects and components. There were no examples of epistemic moves addressing the adaptivity of aims or ideals. Furthermore, there were relatively few examples of moves addressing the caring aspect. This finding has implications for teachers and researchers for strengthening curriculum to address these aspects and components.
2. There are opportunities to strengthen teacher epistemic moves across the components and aspects. Teachers overemphasized description of aims, ideals, and reliable processes in each of the five aspects, yet rarely pushed for justifications of the described components. Encouraging students to describe, label, and justify aims, ideals, and processes would also increase students' epistemic agency when conducting science inquiry, because students can develop their own sense of which aims, ideals, and processes are valuable and build their own understanding of why they are valuable.
3. This analysis provides a portrait of the aims, ideals, and processes science educators thought were most important to discuss during this unit. This allows teachers and researchers to step back and consider

whether the emphasized aims, ideals, and processes are the most productive ones to focus on. They can also consider whether these aims, ideals, and processes appropriately reflect the practices of science.

4. Lastly, our analysis highlights patterns of epistemic moves that could be developed into epistemic routines. Epistemic routines are a series of teacher epistemic moves that teachers are able to embed in their instruction to target apt epistemic performance. For example, teachers can make soliciting feedback from peers an epistemic routine in the classroom, using it every time students engage in science inquiry.

Ultimately, our findings can help researchers and educators identify how teachers can engage in productive discourse with students to improve their scientific thinking during classroom inquiry and beyond. For example, if students are taught to value gathering ample evidence as a well-justified ideal of science reasoning, we expect them to gather ample evidence as they make sense of socioscientific issues in the public sphere. The analysis identifies particular components and aspects that teachers can address with students, and where further growth might be needed for educators to better prepare students to engage in apt epistemic performance. The analysis also identifies areas in which the moves themselves could be enriched beyond describing, labeling, justifying, and prompting in order to advance students' thinking to better prepare them for reasoning in the post-truth world.

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How Do We ‘See’ Engagement in a Classroom?: A Comparison of Researcher, Student, and Teacher Perspectives

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Abstract: This study compares three sources of inferences about the engagement of young science learners: researcher observations of classroom video, student self-reports, and teacher reports. 21 third-grade students participated in a series of embodied learning activities in their music classroom centered on the science behind musical sound. Perspectives from the researcher, music teacher, and students are compared in the context of two video clips from classroom activities that participants co-watched with the researcher during post-interviews. The results highlight the overlaps in how the researcher, teacher and students reported their perceptions of social and emotional engagement, as well as the similarities in reasoning around generative sources of positive emotional engagement. The analysis also surfaces the unique interpretations of events that each source of data offers. Overall, this paper argues that multiple participant and researcher perspectives together can offer a more robust understanding of how and why students engage with learning.

Introduction

Student engagement is a highly desired outcome of learning environments that researchers have struggled to define and operationalize (Appleton, Christenson, & Furlong, 2008). Some studies take an individual-centric approach, using self-report surveys to gather learners’ perspectives after the fact (Greene, 2015) or experience sampling to measure perceptions of engagement in the moment (Beymer et al., 2018). Others use teachers’ observations as proxies for a measurement of students’ experiences, gathering perspectives on how teachers perceive and interpret evidence of engagement in their classrooms (van Uden et al., 2013). Still others take a more sociocultural approach and use video and audio recordings to capture and analyze moment-to-moment shifts in engagement within particular student interactions (Ryu & Lombardi, 2015). The selection of a lens to understand engagement–the student’s, the teacher’s, or an outside research-trained observer’s–shifts what data is available to us and what features of classroom interactions become visible or invisible to our analyses. Some have argued that triangulation across multiple sources of engagement can offer a richer picture of what factors influence the ever-shifting dynamics of how students engage with learning (Fredricks & McColskey, 2012; Karabenick & Zusho, 2015). In this study, I take up a framework of student engagement grounded in sociocultural perspectives on learning, which consider engagement to be a complex and dynamically unfolding process that emerges from interactions between learners and their social, physical, and cultural environments (Humburg, 2020). I define student engagement as the shifting set of actions, and patterns of actions, that influence opportunities for learning in context. Thus, the goal for this paper is to compare multiple sources of engagement data to uncover what different approaches to measuring engagement offer in terms of revealing the contextualized, moment-by-moment mechanisms through which dimensions of engagement influence opportunities for learning.

While observational studies of moment-to-moment engagement patterns have demonstrated the value of a detailed researcher perspective (Sinha et al., 2015; Greene, 2015), this outside perspective may offer a different picture of engagement when compared with individual student perspectives on their own experiences. There may be aspects of socioemotional engagement that are only visible and intelligible to the participants directly involved, as evidenced by the potential disconnects between how teachers and students report students’ emotions in classroom activities (Skinner et al., 2009). Researchers may also wish to honor the expertise of teachers, who are more closely involved and thus attuned to the socioemotional and cognitive dynamics of their classroom than an outside observer. Comparing what aspects of engagement become more or less visible through different lenses gives us a more complex and dynamic understanding of how engagement influences the unfolding learning process. To track and compare these different perspectives on student engagement, this study asks: How do students’ reported ideas about their cognitive, behavioral, emotional, and social engagement with the science of sound match or differ from what we see in the video data as researchers, as well as what their teacher reports?

Literature review

While quantitative self-report surveys remain a common method for capturing student engagement, learners’ perceptions of their own behaviors do not always align with what is visible in records of classroom interactions, or what others in the environment report (e.g., teachers, peers) (Azevedo, 2015). Research that speaks across data collection methods to analyze the temporally unfolding nature of engagement in context is needed to better understand how dimensions of engagement influence learning. Methods of data collection and analysis that focus on individual learners may also miss out on ways that engagement is distributed across individuals and produced through collaborative sensemaking (Ryu & Lombardi, 2015). Analyzing engagement at the group level in unfolding activity can reveal how functional and dysfunctional group dynamics influence the extent to which students are able to cognitively engage with learning (Sinha et al., 2015). The present study demonstrates how triangulating an analysis of engagement between student reports, teacher reports, and classroom video observations reveals the benefits and unique contributions of each source of data, offering a more complete picture of how engagement unfolds (Sinatra et al., 2015).

Despite the value of analyzing the unfolding, moment-to-moment shifts in students' engagement across time, the resources and time required for this form of analysis is substantial. Reliable video analysis of complex interactions can require multiple rounds of watching and re-watching video both individually and with wider research teams (Jordan & Henderson, 1995). To account for the large amount of time and resources required to conduct in-depth qualitative analysis of engagement, some researchers have developed streamlined rubrics to help researchers quickly evaluate and record key features of student interactions when viewing classroom videos (Rogat et al., 2022) or during unfolding classroom interactions (Hsiao et al., 2022).

While much can be learned from detailed analysis of classroom video, and self-report surveys bring with them the limitations discussed above, this measurement approach continues to be popular due to the value of analyzing learners' own perceptions of their learning, even if they cannot capture the variance of learning processes across contexts and time (Karabenick & Zusho, 2015). Some features of students' experiences and engagement are by their nature not visible to an outside observer and are only interpretable by the participants within the interaction. For example, a study comparing students' ability to adapt to challenges found that student self-reports of their adaptability was linked to their engagement levels in mathematics, whereas teachers' reported perceptions of students' adaptive behaviors were not correlated with engagement levels (Collie & Martin, 2017). This suggests that students may in some cases be able to report factors influencing their engagement with more specificity or relevancy for their engagement than their teachers can. Prior research has also found that teachers tend to rate students' behavioral engagement lower than students do themselves, and teachers may also underestimate the strength of students' negative emotions (Skinner et al., 2009). Thus, students may offer a distinct perspective on their levels of engagement that cannot be duplicated by an outside observer.

However, relying solely on student perspectives may not always offer the full picture of why students engage with learning, even if students' perceptions can offer valuable data about their engagement. For emotional engagement in particular, learners are not always able to determine the causes of their own emotions (Silvia, 2006), so triangulating across multiple sources of data (learner self-report, researcher observations, teacher reflections) can give us a more multidimensional picture of how our designed activities might foster particular forms of engagement. Gathering teacher perspectives on engagement can be beneficial when working with young students in particular, given that younger students may encounter verbal and literacy-related challenges when completing self-report surveys and tasks (Fredricks & McColskey, 2012). Teacher reports of engagement can also give educational researchers a better understanding of how teachers make decisions about adopting new instructional practices and the benefits that teachers perceive for student learning (Huizenga et al., 2017).

Overall, the literature does not suggest one clear "best practice" for measuring student engagement, but rather suggests that some blend of multiple methods is ideal for capturing the complex mechanisms of engagement in action and over time (Fredricks & McColskey, 2012; Greene, 2015). A self-report of how learners felt about an activity after the fact does not necessarily offer data about how the designed activity produces particular socioemotional interactions in the moment, but a researcher observing unfolding interactions may also categorize emotional and social displays in ways that don't reflect learners' own labeling of their experiences. Given the varied benefits and drawbacks of observational, self-report, and teacher-report methods of gathering data on student engagement, the present study utilizes these three forms of data side by side within a single classroom context, to further elaborate on what aspects of cognitive, behavioral, social, and emotional engagement are made more or less visible through each analytic lens.

Design and methods

The study took place in a small suburban public school in the U.S. Midwest. Participants were students in a third-grade music classroom (n=21, 8-9 years old) and their music teacher. Students participated in eight days of embodied learning activities centered on the investigation of the science behind musical sound. Students experimented with musical instruments and a tablet oscilloscope app in order to figure out how different sound features (e.g., pitch, volume) produced different patterns of sound waves. They also used their hands and arms to create gesture representations of sound waves as well as their full bodies to collaboratively build embodied representations of how sound waves move in response to different sounds. Both students and their teacher were interviewed immediately before and after the unit to gather perspectives on students' engagement. They also participated in video co-watching with the interviewer to reflect on the emotional and social engagement visible to each participant during particular moments of interaction. The use of videos to elicit participant perspectives helps recenter student voices in the analysis of their learning (Takeuchi & Bryan, 2019), offering a richer understanding of how students' behaviors emerge from their own social and cultural worlds, which is not often explored in studies of engagement. The interviews lasted roughly ten minutes each and explored ideas about interesting or boring moments, as well as any "good" or "bad" feelings that participants recalled seeing or experiencing during the activities. Participants were also asked questions about social engagement via the idea of teamwork, to elicit reflections on how participants identified productive versus unproductive collaboration. Interviews were chosen (as opposed to surveys) because in-depth interviews with students and teachers have been shown to help reveal indicators of engagement that may traditionally be overlooked by researchers (Fredricks et al., 2016). All class activities and interviews were video recorded for analysis.

To set up the comparison between researcher, teacher, and student perspectives, clips from the classroom activities were selected to represent different forms of embodied activity, as well as what appeared to the researcher to be different visible levels of social and emotional engagement. Two 30-second clips were selected– one in which students shook strings of pom-poms together to demonstrate how sound waves travel through the air (Figure 1, left) and another in which students stood in concentric circles and used back and forth movements together to create a full-body representation of how air particles move in response to sound (Figure 1, right).

Figure 1
Students moving strings of pom-poms to represent air particles (left) and pretending to be air particles (right)

In clip #1, a pair of students decided on a sound to demonstrate (e.g., high pitch and loud), and their peers mimicked the leading group to show how sound ripples outward to carry information to the ear. Other students sat on the floor and used signs with vocabulary words (e.g., "High Frequency", "Soft Dynamics") to guess what the students were showing. In clip #2, the students were investigating the same conceptual idea (the movement of air particles in response to sound), but using their full bodies coordinated together. As a student in the center played different notes, the rest of the class was tasked with moving back and forth in response to the sounds to represent how the air particles move to carry sound waves out from the source.

To ensure that the researcher perspective was not overly guided by interview responses, interaction analysis of classroom video (Jordan & Henderson, 1995) was fully completed before the interviews were analyzed. Next, the student and teacher post-interviews were analyzed using thematic analysis (Braun & Clarke, 2012). 133 initial codes were generated based on 19 students' post-interviews. Codes were sorted first into initial categories based on apparent overlaps, which led to the generation of six draft themes. Any codes that appeared to be similar were merged together into more general codes that still captured the essence of each subsumed idea. For example, "interested in how sound is made", "felt good to know how air particles move", and "liked seeing what sound looked like" were all collapsed under the broader code of "liked learning ideas about science". This process of merging and renaming codes continued in multiple cycles. After all codes were re-sorted, the six initial themes had been restructured to be five themes. 37 unique codes remained spread across five themes: 1) What it means to be a team, 2) Awareness of social and emotional engagement, 3) Reasoning around emotional engagement, 4) Perceptions of different class activities, and 5) Challenges of embodied activities.

After the thematic analysis of student post-interviews was complete, the teacher's post-interview was then analyzed using the 37 codes drawn from student responses. Codes that overlapped with the teacher's responses were applied, but any responses that diverged were also open-coded for the construction of teacher-specific themes and sub-codes that might contradict or expand on students' ideas. 9 additional codes were added to the existing themes to reflect teacher-specific ideas, and 11 codes were added to create two additional teacher-specific themes: 6) Benefits of embodiment and scientific inquiry for learning, and 7) Challenges around teaching with embodiment and science. Finally, the themes that were created around participant responses were compared with the results of the researcher's video analysis. This comparison highlighted aspects of the classroom activities that were interpreted similarly across all three perspectives, as well as features of the classroom interactions that were attended to more or less closely through each lens. Student and teacher reflections were not assumed to align with how participants experienced emotions and social interactions in the moment of activity, but rather were meant to elicit the broad perceptions that participants may be taking away from the activities. The comparison below is thus not a comparison of how students felt in the moment to what the researcher sees. Instead, it is an analysis of how students reflect on their learning experiences and interpret video evidence in comparison to how teachers and researchers interpret that same evidence through their professional lenses.

Results

The students' perspectives on their own and peers' engagement

In general, the majority of students (18 of 19) reported that the sound and music activities overall felt fun, happy, and/or good when asked questions about their feelings about the lessons. 14 of those 19 students brought up the idea of having fun or feeling happy either three or four times throughout the interview, suggesting that the general perception of positive emotional engagement was a significant feature of how students framed their experiences. Three students (including the one who did not mention having fun or feeling happy) noted that the activities elicited a mixture of positive and negative feelings. Students also overwhelmingly reported that they thought their class worked well together as a team (17 students). In their explanations, students offered a variety of definitions for what it means to be a good team, some of which aligned with typical classroom rules (e.g., following directions, not goofing off; reported by three students) while other definitions of teamwork were specific to embodied activities. 10 students mentioned that the class was successful at coordinating their movements together as evidence of good teamwork. For example, Jeremiah explained good teamwork during the circle of air particles clip (clip #2) by saying, "Erik in front of me, he moved, so when he moved, I moved, and then he ran back and then I knew to run back. So we did the same thing, went backwards backwards, then forwards forwards." Seven students defined teamwork in terms of communicating, discussing, and understanding ideas together with their peers, and four students noted positive socioemotional climate as evidence of good teamwork. Angelica defined evidence of good teamwork in her explanation of Andy's positive social engagement during activities, saying, "he always has great ideas [...] he tries to invite everybody in. Him and Amara always help me when I feel left out." This focus on how peers contributed to the classroom climate provided a complimentary perspective to the researcher's analysis. While the researcher's perspective highlighted moments of positive engagement that were visible during class, the student reflections made visible some of the work students did outside of music class to build patterns of positive social and emotional engagement that could serve as a foundation for in-class activities.

Comparing student perspectives and researcher observations

Within students' reasoning around their emotional engagement (theme #3) and their perceptions of class activities (theme #4), many overlaps were visible between how students discussed the mechanisms of their engagement and the sources of emotional engagement observed by the researcher. In particular, the researcher noted body movement, scientific inquiry, and the creation and experience of musical sound as core sources of emotional engagement for students. Importantly, none of the interview questions asked directly about these sources of engagement, so all student explanations were offered without guidance towards particular topics of discussion.

Responses in students' post-interviews provided significant support for these hypothesized sources of engagement. Seven students discussed being engaged by the challenge of creating embodied representations, and five of those seven (plus two additional students) also noted that in general getting to move their bodies and be active was an engaging feature of activity. Kinsley explained that she liked the embodied activities because the class "got to be the xylophone instead of playing a normal one". Evidence was similar for scientific inquiry as a source of emotional engagement. Seven students noted enjoying activities that involved inquiry and discovery, such as when Elia viewed the circle of particles activity (clip #2) and then explained "I figured out the pattern [for how to move], so then it was really fun." Another six students (plus one from the previous seven) also talked about liking that they were learning things about science. Kinsley reported that the most interesting activity was "when we got to see like how things vibrated and stuff…well, got to be the- how it vibrated, and got to the ear." Here Kinsley notes not only that learning how sound vibrates was interesting, but also that the opportunity to embody the vibrations (or "be" how it vibrated) was a factor that impacted her engagement in the activities.

By far, the most frequent source of engagement recalled by students was the playing of instruments and the experiencing of musical sound. 14 of the 19 students mentioned playing instruments, making music, and/or listening to sounds as reasoning behind their positive feelings about the class activities, and these students mentioned ideas around creating and experiencing music a total of 26 times. Students also offered context for this link between musical expression and positive emotion by discussing additional factors that may be interrelated. Four students noted that the quality of a sound (e.g., loudness, musicality vs. noise) impacted whether they liked an activity, and seven talked about the newness of experiences (e.g., getting to play instruments they'd never seen before) as a source of their emotional engagement. Opportunities to collaborate with peers (four students) and the freedom to explore with fewer constraints (three students) were also discussed by some as reasoning for their feelings about the activities. For example, Layla noted that when using the ropes to demonstrate sound waves, "there was no limit to how high you could go, or how fast you could go." Students' perceptions of which activities were more or less engaging seemed to broadly align with the researcher's analysis, though the students' reasoning about their emotional engagement offered additional depth to the researcher's understanding of why different forms of embodiment might encourage or discourage expressions of positive emotion.

When analyzing the video clips during their post-interviews, students also highlighted much of the same social and emotional evidence that the researcher called out in research notes. Four students noted the frustration that they and/or their peers felt when trying to coordinate movements together. Another five talked about how it was hard to figure out how to move together. These observations mirror the researcher's findings, which highlighted moments of negative social and emotional engagement in which students appeared to struggle to move together or coordinate the movements of materials productively and shouted directions to each other in frustration.

There were also aspects of these collaborative moments where student perspectives sometimes diverged from the researcher's interpretations. For example, at the end of the circle of air particles clip (clip #2), Owen shouts "go!" at his peers several times and then follows up with "Do I have to say go every time?!" Interestingly, while the researcher had noted Owen's shouted directions as negative social and emotional engagement, given the intensity of his tone and the complaints of his peers in the moment, the students were somewhat split in their post-interview reports. Of the 11 students who co-watched this clip during their interview, three students explicitly mentioned that they disliked being yelled at or bossed around by their peers, and Elia explained her interpretation of Owen's shouting in the video clip by saying, "I don't like that because I mean we were just learning, so it was kind of annoying." However, other students did not comment on Owen's directions at all, instead focusing on the ways their peers were moving well together and helping each other figure out how to coordinate their movements (three students). Still others (three students) directly complimented what they viewed as Owen taking charge and directing others, like when Erik said, "I liked how Owen just kept- had to like remind people to go when they needed to. Like he was kind of the leader I guess." Owen himself did not report feeling any certain way in his post-interview when asked how he felt during the circle activity, and he noted only that "everybody they needed to move a little more, they had to listen to if it got quieter."

These contradictions in students' responses remind us that there is not one "true" interpretation of a moment of engagement, and that participants are always in the ongoing process of building intersubjectivity together. Considering the varied ways that students may interpret and react to an expression of emotion from their peers can help to guide our understanding of what such moments might contribute to learning for different students. This also suggests that negative emotional and social engagement may influence different students' learning in unique ways, depending on how they make sense of their peers' comments and reactions. This example highlights how classroom video data may reveal potential emotional engagement that is not reported in students' interviews, but also that researcher interpretations of potential negative emotions may not be remembered or experienced by participants in the same way that an outside observer perceives them. The difference in overlap between interpretations of positive emotions (which were very similar across student and researcher perspectives) and the interpretations of negative emotions (which were more varied) also suggests that student interviews may be more vital in understanding the possible sources of negative socioemotional interactions.

Comparing student and teacher perspectives on engagement

As with student and researcher comparisons, the overlap between student and teacher perspectives on engagement was clearly visible in the reasoning that participants offered for students' emotional engagement. In her explanations, the teacher noted the opportunity to move one's body, the freedom of movement and actions, the novelty of new experiences, and collaboration as sources of students' positive emotional engagement, all of which were brought up by multiple students in their post-interviews. The teacher also noted the idea of turn-taking and everyone wanting their turn to be a leader, which overlapped with the students' ideas around fairness and making sure everyone got a chance to participate. The teacher called out many of the specific activities that students brought up as being engaging as well, such as playing instruments, doing inquiry activities, and using materials in the embodied activities. She recalled noticing during the activities that "you could see pure joy and freedom in them just being able to play music and enjoy it." The teacher's general perceptions of the activities as fun, exciting, and full of good teamwork also aligned with the majority of the students' reported perspectives.

The evidence the teacher used to reason about students' engagement also overlapped with how the researcher looked for positive emotions in the video data (e.g., "I heard a lot of laughter and a lot of excitement in their voices, and they just seemed overall relaxed and enjoying the activities"). The teacher accurately identified one of the less-common perceptions of students as well, which was that some students found the group discussions boring or less interesting than the more active and embodied activities. However, there were other less-common perceptions articulated by the students that the teacher did not bring up in her interview, such as Angelica's comment that she wished the teacher would have been more encouraging when students tried out new ways of moving. She noted that the teacher and facilitator were sometimes quick to critique students for not moving properly, or to praise some students and not others. Explaining how these interactions impacted her emotional engagement, Angelica said, "it feels really sad cause you're like but I tried my best, no one's noticing me." While the teacher reported many overlapping ideas with students' perceptions, these examples highlight that there were still unique and valuable aspects of students' perspectives that were not captured via teacher or researcher forms of data. Attending to these less-common but still valuable perceptions may be key to addressing hidden sources of negative emotional engagement that can trigger students to disengage with learning.

On the other hand, the teacher also provided additional forms of reasoning around students' engagement that were not found in the student data. For example, when co-watching the video clips, she noted that levels of negative social engagement that she saw during the sound activities were on par with the levels she usually sees during class. She added that she did not perceive any "terrible misbehavior" or anything that signaled the embodied activities were encouraging more negative engagement than normal. The teacher also discussed how students enjoyed using technology like the oscilloscope, that they looked forward to the sound activities, and that emotional and cognitive engagement seemed to co-exist during the lessons (e.g., students were "having a good time at the same time that they were learning"). The teacher mentioned that she thought students were engaged by the agency and responsibilities that the activities offered, as well as the open-endedness of scientific inquiry, which was a new pedagogical strategy for her classroom. For example, she explained that "they enjoyed getting to move and move around, and being able to have kind of open-ended answers, to where they didn't feel like they had to be right all the time, that they were just exploring." Like the students' interviews, the teacher's discussion offered additional contextual insight for the researcher that was not available in the classroom video, such as information about the pre-existing socioemotional history of this particular class of students that may have laid the foundation for their productive engagement. She explained that "I feel like this class is connected to me and to each other even more than some of my classes," and that "I give them a little more leeway to have fun and do things because of that." The teacher's perspectives presented another dimension for the analysis of the embodied activities, suggesting that the effectiveness of positive emotional and social engagement for learning may be somewhat dependent on the level of pre-existing mutual trust between students and their teacher.

The teacher's perspectives in the post-interview also offered perceptions that student interviews did not address. The teacher-specific themes that were built around these responses concerned both the benefits and challenges of using embodiment and scientific inquiry for teaching and learning. In terms of benefits, the teacher reported that collaborative embodiment helped students to figure out ideas, observe their peers, and self-correct their movements to learn more deeply (e.g., "they'll remember it more, because it's not just somebody telling you how the air particles move"). She also noted that she thought students' learning was improved by the opportunities for exploration and prediction, and that bringing science ideas into music class could support students' vocabulary learning. The teacher also discussed the value of positive emotional engagement for students' perceptions of music class, saying, "I think even if they don't remember five years from now or even one year from now what amplitude is, I think they'll remember having fun in music." This perception of music as both enjoyable and important was something that the teacher returned to several times, as when she noted the benefits of blending science with music: "I think it helps students to see that science and music are combined, and they play off each other [...] the more you kinda relate music to other disciplines, it helps the kids see a need for it and see the importance of it." Overall, many of these observations were specific to the teacher's perspectives and were not findings that could have been gleaned from student interviews or classroom video alone. The teacher noticed both potential reasons for students' engagement that the students themselves did not report, as well as aspects of students' learning that helped support some of the researcher's hypotheses about the benefits of embodied learning and scientific inquiry.

Discussion

Across the three perspectives, general levels of positive emotional engagement were reported similarly. Many of the potential influences on students' engagement were also reported in similar ways across different participant and researcher perspectives. Some factors, like the novelty of experiences and freedom/choice, are well-known sources of student motivation and engagement (Evans & Boucher, 2015), and this study further supports the benefits of these design features for engaging students' positive emotions. To add to our understanding, this analysis also provides evidence that embodied learning and the ability to move one's body in the classroom can be highly engaging for some learners in terms of emotions as well as social and cognitive engagement. The current study also highlights the importance of disciplinary-specific sources of engagement, such as the creation of beautiful music and the experience of discovering something new during scientific inquiry, which were noted by student, teacher, and researcher perspectives together as key reasons for positive emotional engagement. The large overlap in the ideas discussed by students and the observations of the researcher and teacher give support to the idea that triangulation across multiple participant perspectives can lend strength and complexity to our understanding of the mechanisms at work behind students' engagement with learning.

Beyond the benefits of strengthening existing claims, the use of student and teacher perspectives on engagement can offer the researcher valuable contextual information and insights into the less-visible features of participants' socioemotional interactions both inside classroom activities and in other overlapping spheres of students' lives. While the researcher perspective captured the overall emotional valence of interactions in ways that aligned with the teacher and majority student opinions (e.g., positive or negative), the nuance of why these emotions appeared, as well as negative emotions that were not expressed by the majority of students, were not always visible to the researcher. These insights that are unique to participant viewpoints caution us to not over-focus on our instructional designs as the only mediators that might be influencing learners' social and emotional engagement with one another and their teacher.

The teacher lens opened up a window into both the benefits and the challenges of implementing practices of embodied learning and scientific inquiry into non-STEM classroom spaces. Her perspectives also offered ideas about the benefits of blending science and music teaching together to more deeply engage students in the pursuit of both disciplines. The teacher was able to offer vital contextual information about the socioemotional dynamics between the class at a baseline, to more clearly reveal the ways that designed learning activities intersect with existing engagement patterns. The student lens also provided a similar yet distinct window into the personal histories between students and the socioemotional foundation on which activities were taking place. Participant perspectives overlapped in useful ways for confirming researcher observations, but students and teachers each offered specific reasoning around engagement that was not fully covered by the other viewpoint, as well as the articulation of small moments of engagement that the researcher overlooked. While a standard self-report survey with pre-determined rating scales may not fully uncover these context-specific and dynamically changing interactional details (Karabenick & Zusho, 2015), the present study suggests open-ended interviews can surface valuable information about how and why students engage with learning. Students were also able to communicate reasons for their emotional engagement that neither the teacher nor the researcher noted in their reflections, such as the need for more socioemotional support when being offered feedback. Thus, we should not assume that young students do not have anything meaningful to tell us about how and why they engage with learning, or that teachers and researchers alone have all the answers about what drives learners' engagement. The researcher's perspective was well suited to analyzing broad patterns in engagement across the dataset, but the student and teacher perspectives offered contextual detail that made the mechanisms driving these overarching patterns more visible.

Conclusion

In comparing different perspectives on engagement, the goal is not to argue that one is more true or more accurate to some hidden reality of "what's actually going on" in the classroom when students engage with learning. Rather, gathering and comparing both participant and observer perspectives brings us closer to an intersubjective understanding of best practices for designing engaging learning environments. This process, which was named above as triangulation, has also been framed by qualitative researchers as a process of crystallization (Ellingson, 2008), in which each additional form of data comes together not to locate the position of a singular "reality" but instead to add complexity and depth to a still-incomplete understanding (Tracey, 2010). This perspective on engagement honors the unique and complementary perspectives of students, teachers, and researchers, highlighting what each view brings to our collective picture of what engagement looks like in the classroom and what interactional mechanisms support it. Whether we draw our evidence of engagement from video-recorded moments of negotiation, laughter, and disagreement, teachers' perceptions of how their students experienced learning, or students' reported experiences of joy, frustration, and collaboration, each lens reveals both distinct and overlapping facets of our pedagogical designs that can be further refined to promote more frequent and meaningful engagement with learning. The goal then for future studies of engagement is to continue to expand the crystallization of the concept, by revealing new angles of understanding in regards to how our designs can generate, evaluate, and sustain learners' multidimensional engagement with complex ideas and with each other.

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Design Principles for Teacher Dashboards to Support In-Class Learning

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Abstract: When using learning technologies within classrooms, teachers often face challenges around supporting their students' learning within a digital space. To address this, prior work typically augments learning technologies with teacher dashboards that display real-time student data. Although common similarities in dashboard designs can be found, not all dashboards are designed similarly as teachers and learning technologies vary greatly. There is a lack of prior work around what design principles offer best practices for designing teacher dashboards. Our work addresses this gap through a systematic literature review of research on K-12 dashboards. Our review yielded (a) a concrete list of teacher tasks that teacher dashboards should support and (b) design principles that best support the design and development of teacher dashboards.

Introduction

K-12 teachers are increasingly integrating learning technologies into their classrooms. While learning technologies can be used to support the learning and engagement of students (Bergdahl et al., 2018), they also introduce challenges to teachers' pedagogical practices. Since these technologies shift the learning environment into a digital space, teachers also experience a push to shift their pedagogical practices to best support students within the digital space.

One way to support teachers is by augmenting learning technologies with teacher dashboards. Teacher dashboards can enhance teachers' understanding of student learning by leveraging real-time data collection and analysis to display student progress and engagement within digital learning environments. Recently, there has been an increase in research for designing dashboards for teachers, such as Luna (Xhakaj et al., 2017), PROGDASH (Ez-Zaouia et al., 2020), and MetaDash (Wiedbusch et al., 2021). While these dashboards share several similarities (*e.g.,* display student progress, aggregate data on student and class levels), there are a number of key differences between them. These differences stem from the specific support needs of teachers and the learning technology in which a dashboard is designed to augment. For example, teachers incorporating a computer-supported collaborative learning system in their classrooms may want to observe the collaboration between students within the digital space. Dashboards could display the amount of talking between students (van Leeuwen et al., 2019) and enable teachers to stimulate collaboration between quieter or off-topic students (Tissenbaum & Slotta, 2019). On the other hand, teachers incorporating a learning technology designed for individualized learning may prefer to observe how students interact with the system itself, such as requesting hints from the system (Xhakaj et al., 2016). While these dashboards support teachers in observing student interactions (student-to-student vs. student-to-system), each dashboard displays metrics and visualizations specific to the needs of teachers and capabilities of the learning technology. Thus, one dashboard design does not support the needs of all teachers and learning technologies. Designing dashboards should therefore center teachers' needs; this calls for design principles that can guide the design process of teacher dashboards. Uncovering these design principles by identifying the common support needs of teachers is the focal point of this paper.

While prior work describes the design processes behind certain dashboards, we still do not have a framework that informs the design process of teacher dashboards grounded on the pedagogical practices of K-12 teachers. There are some studies focused on reviewing the current scope of dashboards in education, including Schwendimann et al., (2016) and An et al., (2020). Schwendimann et al., (2016) focuses on multiple contexts, including dashboards for students, teachers, administrators, and researchers, and does not propose a design framework. An et al., (2020) focused on creating a design framework, but one for any type of teacher augmentation tool. Our goal in this paper is to draw design principles from prior literature that speak to designing K-12 teacher dashboards in ways that tie into real-world teacher needs and practices. This paper provides a systematic literature review of research on K-12 teacher dashboards for supporting in-class learning. In this study, we address the following research questions (RQ):

- *RQ1*: What role(s) do teacher dashboards play in supporting the pedagogical practices of K-12 teachers?
- *RQ2*: What design principles could guide the design process of K-12 teacher dashboards and how do these principles support the pedagogical practices of teachers using the dashboards?

Related work and theoretical framework

Our work is driven by insights and theoretical constructs from prior work with teacher dashboards, including, among others, how teachers make sense of data from dashboards to enhance pedagogical practices within K-12 classrooms and work on co-designing with teachers to elicit meaningful design principles for dashboards.

Impacts of teacher dashboards on k-12 classroom pedagogical practices

As learning technologies continue to be integrated into K-12 classrooms, teachers shape and adopt their pedagogical practices to incorporate these technologies to aid in classroom teaching and learning. Eppard et al. (2021) uses the term *EdTech culturation* to describe a pedagogical approach that centers the sociocultural contexts of classrooms through an understanding and adeptness in technology use within and outside classroom teaching. They emphasize the importance of reducing student-teacher barriers by forefronting the needs of students. Teacher dashboards are a common avenue for reducing student-teacher barriers. Often integrated with learning technologies, teacher dashboards display student data to teachers in real-time, enabling teachers to immediately and more effectively respond to students' needs. While researchers have observed that teacher dashboards improve the frequency and efficiency of teacher support for students, we still don't have a profound understanding as to how teacher dashboards shape teachers' pedagogical practices (Molenaar, 2017).

Data sensemaking for teachers

Sensemaking is the process of encoding information to answer task-specific questions. By allowing teachers to reflect on and answer their own questions about student data, sensemaking promotes the ideation of new insights about student and class progress toward learning goals (Bodily & Verbert, 2017). Since teacher actions are based on their sensemaking of student data, it is important for the data to be presented with simplicity and clarity. Although considerable work has been done on data sensemaking, there is still a gap in understanding the sensemaking process of teachers when connecting dashboard data to their pedagogical goals and strategies.

One factor for this gap is the variability of how teachers react toward data visualizations. Teachers' emotional, analytical, and intentional responses affect how they interpret data (Campos et al., 2021). During sensemaking, teachers build narratives around data by using their own unique reactions and experiences. The variability is increased for data with some level of uncertainty (*e.g.,* data that presents open-ended and interpretable questions, such as "*How to improve teaching?"*) (Nguyen, 2021). Therefore, when designing visualizations for teacher dashboards, the variability of reactions, needs, and understandings of the data needs to be considered (Epp & Bull, 2015). While several teacher dashboards exist, there is a lack of empirical evidence around how certain visualizations aid sensemaking of teachers (Bodily & Verbert, 2017).

Co-designing teacher dashboards

Co-design involves the inclusion of participants in the design process, allowing for their unique expertise to drive design and analysis (Penuel et al., 2017). The practice of co-designing teacher dashboards with teachers has been widely adopted and has enabled researchers to identify and address factors that impact teachers' use of dashboards, including experiences, perceptions, pain-points, and frustrations (Ez-zaouia, 2020). Ez-zaouia's (2020) process model for dashboards strongly emphasizes co-design as it enables designs to be robust, attractive, diverse, and equitable. Matuk et al., (2016) addresses the importance of identifying the right tasks for teachers to complete within the design process, including discussing physical artifacts and reacting to scenarios, with each task providing a list of key insights that could positively impact the success of the co-design.

A drawback to co-design is the potential tension between teachers and researchers due to a lack of understanding of the competencies and contributions of all members. Researcher-designed solutions may not seem practical to teachers, and teachers may not be able to articulate their needs to researchers well. Tensions may also arise from time and productivity pressures due to lengthy co-design processes. However, Penuel et al. (2007) notes that when tensions arise and are appropriately addressed, they have the potential to lead to innovative results. Thus, educational technology researchers value the inclusion of teachers in the design process and may consider collaboration with teachers to be a design principle for these technologies.

Methodology

To understand the role that teacher dashboards play in supporting classroom pedagogical practices and the principles that drive the design of teacher dashboards, we conducted a systematic literature review on K-12 teacher dashboards. In this work, we define pedagogical practices as the methods and strategies behind teachers' teaching and learning approaches. Within these pedagogical practices are specific *teacher tasks* that teachers perform to promote learning in students (adopted from Medley & Crook's (1980) definition), and which teacher dashboards may be of aid to. We also sought to identify design principles for teacher dashboards. We define design principles to be guidelines with context considerations for designing a system like a teacher dashboard. We followed Okoli and Schabram's (2010) 8-step guide for systematic literature reviews. Our search string included keywords used by Wiedbusch et al. (2021): "teacher dashboard", "learner analytics dashboard", "instructional panel", "teacher interactive dashboard", "educational dashboard", "learning dashboard", "data visualization dashboard", and "learner progress monitoring".

We used Google Scholar for our search engine. To account for recency of the results, we limited the result list to the last 20 years from January 2002 to April 2022 (we retrieved results in May 2022). Our search string and publication date range returned 2620 results. We first screened the results by reviewing their titles, abstracts, and publication details based on the following criteria: (a) published between January 2002 and April 2022, (b) peer-reviewed journal or conference proceeding, (c) abstract available, (d) paper available in English, (e) context of paper is K-12 teacher-facing dashboards for in-person learning, (f) research includes teachers as a participant or co-designer, and (g) article addresses at least one of our research questions. Criteria (f) is specifically important for this study as teachers have been considered guides to the design process of teacher dashboards and can act as validators to whether a dashboard meets their needs (Ez-Zaouia, 2020). If an article failed to meet any of the eight criteria or if an article focused on MOOCs or was a review of other studies, it was excluded from this study. Following Ojoli and Schabram (2010), if we had any doubts about the alignment of a paper with our inclusion criteria, we included the paper in our results list. As we reviewed the results (ordered by Google Scholar's relevance filter), we found that relevance significantly decreased as we approached 1000 articles; we thus limited our analysis to the first 1000 articles. In total, 118 research papers passed the first screening.

We conducted a second screening of the 118 eligible articles by applying our inclusion criteria from the first screening round to the entire content of each article. Criteria (f) and (g) were of particular importance during this screening round. Articles needed to clearly state how teachers were included in the design process and what needs those teachers expressed. Design processes also needed to be detailed to include the logistics and justifications for each phase of their process. Of the 118 articles, 19 articles passed the second screening (1).

Finally, we performed Braun & Clarke's (2012) six-phased thematic analysis on the 19 articles. In Phase 1, we reviewed the 19 articles once more to further familiarize ourselves with the studies and dashboards that each article presented. We then performed an initial coding of the articles (Phase 2) by manually extracting data from each article into a spreadsheet. We coded for publication details (*e.g.,* date, publication type, authors, keywords), study protocols (*e.g.,* research questions, methodology, results, limitations), teacher dashboard details (*e.g.,* input data, features, data visualizations, stage of development, role in supporting teachers), design processes (*e.g.,* design methods, teacher involvement, duration, evaluation, limitations), and learning technologies (*e.g.,* name, targeted grade level and subject, key features). Within our codes, we searched and identified themes (Phase 3) and used the themes to cluster similar codes. We reviewed our findings (Phase 4) by collaboratively discussing relationships between the codes within each theme. In Phases 5 and 6, we labeled our themes and created tables to summarize them (Tables 1 and 2). In the end, we found themes across the 19 papers focusing on two key dimensions: teacher tasks and design principles. In the following section, we describe our findings, exploring these dimensions that we distilled from our systematic literature review.

Results

While our search criteria included a publication range from 2002 to 2022, all 19 articles were published between 2013 and 2021. Most of the teachers described in the articles taught at the middle school level (middle: 8, secondary: 6, primary: 4, multiple levels: 1) and most teachers taught math (math: 9, science: 4, history: 1, grammar: 1, problem-based learning: 1, unknown: 3). Additionally, all 19 articles only involved screen-based dashboards, which was not an inclusion criterion. In the following subsections, we list our results from (a) identifying teacher tasks that were supported by the dashboards and (b) the design principles we synthesized.

Teacher tasks supported by dashboards

Table 1 summarizes the seven teacher tasks that the teacher dashboards were designed to support (column 1), and the specific dashboard features that afforded those tasks (column 2). Using van Leeuwen et al.'s (2019) terminology, we assigned *dashboard roles* (*mirror*, *alert*, *advise*) to each teacher task to describe how the dashboard supported the teacher. A *mirroring* dashboard displays data to a teacher without prompting or alerting the teacher (*e.g.,* displaying data using a line chart visualization). An *alerting* dashboard mirrors and flags a teacher's attention to data that may need immediate attention (*e.g.,* using colorful symbols to draw attention). An *advising* dashboard mirrors, alerts, and suggests actions to a teacher to act upon flagged data (*e.g.,* suggesting support interventions for a student). We additionally define two new dashboard support roles: *mediate* and *reduce workload*. A *mediating* dashboard enables teachers to directly communicate with—or promote communication between—students (*e.g.,* chatboard). A dashboard that *reduces workload* handles the orchestration of learning activities (*e.g.,* assigning students to groups). In defining dashboard features, we identified the common features among the dashboards that support each teacher task.

Within the papers, teachers reported a need to view data across multiple levels: at the student level (individual students), group level (collaborating students), class level (all students), and task level (lesson tasks). Of the 19 papers, 13 discussed dashboard aggregation of data into separate views (e.g., student view vs. class view). 13 demonstrated (either in text or in screenshots) the use of simple data visualizations, including 3 that explained specific ways teachers can interact with the visualizations. For alerting teachers, 7 papers exhibited alert indicators. Four papers additionally explored how dashboards can advise teachers on alerted events. While only 3 dashboards discussed chat features for teacher-to-student communication, several papers did discuss how teachers communicate with students in-person after dashboard consultation. One paper found teachers requests for data about subsequent teacher-to-student interactions. Five papers discussed features for observing student-to-student collaboration, 2 of which plotted the amount of talking per student, and another 2 that displayed conversation transcripts. Five dashboards mention features to save data, with 1 mentioning that teachers would print dashboard-generated reports for review offline. Although only 1 paper described the software agents implemented into their dashboards, all papers expressed automation of some orchestration tasks.

Table 1
Teacher Tasks Supported by K-12 Teacher Dashboard Features

Teacher Task (Dashboard Role)	Dashboard Features (Number of Papers)
View data at student, group, and class levels (mirror)	Multiple views (13), Simple data visualizations (13), Interactions on visualizations (3)
View students' task performance on specific tasks (mirror, alert)	Multiple views (13), View of class trends (10), Simple data visualizations (13), Alert indicators (7)
Provide feedback and support (alert, advise, mediate)	Alert (7) and warning (3) indicators, Suggestions (4), Chatboard (3), Details about subsequent interventions (1)
Personalize learning for students (advise, reduce workload)	Grouping of students based on performance (2), Automated activity recommendations (1)
Monitor and support collaboration between students (mirror, mediate)	Talking indicators (2), Conversation transcript (2), Chatboard (3)
Reflect (mirror)	Student and class reports (5), Metrics for specific time periods (1)
Orchestrate activities (reduce workload)	Automate orchestration/managerial tasks (19)

Design principles for teacher dashboards

Table 2 summarizes the design principles (column 1) that drove the design of K–12 teacher dashboards and the context considerations (column 2) that designers should think about when applying each design principle. Although the inclusion criteria for this study enforced the involvement of teachers, it is worth pointing out that the number of teachers involved in each study varied greatly, ranging from 1 (Tissenbaum & Slotta, 2019) to 17 (van Leeuwen et al., 2019). Of the 19 papers, at least 18 *evaluated dashboards on real classroom data*. One paper stated they used "simulated, fictitious situations" to evaluate dashboard design effectiveness but it was unclear if the simulations used real student data (van Leeuwen et al., 2019). All 19 papers designed for *simplicity* and *glanceability* (to various degrees) and 13 designed for *modularity*. Lastly, all 19 papers *focused on informing to support sensemaking*, a primary goal of dashboard design.

Discussion

In this section, we discuss our findings regarding (a) teacher tasks supported by K-12 dashboards and (b) design principles for teacher dashboards.

Teacher tasks supported by dashboards

We describe below our findings from our systematic literature review on what dashboard features best support teachers in their tasks during in-person classes.

Table 2
Design principles for designing K-12 Teacher Dashboards

Design Principle (Number of Papers)	Context Considerations
Design for simplicity (19)	Clarity of information, time and effort needed for sensemaking, familiarity to teachers
Design for glanceability (19)	Clarity of information, time and effort needed for sensemaking, summaries of information, indicators for immediate attention
Design for modularity (13)	Aggregation of data, layout of interface, transitions to focus on specific modules
Focus on informing to support sensemaking (19)	Tasks teachers do and do not want automated, teacher sensemaking and resulting actions
Evaluate on real classroom data (18)	Methods, classroom setting, teacher experience

Teacher task 1: View data at student, group, and class levels

Most of the papers focused on the goal of aggregating data into views to reduce the information overload of teachers. This was done by mirroring data that has been aggregated into student, group, and class levels to reduce teachers' experience of information overload. Some papers also provided multiple dashboard views and enabled teachers to toggle between these views. Some papers also enabled teachers to filter data on students such that they design their own views. Overall, dashboard designers should consider displaying simple visualizations that summarize views on a main screen and enable teachers to further explore those views by selecting visualizations of interest.

Teacher task 2: View students' task performance on specific tasks

Several of the papers discussed displaying aggregations of students' performance data based on tasks. Some papers displayed tasks that belong to the same lesson on a single view, often referred to as the *lesson overview*. These papers indicate students' performance, progress, and engagement using colors in the *lesson overview* (*e.g.,* green: task complete, red: task attempted but not complete). Some papers also displayed students' progress and engagement for a single task as a separate view, referred to as the *task view*. For the *task view*, these papers included metrics such as student actions, attempts, and performance trends, among others. Overall, dashboard designers should consider a *lesson view* that acts as a gateway to specific *task views* to reduce information overload for teachers, especially for lessons composed of many tasks.

Teacher task 3: Provide feedback and support

Some of the papers focused on helping teachers to support students more efficiently. This was done by alerting teachers to students in need of intervention. Some papers used colors to highlight students' names, while others used symbols to draw attention to students. In addition to alerting, some papers included dashboards that display advisory text to teachers for providing suggestions on supporting students. One paper addressed teachers' needs for reviewing support suggestions from previous student interventions. Overall, dashboard designers should consider strategies to flag teachers' attentions and to advise teachers in supporting flagged students.

Teacher task 4: Personalize learning for students

A few papers displayed a need for dashboards to assist teachers in creating a personalized learning experience for students. Some papers showed how grouping students with similar performance metrics can assist teachers in personalizing their instructions for specific groups. In doing so, it was found that teachers could support more students in less time. One paper demonstrated how dashboards can advise teachers in finding additional materials that may aid particular students. Overall, dashboard designers should consider affording teachers the ability to group similarly performing students so teachers can communicate to students more effectively.

Teacher task 5: Monitor and support collaboration between students

Some of the papers addressed designing dashboards for learning technologies that support student collaboration. Those papers displayed two ways to mirror collaboration to teachers. One approach used line charts to display the frequency of communication per student. The other method used live transcripts of speech or chat messages to show the entirety of communication between students. Some papers involved color-coding the transcripts by students. Other papers used highlighting to draw attention to concept-related words within the transcripts. Some papers also addressed the need for teachers to intervene and stimulate task-focused collaboration between students by supporting teacher-to-student chat messaging. Overall, designers for collaborative learning technologies should consider ways to present communication with clarity to allow teachers to quickly observe the ideas and engagements of collaborating students.

Teacher task 6: Reflect

A few of the papers addressed the need for dashboards to support teacher reflection. Some papers indicated that reflection can be supported if dashboards allow teachers to save reports. Some papers also showed that filtering the data by date can aid teachers' reflection on trends in class performance. One paper discussed the option for teachers to add summaries to saved dashboards so they can revisit their summaries during reflection. Overall, dashboard designers should consider how teachers intend to use dashboards after class.

Teacher task 7: Orchestrate activities

All papers discussed ways in which dashboards can reduce teachers' workloads by automating orchestrational tasks. One paper mainly focused on the use of software agents to automate some teacher duties such as assigning students tasks and forming groups. Overall, dashboard designers should consider which tasks that teachers would benefit from being automated. However, designers should be cautious of the negative impact that much automation can cause on data sensemaking for

Design principles of teacher dashboards

Design principles have been studied greatly within the human-computer interaction space, and many proposed principles can be carried over to the design of educational technology. However, there is a gap in understanding how to apply these principles to the design of technologies for real-world classrooms. In the following subsections, we discuss the common design principles found in the literature for teacher dashboard. We aim for the design principles that we identified to provide a starting point for designers of teacher dashboards and to support the iterative design processes that are often adopted when designing these systems.

Design principle 1: Design for simplicity

A common theme among all papers is designing for simplicity to minimize teachers' sensemaking efforts and maximize teachers' ability to support students. Several papers emphasized the importance of simple data visualizations for displaying student data. One study found that, by showing simple data visualizations to teachers in the early stages of the design process, teachers were able to propose changes that they believe would work best in their classrooms. Overall, dashboard designers should consider using data visualizations that are easily interpretable and reflect what teachers need in a classroom setting.

Design principle 2: Design for glanceability

As with designing for simplicity, all papers reflect dashboards that are designed for glanceability. Some papers reported the need for teachers to glance at dashboard data and quickly process the data during class. These papers emphasized that, immediately after students have completed a task, teachers' glance at the dashboard to check students' performance. Some papers noticed that visual alert indicators supported teachers in identifying low performing students at a glance. Additionally, providing glanceable summaries and comparisons of students aided teachers in quickly identifying students who need additional support. Overall, dashboard designers should consider using alert indicators and visual comparisons to increase glanceability in a classroom setting.

Design principle 3: Design for modularity

Here, modular design refers to splitting a dashboard's user interface into independent sections. Some papers split the dashboard's design using a grid layout. These papers aggregated data into tiles reflecting separate modules that correlate to different views. Some papers additionally allowed teachers to interact with tiles by clicking, which expands a tile's view. Rather than tiles, some papers addressed modularity by using buttons on a main screen. The buttons allow teachers to transition to different views. In both examples, modularity organizes student data displayed on a screen, reducing the teachers' experience with information overload. Overall, designers should consider modularity for organizing and reducing the display of student data.

Design principle 4: Focus on informing to support sensemaking

All dashboards focused on informing teachers to support their sensemaking of student data. While some papers address the use of automated advisory to support teachers, no papers forced teachers to accept the suggestions. Rather, these papers adopted the "show, don't tell" motto, in which information was presented to teachers but the sensemaking of the data was left to teachers. Some papers explored how software agents could automate tasks, but no papers automated all teacher tasks. Thus, dashboard designers should be wary as to what teachers want automated. Overall, dashboard designers should explore the automation needs of teachers and avoid automating tasks that are important to teachers' pedagogical practices.

Design principle 5: Evaluate on data from real classrooms

Almost all papers explicitly stated their use of real classroom data in the evaluation of teacher dashboards. Most papers evaluated the dashboards during the co-design process by including observations and interviews. Thus, these studies used real teachers and/or live classroom data. The papers that evaluated dashboards using real-class observations noted the benefits of watching exactly how and when teachers use the dashboards during class. Furthermore, papers that interviewed teachers after observing them found that the interviews uncovered more specific details as to teacher usage of the dashboard during class. Overall, dashboard designers should consider including observations and interviews with teachers using real student data (*e.g.,* live classroom data) when evaluating the dashboard design and effectiveness.

Conclusions, limitations, and future work

In this study, we conducted a systematic literature review of research on K-12 teacher dashboards to understand the role(s) dashboards play in supporting the pedagogical practices of teachers, and to understand the design principles that guide dashboard design. We found that dashboards typically support teachers with the following tasks: viewing data at student, group, and class levels, viewing data at task level, providing feedback and support to students, personalizing learning for students, monitoring and supporting collaboration between students, reflecting on class outcomes and pedagogical practices, and orchestrating activities to reduce workload. We also found the following design principles for building dashboards that support teachers: design for simplicity, design for glanceability, design for modularity, focus on informing to support sensemaking, and evaluate on real classroom data.

Systematic literature reviews come with the inherent risk of bias due to subjective interpretations of literature. In this study, researchers may have experienced additional bias due to author and publication details not being blinded. Additionally, articles selected for this study were limited to Google Scholar's coverage. One strategy for expanding beyond a search engine's coverage is backward searching in which references of selected articles are screened as well. However, this strategy was not implemented in the present study.

In studying the design processes of K-12 teacher dashboards, we uncovered ways in which designers and teachers can collaborate to design systems that will better support teachers in helping students effectively engage in learning. Future studies can use our findings as a starting point for their design processes for teacher dashboards, and we encourage further research on validating and expanding on the design principles presented here. Furthermore, we encourage further research on testing our findings on the design of teacher dashboards within informal learning environments. Going forward, we plan to follow the design principles identified in this study to implement and pilot a teacher dashboard for our own learning technology, *WearableLearning (wearablelearning.org),* designed to teach math and science through interactive games with wearable technologies (Castro, 2022).

Endnotes

(1) Due to space constraints, a link to the full list of the 19 articles analyzed in this study, including the details of each paper, is available in https://osf.io/tx9ab/.

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Analyzing Teacher Learning in a Research Practice Partnership

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Abstract: Teachers are increasingly participating in RPPs with the goal of improving their schools and districts. This context provides teachers with unique learning opportunities as they directly take part in district-level instructional improvement work. However, we know little about what teachers learn from their involvement in RPPs. This study explores teacher learning over the course of the first year of a multiyear RPP which involves a group of elementary teachers and a team of researchers from a local university. Findings reveal shifts in three areas: teacher reasoning about relevant problems of practice, teacher contributions, and teacher roles. These findings not only shine a light on the nature of teacher RPP participation, but they also highlight how RPPs can be a context for teacher learning.

Introduction

Research practice partnerships (RPPs) are long-term collaborations between practitioners and researchers in which the collective engages in school improvement work by investigating persistent problems of practice and solutions (Coburn & Penuel, 2016). RPPs are increasingly utilized for school improvement purposes because they address local problems of practice and enable greater use of research in decision making (Coburn & Penuel, 2016). Despite a growing body of literature related to RPPs, there is still a need for more detailed research, including the need to better understand conditions that foster or inhibit their success (Farrell et al., 2021) and the processes and outcomes of these partnerships (Klar et al., 2018). Increasing our understanding of how teachers participate in and what teachers learn from RPPs, may provide some insight into what helps these reform efforts either succeed or fail. Previous studies have focused on the learning of district leaders (e.g., Rigby et al, 2018), but few previous studies have focused on teacher learning within RPPs.

Teachers and research practice partnerships

RPPs promote productive relationships between researchers and school district personnel, during which goals are collaboratively determined with the aim of achieving districtwide instructional improvement (Henrick, et al., 2016). Five key features of RPPs have been recently identified (Farrell et al., 2021): (1) they are long-term collaborations, (2) which often disrupt traditional power relationships, (3) whose goal is educational improvement, achieved through (4) the application of research (5) by its members who hold diverse expertise. Since addressing challenging educational issues is generally the goal of RPPs, these partnerships must therefore provide ample time for goals to be achieved. This means that RPPs in their first or second year are in the early stages of the work, and an RPP is only considered mature after 3 or more years (Farrell et al., 2021). While other change initiatives also rely on research, expertise, and shifts in power, the way RPPs leverage such resources is unique. RPPs both produce and promote the use of research in decision making. In terms of expertise, RPPs tap into the diverse knowledge and experiences the various participants bring with them. This commitment to engaging all participants meaningfully in the work of the RPP contributes to shifts in traditional power relationships, such as those between teachers and school administrators.

Given the previously listed features of RPPs, they can be considered as a community of practice. A community of practice is a group that collectively engages in a shared repertoire of routines as the group works towards a common goal (Wenger, 1998). RPPs can be considered a community of practice as they consist of a group of individuals who come together regularly to collectively investigate and solve persistent problems of practice. Previous studies have explored teacher learning as they engage in various types of communities of practice and Levine and Marcus (2010), in particular, found that different teacher collaboration structures provide different opportunities for teacher learning. However, we know little about what learning opportunities for teachers are provided by an RPP structure.

One of the defining characteristics of RPPs is that they require participants to take on roles that are unfamiliar or even oppose traditional norms (Farrell et al., 2019). This is especially true for teachers who often do not have opportunities to be directly involved in district-level instructional improvement efforts as districts' hierarchical leadership structures diminish the likelihood of such teacher participation (Leithwood et at., 2007). Unlike typical classroom-based instructional improvement efforts, RPPs have the potential to directly involve teachers in the design stages of district-level improvement efforts because they intentionally employ flatter, less hierarchical, structures (Farrell et al., 2019) which encourage distributed leadership (Leithwood et at., 2007).

Given the nontraditional roles that teachers may take on in RPPs focused on districtwide improvement efforts, it raises the question of how teachers engage in and what teachers get out of such an experience. More specifically, what do teachers learn as they participate in RPPs? In this study, we investigate teacher learning in these partnerships by examining teacher reasoning of, contributions to, and roles in RPP work. Our three research questions are: As teachers engage in RPP work, (1) how does their reasoning about improvement work shift over time?, (2) how do teacher contributions shift over time?, and (3) how do the roles teachers take on change over time?

Previous studies of teacher groups

To better understand the unique context that RPPs can provide for the study of teacher learning, an overview of more typical studies and contexts involving the study of teachers is necessary. Studies of teacher groups have become more popular in recent years (Lefstein et al., 2020) because teacher collaborative groups have been recognized as a potential structure to support school improvement (Horn & Little, 2010). For example, Kazemi and Loef Franke (2004) examined how math teachers' participation in after-school workgroup meetings shifted over time as teachers came together to discuss students' work samples. Horn (2007) compared the conversations of two different teacher groups as they discussed the problems of practice they encountered in their classrooms. Bannister (2015) provided an empirical example of teacher learning within a community of practice by focusing on teachers' framing of various problems of practice. Although the studies differ in terms of methods and goals, they reveal how the study of teacher groups is typically tied to classroom-based problems of practice. RPPs however, have the potential to provide a context for teachers to engage in work that falls out of the realm of classroom. In this study, we explore teacher learning as teachers participate in conversations about problem identification and solution formulation that will not only impact their own classrooms, but all classrooms across the district.

Conceptual framework

This study is grounded in a situated theory of learning which identifies learning as shifts in participation within a community of practice (Lave & Wenger, 1991). In this study, we explore how teachers' participation patterns shift over time as they engage in a routine of participating in district-level instructional improvement meetings. Through these regular meetings, a community of practice is formed between the participants.

We define the teachers' participation in this community of practice as their contributions to the collective reflective and planning discussions. More specifically, we conceptualize these contributions as episodes of improvement work reasoning (EIWRs), an adaptation of Horn's (2007) episodes of pedagogical reasoning (EPRs). Horn (2007) defined EPRs as detailed instances of teacher reasoning, focused on issues or questions about teaching practice. Horn used EPRs to identify conversational category systems, or the classification of things through everyday language. By building on Goodwin's (1994, as cited in Horn, 2007) work on category systems, this allowed Horn to identify teacher talk as one resource for professional learning in a teachers' community of practice. Following a similar line of thought, we too recognize teacher talk as a resource for professional learning. This reasoning aligns with Little's (2002) suggestion that all talk should be treated "as evidence of what is known and as a potential resource for learning" (p. 932).

We define EIWRs as episodes in which teachers exhibit reasoning through talk about the purposes, obstacles, and methods of instructional improvement work. This distinction is necessary because we are interested in what teachers learn about instructional improvement work and not teaching practice. Horn's examples of EPRs clearly illustrate how her definition of EPRs is tied to classroom practice: "I am not using that worksheet because it bores the kids," and "I have a handful of kids who are not successful. How is this going to impact our classes next semester?" (Horn, p. 46, 2007). EIWRs, unlike EPRs, focus on issues outside the classroom that are tied to districtwide instructional improvement efforts. For example, when reflecting on interview data, one of the teachers argues that team members having differing definitions of high-quality math tasks is problematic and should be addressed before further work is done: "…if we still have team members… that are still questioning high quality. Like what does it that look like, I think we definitely need to back up and like assess what we want to continue with because we want to make sure everyone's on the same page." By examining EIWRs, like Horn, we hope to explore professional teacher learning in relation to districtwide instructional improvement work.

Methodology

This study draws on a case study approach (Yin, 2014) and employs an embedded multiple-case study design of four middle school teachers. The data for this study comes from a larger multiyear RPP project, Collaborating

Around Structures, Processes and Instructional Routines (CASPIR), in which a team of researchers from a large Midwestern university collaborates with several local K-8 school districts. The aim of these collaborative efforts is to investigate issues and solutions surrounding math teaching and learning within each district. Each district's RPP team is composed of district administrators, district teachers, university researchers, and university-affiliated math instructional coaches. A subgroup of members from each of these teams meets regularly to plan the work of the respective whole RPP team (see Table 1).

Table 1
Bay School District Subgroup Members

Subgroup Team Member	Role
Frankie	Teacher
Kim	Teacher (Joined after 6th subgroup meeting)
Kristina	University-affiliated Math Coach
Leah	University Researcher
Lenny	Teacher
Mary	District Administrator
Nicole	Teacher

Subgroup meetings are the focus of this study because they prompt teachers to join in rich discussions as they engage in meaning making (Horn, 2007) surrounding problem identification and solution formulation. The four teachers on the Bay School District subgroup are the focus of this study. The district's subgroup also includes a district administrator, one university researcher, and one university-affiliated math coach, all of whom participate in the subgroup's discussions (all names are pseudonyms).

Data sources and analysis

This study utilizes two data sources: video recordings of subgroup meetings and transcripts of subgroup meetings. The subgroup met 15 times over the course of the first academic year of the partnership, for a total of 26 hours. To answer the three research questions, two units of analysis were identified. The two units of analysis allowed us to investigate participation through two different lenses and they also made it possible to analyze the data at two different levels of analysis.

The first unit of analysis is individual EIWRs shared by teachers during subgroup meetings. First, EIWRs were identified in each meeting. Then, EIWRs were coded by topical content so that similar themes can be compared over time (Horn, 2007). We identified six major codes emerging out of the data (Charmaz, 2014): problem identification, norms, individual roles, subgroup role, data, whole group planning, and solution formulation (see Table 2). Some EIWRs fell into only one category, while others fell into multiple. EIWRs can be analyzed individually or collectively. When considered individually, an EIWR allows us to gain an understanding of an individual teacher's reasoning about a specific topic. For example, Table 2 includes an EIWR by Kim about problem identification. From this EIWR, we can see that Kim thinks that looking at the math curriculum is a good starting point for the team as they explore ways to improve the district's math program. When considered collectively, consecutive EIWRs allow us to gain an understanding of multiple teachers' reasoning about the same topic. Since EIWRs allow for the exploration of teacher reasoning and their spoken contributions to collective discussions, this unit of analysis was used to answer the first two research questions (i.e., How does teacher reasoning about improvement work shift over time? and How do teacher contributions shift over time?).

Table 2
Seven EIWR codes used for data analysis

Code	Description	Example
Problem Identification	Talk about issues associated with the district's math program.	Kim: "Well, I think, first we want to look at what we're… our curriculum and what we're teaching day to day."
Norms	Talk about group customs and etiquette.	Frankie: "To kind of piggyback on what Nicole was saying. I was thinking honesty, but also being respectful for each other's ideas, and being trusting that we're all educators and we're all working toward what's best for our staff and our students..."

Solution Formulation	Talk related to formulation of solution(s) that will address issues with the district's math program.	Nicole: "...to me it just to have a conversation with somebody makes them feel like they're not in this by themselves, you know, they're in it together, so I would almost like to have that conversation with Owen (non-subgroup teacher), and then I can even ask additional follow up questions…"
Data	Talk about the use of any sort of data, such as student performance data or the feedback from a teacher survey.	Lenny: "…if they read it and digest it and then I think once they look at the tasks that they can then make those connections to the data, along with the tasks."
Whole Group Planning	Talk about whole group meeting agenda and activities.	Nicole: "We don't want them to make a mission statement."
Subgroup Role	Talk about the function or purpose of the subgroup.	Frankie: "I love that idea of us finding tasks already like pre-selecting them and bringing it to everybody, but I feel like we need to do something else before we do that, like we have to get everybody's brain in the zone..."
Individual Role	Talk about one's own role.	See example from the Solution Formulation row.

Ellipses indicate the removal of words without altering meaning due to space limitations.

Analyzing EIWRs sheds light on teacher reasoning and spoken contributions but they do not allow for the analysis of teacher roles, thus a second unit of analysis is necessary. To identify changes in teacher roles, the other unit of analysis, which we call major decision events (MDEs), were used and this allowed us to answer the third research question (How do the roles teachers take on change over time?). MDEs are important decisions made about RPP work. By important, we mean decisions that move the work forward but are not administrative decisions, like picking the time for the next meeting. An MDE is bound by the start and end of talk about that specific decision so MDEs are very lengthy. Due to space limitations, only excerpts from MDEs (see Table 5) have been included here. Many decisions were made during each meeting, such as what norms the team should use, or what sort of work should be done during the next whole group meeting to move the district's improvement efforts forward. Since we are interested in teacher roles, we only focused on MDEs that concerned what a specific teacher did or will do. To identify changes in teacher roles, MDEs which included teacher roles were identified in each meeting.

Findings

Three major findings arise from our analysis. The first finding is that teachers' reasoning about relevant problems of practice shifted over time (see Table 3). In initial meetings, as the subgroup laid the foundation for districtwide instructional improvement work, they discussed problems associated with the district's math program. During this phase, each of the teachers pointed to a different issue they thought contributed to unsatisfactory outcomes of the math program. In the first meeting, Lenny brought up the lack of cross-grade level collaboration opportunities for teachers. During the third meeting, Nicole spoke about low test scores, while Frankie highlighted the lack of math interventionists and coaches. During subsequent meetings, as they continued to engage in discussion surrounding problem identification, all three teachers zeroed in on the fact that the district's teachers lacked a uniform understanding of high-quality math tasks. Thus, as the teachers engaged in RPP work, their reasoning about issues associated with the quality of their math program shifted, becoming more unified and clearly defined.

Table 3

Teacher's reasoning about issues associated with the quality of the district's math program

Teacher	Early EIWR	Later EIWR
Lenny	**Subgroup meeting #1**	**Subgroup meeting #4**

	"… I know that we've talked about before was talking across grade level teams, but then also, fifth grade being able to spend time [with] sixth grade and vice versa, some of those types of things."	I think that that was the question that was asked in the interview is, what do you think a high-quality task is... Some people [are] like I don't know if I'm right or not... So then, having an opportunity to look at what other people are thinking to refine as a district what we think."
Nicole	**Subgroup meeting #3** "…we just feel that there is a problem and we need to address that problem… the staff knows that there's some sort of… we are seeing them [MAP scores] flat line."	**Subgroup meeting #6** "…teachers have to have a reason why they're picking, choosing something [a task]. Not just because they feel like it…. There has to be a reason."
Frankie	**Subgroup meeting #3** "Like what's going on? Why is this not progressing, not changing? Reading has tons of interventionists and coaches... Well, we've brought up a lot of times, well what about math?"	**Subgroup meeting #7** "…if we still have team members… that are still questioning high quality. Like what does it that look like, I think we definitely need to back up and like assess what we want to continue with because we want to make sure everyone's on the same page."

Data for Kim is omitted because she did not participate in initial meetings.

We also found that the content of teachers' contributions changed throughout the course of the year. As time passed, teachers increasingly offered central input to the collective conversations. Table 4 includes two examples of teacher contributions that are noncentral. In the example from meeting #1, we see Mary, the administrator, share her thoughts about the vision the subgroup is crafting and then Lenny, one of the teachers, follows up by saying she agrees with Mary. In the second example from meeting #2, Leah, the university researcher, suggests how something the subgroup is working on should be worded and two teachers follow up by saying that they agree with Leah. Examples of central teacher contributions can also be seen in Table 4. In the first example from meeting #11, Nicole, a teacher, suggests that a tricky task should be included when the whole group engages in a task analysis activity because this may spark some good conversation. In the second example from meeting #13, Lenny, a teacher, suggests that it is important to remind teachers that tasks which are not considered to be high-quality are still necessary sometimes. When comparing the two earlier teacher contributions to the two latter contributions, it is easy to recognize the difference between the two. Central contributions are a teacher's input into the collective discussion that reveals the teacher's thinking about how things should be done. Noncentral contributions simply amount to teachers agreeing with the administrator's or researcher's ideas by saying something like "I agree," "Yeah," or "True." Not all teacher contributions in the earlier meetings were noncentral, but there are more instances of such teacher contributions during earlier meetings than there are in later meetings. Likewise, there are fewer examples of central teacher contributions in earlier meetings than there are in later meetings. For example, there are five instances of noncentral teacher contributions in meeting #2, two instances in meeting #6, and zero in meeting #15.

Table 4
Noncentral versus central teacher contributions

Noncentral EIWRs	*Central* EIWRs
Subgroup meeting #1 Mary: "Yes. And it kind of goes together. The DLT, the BLT, and the vision. It's kind of like a cycle. That's the way I envision it." Lenny: "*Yeah, I agree.*"	**Subgroup meeting #11** Nicole: "And keep the ones that are a little tricky. Like even that eighth grade one that looked like a MARS task that everybody's going to jump in, kind of like what we did, jump in, and go 'Oh, that looks like a MARS task, that should be high quality.' Well just because it looks like it, it doesn't necessarily mean it is. That would lend itself to that conversation."
Subgroup meeting #2 Leah: "So maybe this should say something like rigorous tasks invite multiple strategies?" Nicole: "*I agree.*"	**Subgroup meeting #13** Lenny: "And one of the things that came up that I think it's important to remember is that just because it's not a high-quality task doesn't mean that it's not still

Lenny: “*Yeah.*”	necessary. And so, I think that that's something that's important, so people don't think that they shouldn't be teaching, you know, that they're only teaching just these lessons...”

Like teacher contributions, the roles teachers took on also changed, becoming more teacher-directed over time. The MDE excerpts from meetings #1 and #2 (see Table 5), show how the early roles teachers took on were directed by others. During meeting #1, Leah, the university researcher, suggested roles for the teachers to take on by proposing that they introduce an activity during the next whole group meeting. The MDE excerpt from meeting #2 also shows Leah suggesting a role for a teacher. In both of those examples, a decision was made about what teachers should do, but the decision was made by someone other than the teachers themselves. The self-directed examples from meetings #14 and #15 show examples of teachers making decisions about the roles they take. In the MDE excerpt from meeting #14, we see Kim, one of the teachers, share how she made the decision to include something in the notes from a whole group meeting because she wanted one of the teachers to feel heard even though she did not agree with the teacher’s thinking. In the MDE excerpt from meeting #15, Frankie, a teacher, shares how she and Lenny picked some days for their group to meet over the summer so that it would be easier for them to invite other teachers to join their group. From these two examples, it is easy to see that as the year progressed, the teachers began to take on more self-directed roles as they began to increasingly make decisions about the work they do as part of the RPP initiative.

Table 5
MDE excerpts illustrating teacher roles

Directed by Others	Self-directed
Subgroup meeting #1 Leah: “So, I'm wondering if the three of you, Nicole, Frankie, and Mary, *if you would introduce this activity to the group* next Wednesday, in the way you think it should be. And what I would offer to do, if this is OK with everybody, and Kim can go back and forth a little bit, just to create the instructions on the first slide, send it to you guys to revise it. And if you guys want to, and if it's ok with you, if you could introduce it to your colleagues and kind of shape it the way you think it should be presented, that would be fabulous. As far as I'm concerned, and if you're willing.”	**Subgroup meeting #14** Kim: “Yeah, and then the, the other part was the multiple choice. Selma (non-subgroup teacher) thought that that should be taken out but, I was trying to explain that we kind of wanted to have a start, it was like a pretest posttest. So, we wanted to have a starting point, so we knew where to go. But she was still very uncomfortable with having that multiple choice. She’s like, ‘The teachers are going to want to know,’ but I’m like, ‘That’s the whole point.’ So, we kind of, we’re at a deadlock there. But again, *I wanted to give her voice to be heard, so I typed it in* the Google doc.”
Subgroup meeting #2 Nicole: “Yeah, why start from scratch and start researching new images when we have all of these images already.” Leah: “Yeah, *you sound like somebody who might want to introduce this activity* to your colleagues.”	**Subgroup meeting #15** Frankie: “About that too about trying to reach out and recruit. *We had, Lenny and I, had gone through our calendars to pick some weeks that worked* for us to try to create a doodle poll, to send out to at least the people who have already committed. And we thought that maybe *if we can narrow down some time, then we could approach somebody from K-3* and say these are the three or four dates that we're going to meet. And that might not sound so threatening, like ‘Oh, we're going to meet 10 to 20 hours this summer, can you do it?’ Maybe if we said we're going to meet this day for two hours and this day for three hours, then maybe they'd be willing to commit.”

Discussion and implications

In this study, we set out to explore teacher learning in the context of an RPP through a situated theory of learning lens, in which learning is defined as shifts in participation within a community of practice (Lave & Wenger, 1991). The clear changes in the contributions teachers offered during subgroup meetings and the changes in the roles teachers took on suggest that teacher learning did in fact occur during the first year of the partnership. The findings show that by the end of the first year, teachers made more central contributions during planning meetings and they also began to increasingly take on self-directed roles. Therefore, we can say that the teachers learned how to become productive members of an RPP.

A closer examination of teachers' contributions and roles reveal that the teachers not only engaged in work that is outside their normal daily teaching practice, but we also see that teachers talked about issues not traditionally associated with teachers. Content and pedagogical knowledge are usually associated with teachers (Hill et al., 2018), yet in this study we see teachers engage with ideas that fall outside the realm of those two categories as they took part in districtwide instructional improvement efforts, discussing issues not directly tied to the issues of daily teaching practice. Teachers are not generally responsible for, nor trained in addressing issues at the district level. However, here we see teachers doing exactly that. The RPP context provides teachers an opportunity to engage in nontraditional roles (Farrell et al., 2021) which then creates an opportunity to explore teacher learning in this unique context. Further study of this teacher learning context and how it relates back to what we already know about structures for teacher learning or teacher collaboration is necessary.

Our findings not only offer insight into teacher learning, but they also provide insight into how RPPs function. Addressing major educational problems of practice takes time, thus, one of the things that we know about RPPs is that they are not considered mature partnerships until the third year (Farrell et al., 2021). In our findings, we see one example of the time requirement to do this sort of collaborative work. The teachers did not speak of the same issue, in this case, the lack of a unified understanding of what high-quality math tasks are amongst all district staff, until the seventh meeting. In our study, the subgroup teachers, who participated in planning and steering the work of the whole RPP team, did not come in with a unified understanding of the issue that they should address. Instead, it took several meetings of rich conversation for the teachers to develop a collective understanding of which problem to tackle. In fact, all the teachers did not reach a unified understanding of the main issue that needed to be addressed till the seventh subgroup meeting. This provides one example of how long it took an RPP group to agree upon which direction to take.

While looking for shifts in teacher contributions, the intentional moves the researcher and the administrator made to directly involve the teachers in the subgroup's work became evident. During the first meeting, Mary the district administrator said, "I am looking to build teacher capacity. And starting to, you know, in their buildings, be able to take on more of an integral leadership role." Mary's intention to empower teachers can be also seen in a comment she made later. After sharing her ideas, Mary said, "I feel like I am talking a lot, and I do not want to talk too much," as a way to invite more teacher input. Leah, the researcher, also made multiple moves throughout the year to encourage the teachers to take more of an active role in the work they are doing. For example, during the fourth meeting, Leah said, "Hey, I have done way too much talking so I am going to let you guys take the lead," as a way to encourage the teachers to take charge. One of the defining characteristics of RPPs is a shift of power to those who do not traditionally have it (Farrell et al., 2021). In our study, we see that the traditional power holders, the university researcher and the district administrator, made conscious efforts to empower and involve the subgroup teachers in the group's work. By the end of the first year, we see major changes in teachers' contributions and roles, however, to what extent the efforts of the university researcher and the district administrator facilitated the shifts in teacher participation is not clear. Future studies should explore characteristics of RPPs that successfully engage teachers in the partnership's work. The researcher's intentional moves to invite active teacher participation also provide insight into how researchers can create productive working relationships with teachers, which is something we know little about (Coburn & Penuel, 2016). From this example, it seems like continual reminders and encouragement by a university researcher can help teachers meaningfully engage in the partnership's work.

This revelation about the intentional moves the researcher and administrator made to fully engage the teachers also offers a design implication for RPPs that involve school administrators and teachers. Administrators and teachers typically fall into two very different spots on the hierarchy of power since administrators usually hold all the decision-making power. Furthermore, teachers are rarely positioned as peers to administrators when it comes to decision-making at the district or even school level. Thus, if researchers want to successfully simultaneously engage teachers and administrators, they have to account for this traditional power dynamic. In this case, the district administrator was interested in empowering teachers and creating a space where teachers could participate equally in the decision-making process, so the researcher did not have to take any further action to create such a space. However, even though the administrator was open to sharing decision-making power with the teachers, the researcher still needed to facilitate the transition through which teachers become more active participants. In this case, that transition happened through two specific actions. As mentioned previously, the researcher would pause speaking at times and would then invite teachers to provide input. The researcher also initially volunteered the teachers for roles they were to take on during whole group meetings. RPPs may have the potential to disrupt traditional power dynamics but this disruption may not come to fruition if researchers don't actively work toward it. Therefore, researchers must first be aware of the traditional power dynamics that are present in the RPP context and then they have to be intentional about disrupting them.

This study explored changes in teacher contributions and roles only during the first year of an RPP, so future studies should explore such changes over longer periods of time and they should also investigate how such changes relate to the RPP's overall success.

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What do Log-Files and Learning Outcomes Reveal about Developmental Differences in Self-Regulated Learning with Serious Games?

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Abstract: To explore self-regulated learning (SRL) processes with log-files and learning outcome data across developmental levels in game-based learning environments (GBLEs), 26 high school and 26 undergraduates learned microbiology playing Crystal Island as their test scores and log-file data about scientific reasoning activities were collected and analyzed. Results show that undergraduates were more likely to solve a mystery than high school students despite no significant differences in test scores. The frequency of SRL for undergraduates was greater than the frequency for high school students, but the proportional duration of SRL within total duration showed that both groups utilized different strategies. Moreover, developmental levels were related to how likely students were to solve the mystery. Our findings emphasize not only an important theoretical contribution by demonstrating how SRL models should take developmental variations into account, but also educational implications for GBLEs by showing the advantages of providing scaffoldings across developmental levels.

Introduction and theoretical background

Learners often struggle to use effective cognitive, affective, metacognitive, and motivational self-regulated learning (SRL) processes while learning (Winne & Azevedo, 2022). To help learners, educational games have been developed to foster effective SRL (Cloude et al., 2022; Dever et al., 2020; Taub et al., 2020). Beyond understanding the increase of motivation and engagement game-based learning environments (GBLEs) provide, it is critical to investigate our assessment of student learning and the effectiveness of their learning processes as they relate to the contents of GBLEs. Learners may acquire knowledge from GBLEs by interacting with game system elements (e.g., non-player characters, instructional materials). However, these elements may be designed to help learners to enjoy the game, rather than leverage the elements for SRL during GBLEs (Taub et al., 2020). To evaluate the degree of learning in GBLEs, diverse methods can be utilized including game scores, external assessments, and embedded assessments. For example, game scores may reflect if students acquired targets or overcome obstacles during game while external assessments may be post-test scores based on multiple choice questions (Ifenthaler et al., 2012). However, despite efforts to establish best practices for evaluating the effectiveness of GBLEs, there is still a lack of scientific rigor (All et al., 2021). Since assessment after learning in GBLEs which frequently concentrates on outcome and not process may neglect significant changes during the learning process (All et al., 2021), evaluating GBLEs with only post assessment might not be sufficient.

To deal with this issue, trace data can be utilized since trace data can uncover fundamental learner interactions for learning design, identify specific patterns or strategies learners use, and determine key predictors of specific behaviors (Azevedo et al., 2018; Owen & Baker, 2020). Specifically, trace data in GBLEs have the potential to dynamically evaluate learning and provide feedback in ways that are not achievable in traditional learning settings (Nietfeld, 2018). For instance, diverse data could be collected from learner's interactions with some elements in GBLEs such as time spent reading scientific text and collecting evidence, the number of times interacting with non-player characters, the quality of hypotheses generated when collecting and testing data, etc. (Dever et al., 2020). Utilizing various types of data collected with GBLEs can lead to better insight or understanding of learning processes in broader and deeper ways, especially when it comes to identifying the underlying cognitive and metacognitive self-regulatory processes (Taub et al., 2017).

Even though many previous studies have pointed out the effectiveness of GBLEs, there are few studies focusing on learners' SRL from their developmental perspectives (Plass et al., 2020). In addition to this, research related to SRL tends to concentrate primarily on younger children and academic achievement (Bjork et al., 2013), leaving open the question whether different developmental groups would perform tasks with the same SRL processes. Through the previous studies presenting that learning outcomes and learners' metacognitive skills were varied across learners' developmental levels (Mayer, 2019; Veenman et al., 2004), it can be expected that learners' SRL processes and learning outcomes are different based on learners' developmental levels in GBLEs. For example, previous research has shown that undergraduate students typically know and can use more learning strategies and fair better when it comes to the metacognitive monitoring accuracy (Taub et al, 2020), but there has been no comparison across developmental levels and their use of self-regulatory skills with serious games. More studies related to students' developmental levels on SRL with GBLEs are needed to understand differences in self-regulatory behaviors and to subsequently use the data to provide more adaptive scaffolds in order to meet learners' individual needs based on their developmental levels. Therefore, the purpose of this study is to enrich the understanding of SRL based on developmental levels by using log-files and learning outcome data. Our study focuses on whether there are developmental differences in students' learning outcomes with two indicators and SRL processes with log-file data in GBLEs.

Theoretical framework

SRL assumes learners monitor and regulate their cognitive, affective, metacognitive, motivational, and social processes (Azevedo et al., 2022; Winne, 2018). Specifically, students can engage in a variety of cognitive, affective, metacognitive, and motivational self-regulatory and reflective processes during GBLEs to ensure they are learning efficiently (Taub et al., 2020). Game-based learning concentrates on the complexities of game design and requires a theoretical framework focused on specific learning processes that are used during SRL (Plass et al., 2020). As such, this study focuses on SRL suggested by Winne and Hadwin's (1998, 2008) model of SRL. According to this model, learning occurs throughout a series of four phases: 1) task understanding, 2) setting goals and planning, 3) engaging in learning strategies, and 4) making adaptations. Each phase which is cyclical and may occur simultaneously allows learners to engage in different self-regulatory processes. While this theory makes assumptions about underlying cognitive and metacognitive processes, it does not make predictions about GBLEs across developmental levels.

Current study

This study aims to further understand developmental differences with self-regulated learning using log-files and learning outcome data during game-based learning. As such, we ask:

RQ 1) Are there differences in learning outcomes (test scores vs. solving mystery) based on learners' developmental levels with Crystal Island? Based on previous studies showing that learning outcomes were different across developmental levels in traditional learning environments (Mayer, 2019; Veenman et al., 2004), we expect that undergraduates will perform better on post-test and solving a mystery during the game compared to high school students.

RQ 2) Are there differences in the frequencies of scientific reasoning activities based on learner's developmental levels during Crystal Island? Considering that learners metacognitive skill increases with age (Veenman et al., 2004) and that undergraduate students can know and utilize more learning strategies (Taub et al., 2020), we expect undergraduate students more often use scientific reasoning activities while learning with Crystal Island.

RQ 3) Are there differences in the proportional duration (compared to total play time) of scientific reasoning activities based on learners' developmental levels during learning with Crystal Island? Considering that learners metacognitive skill increases with age (Veenman et al., 2004) and that undergraduate students can know and utilize more learning strategies (Taub et al., 2020), we expect undergraduate students will spend higher proportion of duration within total game play duration engaging in scientific reasoning activities while learning with Crystal Island.

RQ 4) What is the likelihood that a learner's ability to solve a mystery is related to learner's developmental level during learning with Crystal Island? Prior studies show that learning outcomes are varied across developmental levels (Mayer, 2019; Veenman et al., 2004) and that the correlation between students' use of cognitive strategies and academic performance became significantly stronger across developmental levels (Dent & Koenka, 2016). Therefore, we expect that the likelihood of a learner solving a mystery will be significantly related to developmental levels.

Method

Research context: Crystal island

Crystal Island is a game-based learning environment designed to teach microbiology and scientific inquiry skills. During the game, participants play the role of a medical detective investigating a mysterious infectious disease outbreak on a remote island. To solve this mystery, participants are required to identify a type of disease (e.g., influenza or salmonellosis), a type of infection (e.g., viral or bacterial), a cause of the infectious disease (e.g., egg, bread, etc.), and a solution treatment for the disease (e.g., rest or vaccination). To do so (see Figure 1), participants read complex texts (e.g., articles and books) and posters and then summarize the texts, as they gather important clues. These clues can be collected by finding objects to put into their backpacks while exploring the island, by scanning the objects with hypotheses that they create, and by communicating with non-player characters (NPCs) (e.g., a nurse, patients, a virus expert, etc.) through dialog selection. Based on this evidence, they complete a diagnosis worksheet to solve a mystery. Thus, SRL is fundamental in Crystal Island to foster content knowledge in microbiology and scientific reasoning abilities (Dever et al., 2020).

Figure 1
Activities in Crystal Island to support scientific reasoning and learning about microbiology

BACTERIAL REPRODUCTION

Bacteria reproduce asexually by binary fission, which results in the production of two cells exactly like the parent cell.

Sample complex text (e.g., book)

Sample poster

Objects found in Crystal Island including food items

An inventory in backpack to collect objects

A scientific scanner to test objects

The process of scanning objects by choosing hypotheses

Communication with non-player characters (NPCs) through dialog selection

Diagnosis worksheet to be used throughout the learning session to record data, findings, hypotheses, etc.

Data collection and analysis

Data were collected from 26 high school students (*M*_age=16.04; *SD*_age=0.34; 65% female) and 26 undergraduate students (*M*_age=19.73; *SD*_age=1.49; 69% female). The data for the high school students were collected in a classroom setting while the data on the undergraduates were collected from individual students in a university research lab. On average, high school students spent 48 minutes (*SD*=6.96) and undergraduate students spent 87 minutes (*SD*=22.50) with the game.

This study focuses on two ways to assess learning outcomes in GBLEs (game scoring and external assessment) distinguished by Ifenthaler et al. (2012). We operationalize game scoring by determining if participants solved a mystery while playing Crystal Island. External assessment was operationalized as performance on the post-test about knowledge of microbiology while accounting for pre-test knowledge. Pre-test scores and post-test scores were calculated as normalized change score to alleviate pre-test score biases (Marx & Cummings, 2007).

Log-file data collected during game play was extracted and several activities were analyzed to compare across development levels. Through these data, we identified how many times students interacted with scientific reasoning activities in the GBLE (e.g., opening articles, books, posters, scanning objects, opening backpacks to gather clues, communicating non-player characters (NPCs) through dialog selection, and opening a diagnosis worksheet). Also, we analyzed the proportion of the duration that students interacted with the scientific reasoning within their total amount of the game play.

Results

Learning outcomes

A *t*-test using participants' normalized change scores did not show any significant differences (t=-1.92, p=0.061) between high school students (*M*=0.12, *SD*=0.23) and undergraduate students (*M*=0.23, *SD*=0.22) (see Table 1). Despite no significant difference in pre-test scores, there was a mean difference in normalized changes scores for each group, but the huge variabilities in both groups lead to no statistically significant difference between developmental levels. That is, both developmental levels showed evidence of learning about the same with Crystal Island.

When it comes to a difference in solving the mystery based on developmental levels, a 2X2 chi-square test revealed a significant difference in the distribution of students who solved the mystery correctly across development levels ($\chi2$=16.65, p<.01) (see Table 2). More specifically, 24 undergraduates (92%) solved the mystery compared to only 10 high school students (38%). This suggests that outcomes or performance-based goals were different, but microbiology content knowledge acquisition was not.

Table 1
Pre-test and normalized change scores across developmental levels

	High school students *M(SD)*	Undergraduates *M(SD)*	*t*	*p*
Prior knowledge (pre-test scores)	10.15 (48.33%) (2.09 (9.95%))	11.15 (53.10%) (2.44 (11.62%))	-1.59	.119
Normalized change score (pre-test and post-test scores)	0.12 (0.23)	0.23 (0.22)	-1.92	.061

Note. *p<0.05

Table 2
Frequency of participants who solved the mystery

	High school students (*N*=26)	Undergraduates (*N*=26)
Mystery solved	10 (38.46%)	24 (92.30%)
Mystery unsolved	16 (61.54%)	2 (7.7%)

Frequency of scientific reasoning activities

A *t*-test was calculated using a Bonferroni correction for multiple tests ($p<0.05/6 = 0.008$) and showed that undergraduates had significantly greater frequencies of opening complex scientific texts (*M*=23.00, *SD*=6.79; *t*=-4.90, *p*<.008), scientific posters (*M*=13.88, *SD*=5.48; *t*=-4.79, *p*<.008), scanning evidence with a scientific tool (*M*=26.85, *SD*=15.62; *t*=-5.81, *p*<.008), opening backpack with objects (*M*=100.31, *SD*=38.03; *t*=-6.33, *p*<.008), communicating with NPCs through dialog selection (*M*=59.65, *SD*=18.87; *t*=-3.52, *p*<.008), and opening diagnosis worksheet (*M*=29.81, *SD*=15.92; *t*=-6.29, *p*<.008) compared to high school students (see Table 3). Overall, frequently using these game features related to scientific reasoning by undergraduates is indicative of their high use of SRL strategies compared to high school students.

Table 3

Summary statistics in frequency of scientific reasoning activities

Activities	High school students *M(SD)*	Undergraduates *M(SD)*	*t*	*p*
Complex text (Books and articles)	15.12 (4.59)	23.00 (6.79)	-4.90	.000*
Poster	7.46 (4.10)	13.88 (5.48)	-4.79	.000*
Scanning	7.88 (5.74)	26.85 (15.62)	-5.81	.000*
Backpack open	47.69 (18.79)	100.31 (38.03)	-6.33	.000*
Dialog selection	44.46 (11.31)	59.65 (18.87)	-3.52	.001*
Diagnosis worksheet	9.00 (5.59)	29.81 (15.92)	-6.29	.000*

Note. **p*<0.008 after Bonferroni correction for multiple post-hoc comparisons

Duration of scientific reasoning activities proportionate to total game play time

High school students played the game for an average of 48 minutes (*SD*=6.96) while undergraduate students played for an average of 87 minutes (*SD*=22.50). A t-test was calculated using a Bonferroni correction for multiple tests ($p<0.05/4 = 0.012$) in order to compare the two groups' time spent on each scientific reasoning activity within their total game play time. Considering each proportion of activities within total game play duration (see Table 4), high school students spent a higher percentage of their time reading complex text such as articles and books (*M*=43.77, *SD*=11.91; *t*=2.88, *p*<.012) during the game compared to undergraduates. This can help explain our earlier finding such that it appears high school students were focused more on the concrete knowledge acquisition through reading and information gathering while undergraduates were focused more on solving the mystery and potentially using scientific reasoning skills. There was no significant difference between high school students and undergraduates in the proportions of poster (*p*=.165) and diagnosis worksheet (*p*=.020). However, undergraduates had a significantly greater proportion of durations on scanning objects (*M*=2.33, *SD*=1.10; *t*=-3.70, *p*<.012) compared to high school students while they played. These results show that undergraduate students spent a considerable amount of time within the total time on gathering clues by scanning objects to test hypotheses for solving the mystery rather than reading complex text or poster while playing games while they learned in GBLE.

Table 4

Summary statistics in proportion of activities within total game play duration

Activities	High school students *M(SD)*	Undergraduates *M(SD)*	*t*	*p*
Complex text (Books and articles)	43.77 (11.91)	34.95 (10.05)	2.88	.006*
Poster	1.06 (0.63)	1.29 (0.54)	-1.41	.165
Scanning	1.30 (0.92)	2.33 (1.10)	-3.70	.001*
Diagnosis worksheet	6.45 (3.29)	8.90 (4.02)	-2.41	.020

Note. **p*<0.012 after Bonferroni correction for multiple post-hoc comparisons

Predicting solving the mystery based on learners' developmental level

A binomial logistic regression analysis was conducted to determine the likelihood that a learner solves the mystery illness given the learners' developmental levels with Crystal Island (see Table 5). The likelihood of a learner solving the mystery was significantly related to learners' developmental levels (p<0.025). In other words, the higher learner's developmental level was, the more likely the learner was to solve the mystery. Specifically, the odds of a learner solving the mystery were 0.05 times greater if the learner was an undergraduate student.

Table 5
Logistic regression analysis of solving mystery by developmental levels

Predictor	β	*SE*	*Wald*	*df*	*p*	e^{β}
Constant	2.49	0.74	11.40	1	0.001	12.00
Developmental levels	-2.96*	0.84	12.40	1	0.000	0.05

Note. e^{β}= exponentiated beta or odds ratio; *SE*=standard error; **p*<0.025

Discussion and conclusion

Despite the panacea of using GBLEs to solve STEM learning issues, we argue that these environments do not always lead to significant learning outcomes because students have different self-regulatory skills. Secondly, GBLEs designed on the principles of agency or without instructional scaffoldings need to be examined especially when it comes to understanding how students of different ages use and learn from them. Results found that undergraduate students were more likely to solve a mystery than high school students with Crystal Island although there was no significant difference in learning gains measured by test scores. The fact that both age groups did equally well on the post-test learning outcomes could reflect the fact that high school students are not that much younger than the undergraduates. High school students are currently learning about biology while it may have been several years since undergraduates learned about biology. Furthermore, high school students may have spent just enough time while undergraduates spent significantly more time (to activate their prior knowledge) while learning with Crystal Island. The significant difference in solving the mystery in Crystal Island can be understood through investigation of learner's SRL processes with previous studies (Nietfeld et al, 2014; Sabourin et al, 2013) showing that students' use of SRL was different based on their learning gains or performances. For instance, Nietfeld et al. (2014) found that the use of SRL strategies was positively related to performance in Crystal Island by revealing that learners using more SRL strategies had higher game-score performance.

Furthermore, there were significant differences in the use of SRL strategies depending on developmental levels. In terms of frequency, undergraduates not only opened books, articles, posters, or diagnosis worksheets more often than high school students, but also scanned food items by opening backpack more often than high school students. Also, the undergraduates spent more time communicating with NPCs through dialog selection than high school students. Considering the higher frequency of dialog selection compared to the frequencies of scanning and opening backpack for both groups, we can assume that high school students did not have huge difficulties communicating with non-player characters (NPCs) while they played compared to university students. This can be explained by the fact that NPCs may be easier to find than other clues such as food items which students need to explore carefully to find on the island. For example, some specific items (e.g., cheese) which give students important clues for the mystery might be hard to detect for the students since they only can find certain food items when they open a refrigerator during the game. They then must develop a hypothesis about that food item (usually through talking with NPCs) and then scan the items that may be important. This difficulty to utilize game elements for high school students is also supported by the frequencies of scanning and backpack open. Compared to university students, high school students showed significantly lower frequency in scanning and opening backpack. This shows that high school students might have difficulties finding clues while playing or did not make it as much of a priority as reading materials about microbiology. To scan food items to formulate hypotheses in Crystal Island, students need to find and put food items into their backpack or change the items, which means that the more they find the food items, the more they can open backpack and scan. These features led to a low possibility to solve the mystery, presenting that learners' use of SRL strategies with GBLEs is varied based on their developmental levels.

The difference in frequency of activities might not be surprising since undergraduates spent more overall time playing Crystal Island than high school students. This is also true that undergraduates spent greater durations on all elements related to scientific reasoning while they played Crystal Island compared to high school students. In addition to this, the fact that there was no significant difference between normalized change scores showed that high school students performed just as well as on the post-test with less time compared to undergraduates. However, considering the proportion of each activity within total game play duration, the results could provide a different new perspective in the students' SRL abilities. Although high school students showed a greater proportion of durations on reading articles and books within their total game play duration compared to university students, they were less likely to solve the mystery. Unlike high school students, college students spent a significant proportion of time gathering clues and formulating their hypotheses through scanning objects, which led to a higher possibility to solve the mystery. This shows that high school students might lack the same level of SRL abilities such as planning or monitoring the difficulties of utilizing game elements while learning in GBLEs. This is consistent with the previous study showing that learner's metacognitive skillfulness increases with age (Veenman et al., 2004). However, we also acknowledge that the main goal of these two groups could be driving their action differences. That is, if high school students were more focused on learning as much as they could about microbiology (knowing there is a test at the end of the game), they would not be as focused on the game goal of solving the mystery. In comparison, the undergraduates appear to be more focused on solving the mystery as shown by the larger duration time spent doing other activities (e.g., scanning objects with a scientific tool to test hypotheses). Both goals were presented to the learners, however, our results suggest that each developmental group focused on a different aspect of these two goals. Task-wise learning about microbiology is simpler and more straightforward while developing non-explicit scientific reasoning skills through exploratory learning is more abstract and requires more metacognitive skills and abilities.

According to the binomial logistic analysis, older learners (i.e., undergraduates) are more likely to solve the mystery than high school students. This is supported by the results of the previous studies indicating that learning outcomes were different for different age groups (Mayer, 2014; Veenman et al., 2004). Specifically, Mayer (2014) presented that GBLEs influenced learning outcomes differentially across learner's developmental levels with different effect sizes; the effect size for college students was higher than secondary school students.

An important theoretical implication of our work is a general suggestion for models to incorporate the role of developmental differences in the assumptions of monitoring and strategy use (e.g., Winne's [2018] COPES and SMART schemas should have different assumptions based on learner's developmental levels). Our work provides empirical evidence to further support the idea that even when close in age, SRL processes may have developmental differences that impact one's efficiency of learning with GBLEs. Moreover, our findings have implications for designing various types of scaffolds in GBLEs, depending on developmental levels. Since the effects of learning at the age groups can be different through theoretical background and instructional strategies (Dignath & Büttner, 2008), utilizing differentiated scaffolds based on developmental levels in GBLEs can lead to more effective learning. For instance, high school students may benefit from procedural scaffolding to help them to fully explore learning elements in GBLEs or to foster increases in the frequency and duration of specific activities which might be useful for learning and scientific reasoning. In contrast, undergraduates may benefit from more conceptual and metacognitive scaffolds given their higher frequency and duration of activities (Lim et al., 2023).

Despite these results worth noting related to developmental differences of SRL in GBLEs, this study still has several limitations for future studies. This study focused on two different age groups related to developmental differences with the small sample size. In order to understand specific SRL patterns from various age groups with developmental differences, more studies comparing the diverse groups with developmental differences are needed. Furthermore, while log-file data were effective in measuring learning processes in this study, a deeper understanding of developmental differences of SRL in GBLEs can be strengthened with the consideration of more diverse trace data (e.g., eye-tracking, facial expressions of emotions, think-aloud protocols, etc.). Along with the rich trace data, a mixed methods approach and semi-structured interviews can be supplemented to lead to a richer and better-informed explanation of learners' SRL and decision making within GBLEs. Future research should compare multimodal multichannel data to provide a comprehensive understanding of the temporally-based developmental differences across age groups and design intelligent, adaptive scaffolding in GBLEs for STEM.

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Teacher Professional Development in Critical Action Pedagogy: A Culturally Responsive Approach

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Abstract: This paper reports on the recent developments of the Critical Action Learning Exchange (CALE) project, an international network of Professional Learning Communities (PLCs) where teachers are supported to design and enact new forms of critical action curriculum (Carvalho et al., 2021; 2022). CALE curriculum is dedicated to empowering students as transformative agents when facing socio-environmental issues (i.e., climate change, social justice, pandemics, economic inequality, etc.) that affect themselves and their communities. This paper presents a comparative analysis of activity-theoretical formative interventions in CALE communities in China, India, and Canada. For each of these enactments, we present the professional development designs and evaluate the efficacy of the interventions by analyzing teacher participation and resulting curriculum products. We close with a discussion of sustainable teacher PLCs and the next steps in the CALE research.

Introduction

This paper reports on the recent developments of the Critical Action Learning Exchange (CALE) project (Carvalho et al., 2021; 2022). CALE is an international network of Professional Learning Communities (PLCs) where teachers are supported to design and enact new forms of critical action curriculum. CALE teachers join professional development workshops and other activities designed to facilitate the collaborative creation and exchange of lessons, resource sharing, and reflective discussions about critical pedagogy and practice. CALE curriculum is dedicated to empowering students as transformative agents when facing socio-environmental issues (i.e., climate change, social justice, pandemics, economic inequality, etc.) that affect themselves and their communities. This paper presents a comparative analysis of activity-theoretical formative interventions in CALE communities in China, India, and Canada, where the third version also included a wider international component. We adopted the formative intervention methodology, which has been advanced by Engeström and his colleagues as a design-oriented approach that intends to enhance the agency of practitioners and students in the design process (Engeström et al., 2014). An important value of formative interventions is their sensitivity to the context of the intervention, making this approach responsive to cultural, historical and systemic factors.

This work endeavours to deliver on the promise of Freirean pedagogy (Freire, 1970), which has deep relevance to education in the world today, but whose implementation is considerably challenging, for it demands from teachers a radical paradigmatic shift in regards to classroom practices (Duncan-Andrade & Morrell, 2008; Tinning, 2002). Our work takes on the challenge of making this pedagogical approach more practicable and accessible to teachers within diverse international contexts. CALE responds to this challenge by offering a framework for critical action (Carvalho et al., 2021; 2022) as well as scaffolds to support the design and enactment of critical action curriculum. However, we also require a professional development approach that allows us to work closely with teachers in any given context, and to be responsive to that context in order to support teachers develop their own understandings and applications of these ideas. This has led to the establishment of distinct teacher professional communities in India and China, as well as a third multi-cultural online community, centred in Canada. For each of these enactments, we present the professional development designs and evaluate the efficacy of the interventions by analyzing teacher participation and resulting curriculum products. We close with a discussion of sustainable teacher communities and the next steps in the CALE research.

Theoretical framework

Critical action education

The *critical action* component in CALE's name refers to the behavioural component in the Freirean concept of *conscientização*, which can be understood as the process of acquisition or development of critical consciousness. Critical consciousness is conceptualized as comprising three mutually reinforcing elements: critical reflection, critical motivation, and critical action (Watts et al. 2011). Critical reflection refers to the process of learning to distinguish *culture* from *nature*, or in other words, of acquiring a perspective that allows for social constructs and structures to be perceived as questionable and malleable, instead of being regarded as inescapable, naturally imposed realities. Critical motivation is an individual's perceived capability and commitment to contribute to social advancement through the reinvention of social structures that enable unjust, oppressive, harmful, or unhealthy conditions. Finally, critical action refers to the engagement in action dedicated to producing socio-political changes perceived as conducive to more just and healthy conditions (Freire, 1973; Watts et al., 2011). We employ the term Critical Action Education to refer to educational practices that aim to support students through the process of *conscientização*, so they are empowered as transformative agents capable of assuming an active stance when facing complex socio-environmental issues that affect themselves and their communities.

Professional learning communities (PLCs)

For many teachers, incorporating Critical Action into their practice would constitute a significant departure from their more traditional modes of teaching and learning. To support such a paradigmatic shift, CALE organizes PLCs, in which participants learn from one another, stay in touch during their efforts, and share and exchange ideas and resources. The research literature describes professional learning communities (PLCs) as groups of professionals collaborating in an ongoing, learning-oriented, critical interrogation of their practice (Toole & Louis, 2002). Hipp et al. (2008) argue that success in establishing such a community “requires informed and purposeful action based on learning”. Slotta (2002) argued that successful communities require three elements: critical mass, critical identity, and critical function. PLCs may offer a powerful context for professional development of teachers, with opportunities for knowledge building, collaborative design and exchange of resources, new curricula and teaching practices, social and emotional support, and continuing development of one's professional identity.

Members of any CALE PLC participate in synchronous and asynchronous professional development activities to advance their understanding of critical action education and engage in designing new curriculum. Over the past two years, CALE researchers have supported PLCs in the design of activities, resources, and technology environments to support their activities. This sustained effort has allowed us to test our design ideas through cycles of implementation with teachers, and continuously improve our framework to help the PLCs become sustainable communities of practitioners (Carvalho et al., 2021). Participants can find technology support within the CALE online environment, where they can share their experiences designing and enacting new critical action lessons and engage in further authoring, discussion, and resource sharing.

In the CALE PLCs, our goal has been to understand how educators' critical interrogation of their practice leads to transformative action. This question has guided our development of distinct interventions for several PLCs that respond to sociocultural contexts. The underlying questions we have asked in developing these formative interventions, which include workshops, small group design teams, and individual reflections, were: (a) What interventions are productive in a particular context? (b) How can those interventions be conducted to generate actionable knowledge that enables transformation of participants' teaching practices? (c) How can our workshop model help teachers become critical action educators?

Method

Activity-theoretical formative intervention

The Activity-Theoretical Formative Intervention methodology (Engeström et al., 2014) relies on two epistemological principles: double stimulation (Vygotsky, 1978) and the principle of ascending from the abstract to the concrete (Ilyenkov, 1982). The first stimulus is typically a conceptual *mirror* that "reflects" the problematic situation experienced by practitioners, while the second is a series of external artifacts, or *visions*, that support or sustain the transformation of practices (Engeström et al., 2014). These stimuli help participants to visualize and advance toward their collective zone of proximal development (ZPD), which is “the distance between the present everyday actions of the individuals and the historically new form of the societal activity that can be collectively generated as a solution to the double bind, potentially embedded in the everyday actions” (Engeström, 2014, p.

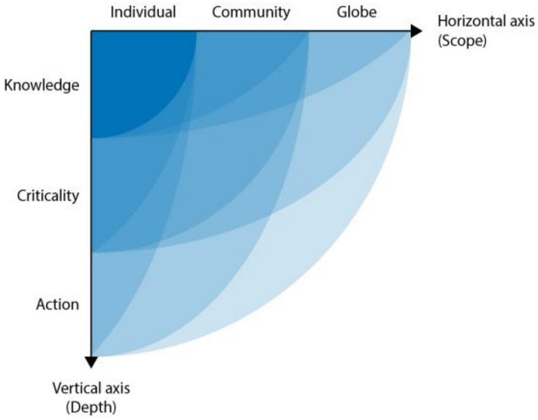
138). Below, we describe three elements of our formative interventions: (1) a framework for designing critical action curriculum, (2) a knowledge base with information on four pedagogical approaches suitable for Critical Action Education; and (3) a design guide to scaffold teachers' development of new curricula.

We report on the enactment of three formative interventions in teacher PLCs in distinct cultural contexts. Two of these communities are deeply embedded in their own local contexts (i.e., country, local region, culture and economy, educational system, students, families): 68 teachers in southern China are engaged in designing climate action curricula; and 60 elementary and middle school teachers in Bangalore, India, coordinated by local partners, are creating curriculum to address a variety of issues confronted by students and their families. The third is an online community of 45 teachers, centred in Canada, but with members joining from several other countries, including the US, the Netherlands, Colombia, Turkey, Egypt, and Iran. This third PCL, therefore, has an important multicultural context that must be taken into account. However, the pedagogy and discussions in this PLC were largely focused on North American and European contexts, and many participants arrived from the International Baccalaureate schools, thus sharing a common, largely western, curriculum and teaching framework.

CALE curriculum design framework

The first conceptual artifact that served as a *vision* for the communities was the CALE curriculum design framework, which intends to help teachers move from theory to practice in designing activities, lessons, units and courses that incorporate critical action. The CALE framework has six components, divided into two axes (Figure 1), and includes design questions elaborated to help teachers advance their designs in these two dimensions. The vertical axis includes components intended to move students "deeper" towards action: from knowledge, to criticality, to action. The horizontal axis increasingly expands the scope of the students' critical action: from the individual, to the community, and finally to the globe.

Figure 1
Components of the CALE curriculum design framework



Vertical Axis: (1) *Knowledge*: Critical Action begins with an understanding of the issue being addressed. This goes beyond helping students acquire knowledge within a domain, to help them develop abilities to acquire, assess, and build new knowledge. (2) *Criticality*: The process of social transformation implies a value judgment on the forces and structures that affect the issue and how they might constrain or empower their actions. (3) *Action*: Critical Action Education aims to reinforce students' sense of agency and to empower them as transformative agents, shifting their perspective from "that's just the way things are" to "that's a problem that I can act upon."

Horizontal Axis: (1) *Individual*: This component aims to provide opportunities for students to explore their intersections with the issue, helping each student create personal meaning and purpose in learning and develop a sense of direction. (2) *Community*: aims to help students work collaboratively, and recognize the value of community in any action. (3) *Globe*: Problems such as climate change, social injustices and economic inequalities are global, and the efforts to find solutions must transcend borders. This component aims to help students recognize and understand how the problems—and their actions—affect the whole world.

Pedagogical approaches to critical action education

A second aspect of the *vision* offered to teachers in all PLCs were four approaches to Critical Action Education. While there are many approaches within critical pedagogy, and this remains an active area of research in the learning sciences, we sought to define a set of approaches in terms of: (1) how it implements critical action, (2) the requirements and roles for the teacher, (3) richly described examples, and (4) design guidelines. For each approach, we collected additional examples and resources, as well as discussions from the CALE community. These approaches and their associated content were also instrumental for the communities to construct a vision of possible ways to incorporate Critical Action Education into their practices. The approaches are as follows:

Arts-based Critical Action, which often includes a written and introspective component (e.g., artist's statement), offers a vehicle for students to communicate abstract or complex ideas, express their identities, and tell their stories in an intellectually and emotionally engaging way. One effective strategy is that of theatre games, such as the "Theatre of the Oppressed" (Boal, 1992), which engages participants in activities such as the Forum Theatre, where members of the audience are encouraged to intervene by coming on stage to replace the protagonist. Through this process, participants are able to assume a critical stance on the situation being enacted and experience the challenges of implementing their envisioned changes (Monfort, 2003). In another example, students created an interactive drama that addressed issues related to one's body image and social pressures to conform to beauty standards (Howard, 2004). As a result, students created knowledge and renegotiated meaning about personal behaviours and engaged in critical reflection on cultural norms and expectations.

Critical Making includes but is not limited to drawing, painting, sculpting, crafting cardboard creations, folding origami, performing puppetry, and making with e-textiles, paper circuits, Arduinos, Raspberry Pis, micro:bits, littleBits, and web tools (Gerstein, 2019). Critical making emphasizes the situated, context-specific, and material selection aspects of the design process (Ratto, 2011). This approach helps teachers and students explore the relationship between process and end product; the role of collaboration; the entanglement of theory and practice; the relationship between art, craft, design, and making; and connections between makers and communities, among other things. Critical Making contributes toward critical action by putting the human experience above the technological one and making a conscious effort to make space for thoughts, emotions, and feelings to permeate and leverage the resources available at the maker's disposal.

Storytelling has been used to empower and engage students, allowing them to craft their own stories that connect learning with their own lived experiences (Burk, 2000). In addition, storytelling can bring forward multiple perspectives and artistic interpretations, allowing teachers to build on the breadth of ideas in support of an inclusive learning environment. As a Critical Action approach, storytelling allows students to adopt a critical perspective in which they interpret and respond to the world, in relation to a particular topic or issue, adding their voice to the communities in which they may otherwise feel silent or silenced. One study reported by Rish (2022) asked students in India and Mexico to create graphic novels related to their experience of the Covid-19 pandemic, with an emphasis on their local neighbourhoods and households. This study reported differences in complex systems thinking abilities between students who viewed the pandemic as a primarily personal issue versus those who viewed it as a collective issue. This work also explored different representations of community and the extent to which community played a role in the students' pandemic experience.

Youth-Led Participatory Action (YLPA) can empower students by engaging them directly with the socio-environmental issues that concern them personally, as well as their families and local communities (Ozer, 2017). Through YLPA, young people engage directly with organizations and members of their community to generate positive transformations and feel empowered by adding their own voices. YLPA is a cyclical process of learning and action in which students work in small groups or individually to conduct their own research, brainstorm ideas, survey community members, and develop designs that respond to problems they care about. A range of YPLA strategies has been used by teachers and scholars to engage students in personally meaningful community engagement. In Civic Planning and Youth Design, students work with city planners or other stakeholders to offer their own design ideas for problems that directly concern them. This strategy involves engaging youth in thinking about design and partnering with some "authentic client" (i.e., in the real world) that listens to their designs and potentially gives input. For example, in the Y-PLAN project (McKoy & Vincent, 2007), teachers engage their students with city planners to address real problems. Working in small design groups, students advance possible solutions, which are ultimately presented to the city planning partners, with the prospect of potentially influencing specific planning projects.

Design guide

In addition to offering teachers the CALE framework and critical action approaches, we prepared a technology scaffold that could be used by design teams in developing a critical action lesson of their own. This scaffold, which has employed different platforms depending on the context (i.e., paper, Google Doc, web forms), is referred to as the CALE Design Guide. It includes seven major sections: (1) *Overview of Team*, including members, topic and age level of students, and creative team name; (2) *Getting Started*, in which teachers reflect on issues confronting their students, such as climate change or food insecurity, and define a critical action challenge that can guide their design; (3) *Learning Goals*, in which they articulate the specific content, competencies, and perspectives they wish students to gain, how the curriculum will empower students, and what some of the main activities will be; (4) *Approaches and Resources*, which could be one or more of the CALE approaches, links to similar designs, websites, other projects, or student resources; (5) *Fitting the Framework*, in which the two dimensions of the CALE framework (with three levels each) are outlined in terms of guiding questions to help teachers fit their designs into those elements; (6) *Outline of Activities*, in which they further explicate a sequence of curriculum activities; and (7) *Enactment Plan* in which they articulate some details of when the curriculum will run, what class of students, any remaining challenges or concerns, and final to-do list.

Outcomes

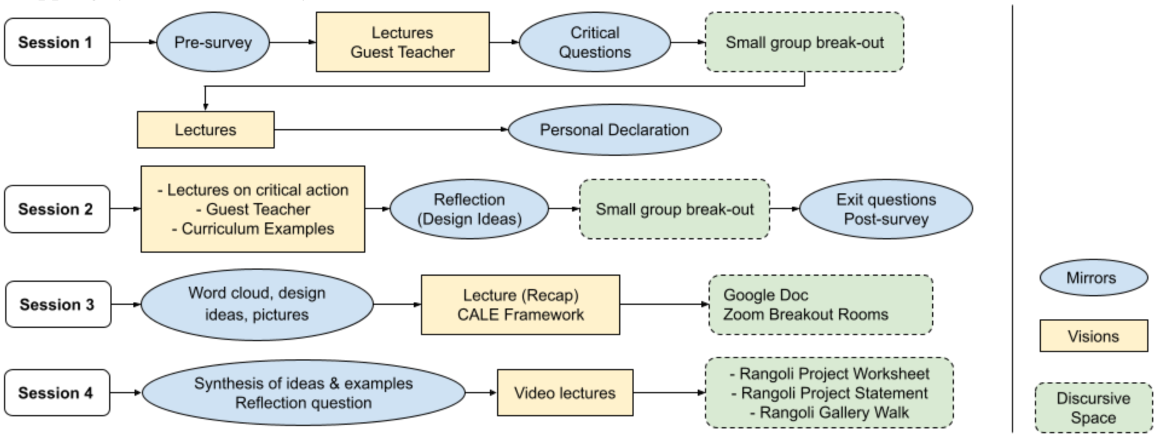
Design of PLC activities

While the elements above are common to all CALE teacher participants, the remaining elements of our formative intervention varied amongst the three PLCs, reflecting how the communities conceptualized their collective ZPDs, the efforts the communities made to realize their visions, and the outcomes of teacher design efforts. The sections below describe the activities of each PLC and map them in terms of the conceptual components of activity-theoretical formative interventions (i.e, *mirrors, visions,* and *discursive spaces*).

India

The formative intervention in India was organized in four sessions (Figure 2). One distinction from the interventions in Canada and China was the inclusion of paper handouts that aimed to help participants interrogate their current educational approaches and reinforce the sense of identity as a professional learning community. The first two sessions were planned to function as *mirrors* of participants' current teaching practices and offer possible *visions* in the form of lectures, examples of critical action curriculum, and discussions with a teacher guest. The final two sessions included a representation of the ideas and understandings of participants as *mirrors* and reiterating the discussion of *visions* to reinforce the pathway toward transformations.

Figure 2
Mapping of activities in the formative intervention in the CALE PLC in India

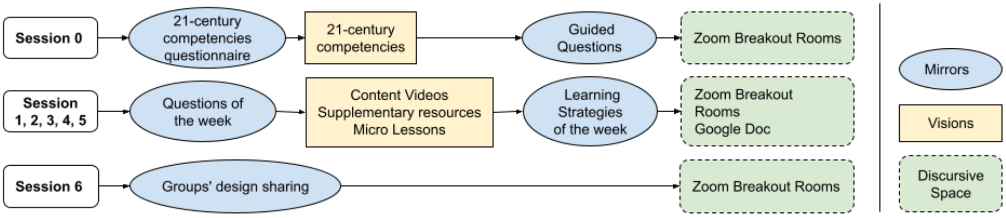


China

The first stimulus that showed up for the China PLC, from data gathered in pre-surveys and interviews, was to break the epistemological commitments of exam preparation. While educators in China reported being experienced with problem- and inquiry-based approaches, these were characterized as being largely extracurricular, given the heavy focus on lecture and exam preparations at the secondary level. We organized six one-hour workshop sessions that were conducted after a week of pre-workshop discussions and introductions (Figure 3). The aim of the pre-workshops was to function as a *mirror,* aiming to engage teachers with new ideas about 21st-century competencies. In the following five sessions, a pattern was implemented with detailed and specific expectations of topics and activities. Weekly questions served as *mirrors*, content videos served as resources, and "micro-lessons" functioned as *visions*. Reflective questions on learning strategies were presented as a second *mirror* of each week. Zoom meeting rooms and Google Docs were provided as a *discursive space*.

Figure 3

Mapping of activities in the formative intervention in the CALE PLC in China

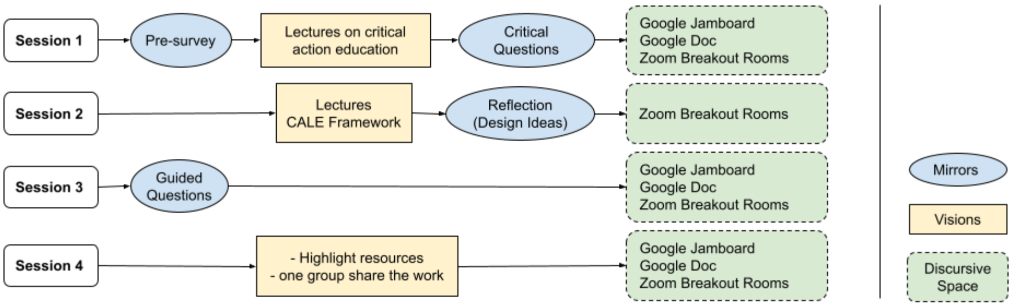


Canada

This community was established amongst climate change educators who were interested in designing and implementing “climate action” lesson plans to address environmental issues. Four sessions were carried out in the summer workshop (Figure 4) A pre-survey and critical questions functioned as *mirrors*; lectures and resources on critical action pedagogy and the CALE pedagogical framework for designing critical action curriculum were offered to generate *visions*, and Zoom breakout rooms, Google Jamboard, and Google Docs functioned as a *discursive space*. Since educators of the International online PLC were interested in understanding the importance of changing teaching practices relating to climate change education and student climate anxiety, the socio-cultural context was adjusted to provide critical questions to help educators conceptualize and respond to these interests.

Figure 4

Mapping of activities in the formative intervention in the CALE PLC in Canada



Teacher progress within the CALE PLCs

In a previous paper (Carvalho et al., 2022), we identified two main *contradictions* in activity systems for all three communities: (1) the demanding curricular expectations encumber a deep exploration of topics needed for critical inquiry; (2) teachers experience conflicting pressures between the demand to equip students with “21st-century competencies” (e.g., critical thinking and collaboration) and heavy content standards measured by standardized tests. Participants found this working hypothesis consistent with their experience and articulated their *conflict of motives* in terms that express their anxiety about being expected to incorporate 21st-century competencies and critical action into their practice, while also facing barriers to do so. Finally, communities were able to articulate their *collective ZPD*. Teachers in the Chinese PLC identified a need for enhancing students' communication and collaboration skills. Participants of the Indian PLC manifested a particular interest in the arts and critical making as approaches for critical action. Teachers in the international PLC focused on climate anxiety and climate action and identified the need for ideas that promote collaboration, the exchange of ideas and resources, and a sense of community.

In Summer 2022, we have successfully run another workshop in each of the three PLCs, and guided teams of teachers in designing and enacting CALE curriculum projects. While this is a longitudinal study of PLCs, and not all teachers have yet enacted their designs, here we can report on those who have participated.

India projects

(1) *Rangoli Festival (6 teacher-designers)* - Students of the whole school used the traditional art form of rangoli (i.e, coloured drawings with sand and other materials) to discuss a series of socio-environmental issues. They will discuss and explore issues such as the Covid-19 pandemic, gender inequality and climate change, and will design rangolis that represent their critical reflection on these themes.

(2) *Impurities Toward Purity (2 teacher-designers)* - 7th-grade students engage in the Critical Making approach to explore wastewater management. They develop and test a water filtration system and

conduct water quality tests, interview people lacking access to clean water and present their solutions to the community.
(3) *Rainwater Harvesting (2 teacher-designers)* - 9th-grade students explore rainwater harvesting as a solution for the lack of access to clean water, design and install rainwater collectors and investigate their effectiveness.
(4) *Data Pirates (2 teacher-designers)* - 10th-grade students investigate the correlation between educational level and income in their community. Students design and conduct a survey of their community and learn concepts of statistics while discussing possible career paths and how they are remunerated.
(5) *Equality of Opportunity (2 teacher-designers)* - 7th-grade students investigate the consequences of inequality of access to education while learning about fractions.
(6) *The Ultimate Guide (3 teacher-designers)* - 10th-grade students use storytelling to explore the link between human activity and climate change and possible actions to minimize environmental degradation.

China projects

(1) *Design and creation of future Cantonese architectural model (2 teacher-designers)* - 11th-grade students investigate the characteristics of Cantonese architecture and develop ideas for adapting buildings to respond better to climate change. Over 500 students will showcase their solutions to the school community.
(2) *Prosperity and Trauma: Mangrove forests on Dongguan coast (2 teacher-designers)* - A transdisciplinary unit engages students in an inquiry-based project on the mangrove communities in the Dongbao estuary in Dongguan. Students will discuss ways to protect the coastal mangrove.
(3) *Vegetable Garden Plan (7 teacher-designers)* - Students of grades 4 and 5 work on an inquiry-based project to investigate how food is produced and devise ways to make food production more efficient and sustainable.
(4) *"Low-Carbon" Food Plans (3 teacher-designers)* - Students of grades 4 and 5 investigate how food consumption affects carbon emissions.
(5) *Creating a "zero waste" campus (8 teacher-designers)* - Students of grades 7 and 8 investigate the garbage production of households and devise ways to minimize it.

Canada projects

(1) *The Community of Trust (3 teacher-designers)* - Pre-service teachers engage in arts-based or critical making lessons so they can learn how they can use those methods themselves. They explore concepts of critical pedagogy to learn how to empower their students and support critical action.
(2) *Water Action Decade (7 teacher-designers)* - Engineering undergraduates take a chemistry course with a focus on water-related SDGs. Using the YPLA approach, students explore issues such as the impacts of fertilizers on waterway systems, the impacts of salting the road on the environment around it, etc.
(3) *The Trees of Uxbridge (7 teacher-designers)* - 9th-grade students take a lesson that connects Citizen Science with the SDGs and Ecology. They investigate how they can influence changes in their community as they seek to recover from the F2 tornado that impacted their town.
(4) *Stories of Food From My Family (1 teacher-designer)* - Students use storytelling and arts to explore socio-environmental issues related to food, such as the culture of food, where our food comes from, how our food is prepared, food insecurity, climate change and food, etc.
(5) *Water Heroes (1 teacher-designer)* - Kindergartners learn about the importance of water conservation and marine biodiversity and how they can help preserve the oceans.
(6) *How will our children find water and clean air? (2 teacher-designers)* - Students of grades 8 to 11 explore the effects of climate change in Iran and the middle east. They use critical making to design possible engineering solutions and create a podcast to communicate their findings to their communities.

Discussion and conclusion

In this study, we have applied cultural-historical formative intervention as a methodology to understand how PLCs can facilitate teacher professional development in critical pedagogy, and how teachers progress in such communities. In order to help teachers incorporate Critical Action Education, CALE PLCs scaffold teachers' work as curriculum designers, while responding to local cultural contexts and preserving teachers' agency. This study helps to identify important attributes of such communities, including how they can accommodate cultural differences. The teachers in each CALE PLC are now entering their third year of engagement in classrooms. While not all CALE teachers have yet succeeded in putting their lesson designs, there are dozens who have done so, and many who have enacted their lessons twice. While our three PLCs may not yet be fully established, there is in each of them a core group of teachers who are engaged and reflective practitioners. These teachers are committed to critical action pedagogy, and many will return for next summer's workshop. Still, we are concerned with how to sustain such a community, and what forms of evidence can be shared that engage all members in reflection and peer support. This will be one focus of our future work. Another will be to study the impact of CALE curriculum on students, in terms of the six components of the CALE framework. Technology developments will include scaffolds that allow teachers to share and modify curriculum designs, socially annotate designs, and curate resources. We will also establish partnerships for the various critical action projects.

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Arguing Racialization: Race Talk Dilemmas, Disciplinary Learning, and Student Socialization in Doctoral Coursework

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Abstract: Despite being a consequential site for graduate student learning and socialization, doctoral-level coursework remains undertheorized in higher education literature. Even less explored is how faculty pedagogy in coursework shapes students' understandings of their discipline's racialized histories and legitimated practices. Drawing on insights from critical theories of racialization and Cultural Historical Activity Theory, this paper highlights the contours of a race-talk dilemma and its implications for doctoral student learning and joint activity in a political science Ph.D. course on international law and politics.

Introduction

People describe doctoral education as being marked by a shift from being a consumer to a producer of knowledge. However, the truth is that learning is central to pursuing a Ph.D. In addition to amassing extensive content expertise to carry out original research, doctoral students are expected to internalize, master, and perform the legitimated ways of knowing and being in their discipline (Rodgers et al., under review). Indeed, socialization, or "how to behave, what to hope for, and what it means to succeed or fail" (Tierney, 1997, p. 4), remains the dominant framework for conceptualizing learning in doctoral education (e.g., Walker et al., 2008). Faculty evaluate students' engagement with the valued tools and artifacts that are valued in their field via various milestones in a doctoral student's developmental trajectory (e.g., coursework, qualifying examinations, dissertation defense) (Posselt, 2020; Rodgers et al., under review). If doctoral education functions as the "academy's own means of reproduction" (Shulman, 2008, p. xi), we might ask what is being reproduced and how?

One possible answer is racial meanings. Racial meanings are the taken-for-granted beliefs and (mis)understandings people have about race. In the racial capitalist and colonial U.S. context, where race is one of the most salient social identities, systems of power, and sources of stratification, race talk is omnipresent (Thomas, 2015), and racial meaning-making is a routine form of joint activity in formal learning environments (Nasir & Hand, 2006). Pollock (2009) introduced the concept of race talk to describe everyday conversations about when and how race matters. Ironically, despite race talk being a typical dimension of classroom joint activity, engaging in race talk remains a threatening activity that causes feelings of discomfort, stress, and danger for many people (Bryan et al., 2012; Leonardo & Manning, 2017). The tensions that arise during race talk in classrooms can generate race talk dilemmas, or situations wherein the discussion of race can become contentious (Pollock, 2009; Thomas, 2015). As these dilemmas emerge, members of a classroom community decide whether to speak and what to say. For faculty, whom I perceive to have a pedagogical responsibility to develop students' capacity for generative racial meaning-making and racial literacy, the implications of their interventions are deeply consequential to doctoral student learning and socialization. This paper highlights the contours of a race-talk dilemma and its implications for disciplinary learning and joint activity in a political science Ph.D. course on international law and politics. Mainly, I focus on one faculty's pedagogical move to 'play a devil's advocate,' discussing the importance of race in their discipline.

Literature review

Traditionally, faculty have conceptualized the primary aim of doctoral education to be the socialization of their graduate students to enter the professoriate in their discipline (Walker et al., 2009). Moving beyond pursuing intellectual expertise and content knowledge, a focus on formation in doctoral education encompasses "the scholar's professional identity in all its dimensions" (Walker et al., 2009, p. 8). Scholarly formation often occurs by way of apprenticeship, which is considered "the signature pedagogy of doctoral education" (Golde et al., 2009, p. 54). Apprenticeship "focuses on a system of interpersonal involvements and arrangements in which people engage in culturally organized activity in which apprentices become more responsible participants" (Rogoff, 1995, p. 143). Through interacting with faculty members in a variety of settings, doctoral students learn how to become members of their disciplines. For instance, students in a political science Ph.D. program learn to *become* political scientists (explicitly and implicitly) through their engagement with faculty in classrooms, research groups, and other professional settings. In this way, faculty-student interaction is "the lynchpin of doctoral education" (Anderson & Anderson, 2012, p. 249).

Despite being central to doctoral student learning, socialization, and scholarly formation, doctoral coursework and faculty teaching therein have largely been understudied (Khost et al., 2015). The scant literature on doctoral coursework has emphasized that the premise of learning in many graduate-level social sciences and humanities courses revolves around conversation. Khost and colleagues (2015) described the role faculty play in graduate seminars as "orchestrat[ing] conversations about texts, figures, periods, and methods" (p. 20). As students engage in classroom discourse, faculty often encourage students to raise questions, make assertions, and extend the readings in new and exciting ways. Yet, the discourse that students leverage in classrooms is about much more than content knowledge; classroom discourse serves a socializing function and is guided by a set of occluded norms (Cazden, 2001). Within higher education, faculty, who help form students' scholarly identities, often set the stage for what is considered acceptable forms and frames of talk and sensemaking (Author, 2022). Thus, studying how faculty support or impede certain forms of talk and meaning-making is an important topic for empirical inquiry.

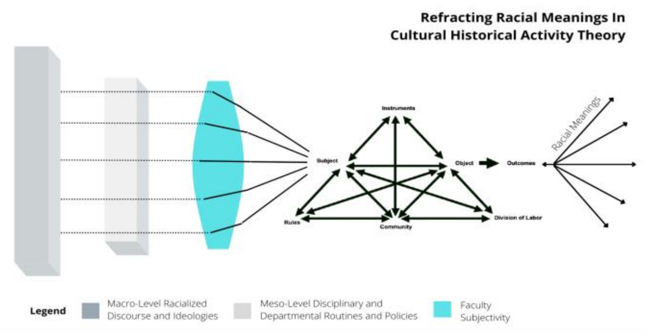
Conceptual framework: Racialized cultural-historical activity theory

Racial meaning-making is a dynamic sociocultural process that can and should be understood as a *learning* process. Race is a sign system (Wertsch, 2007), "…made real, in part, through the dynamic systems of thinking and speech that reinforce the hegemonic racial values mediating people's interactions with the world" (Leonardo & Manning, 2017, p. 20). In this way, racial meanings do not just exist—they are made and re-made as people engage in cultural practice over time. People *learn* the diverse meanings of race in various settings, a vital setting being classrooms.

Given how power unfolds in classroom settings, paying attention to the instructor is vital for understanding classroom learning. Even in the most democratic classroom environments, instructors are imbued with positional power and authority over students. Instructors are considered 'a more knowledgeable other,' someone who has a greater level of proficiency and can therefore support the learning and development of their students. In some instances, that assertion is accurate. For example, faculty generally have more experience and expertise with the subject matter they teach than their students (Postareff et al., 2006). However, given that People of Color remain underrepresented in the professoriate (NCES, 2020) and race talk is often not considered central to the intellectual work of most disciplines (Bryan et al., 2012), faculty are rarely the experts on race in university classrooms (Jones, 2021). Because faculty directly influence the shared sensemaking that happens in classroom contexts, who faculty are, what they believe, and how they approach the work of their discipline matter for student learning and the social organization of joint activity within classrooms. Surfacing how faculty subjectivity, including the various epistemological, axiological, and ontological commitments faculty hold regarding race and racism, influences classroom learning is essential to transforming doctoral education. While CHAT scholars have emphasized that tools and artifacts are products of cultural practice (Engeström, 1999), many scholars underemphasize the cultural histories and subjectivities of the subject (i.e., the people acting agentically within activity systems) and how they impact joint activity. I needed a conceptual framework that put subjects (e.g., faculty) and their subjectivities *in* the shared work of teaching and learning.

R-CHAT pairs the best parts of CHAT with wisdom from scholars of racialization (Omi & Winant, 2015; Saha, 2018) to provide important affordances for articulating the nuances of racial meaning-making in learning environments and theorizing its implications for supporting or impeding learning. A key distinction in R-CHAT's model of classroom joint activity emphasizes the role of faculty and their subjectivity in mediating what gets taken up in the shared work of classroom learning and development. Instead of using a triangle to symbolize joint activity, I employ the metaphor of a prism. A prism is a transparent, triangular figure that refracts or disperses a light beam. As light enters the prism, it undergoes a process of refraction, becoming bent and separating the light into wavelengths as it exits the other side. R-CHAT (reference Figure 1 below) illuminates how racial meanings (like beliefs about racial hierarchy, the fallacy of white supremacy, and antiracism) relate to the subject matter learning faculty and students do together in doctoral-level courses. Notably, I situate faculty's subjectivity as the lens of the prism—it refracts the racial meanings they reflect onto the activity system. As students and faculty collectively engage in classroom learning (via discourse and interaction), those meanings are often refracted—bent, extended, and shifted in ways that produce multiple new meanings. Moreover, by understanding CHAT's focus on community, division of labor, and rules as racialized, I consider questions like: Who gets included/excluded as members of an academic or classroom community? Who does the work of raising race-conscious perspectives in class? Is the division of labor equitable, or is it racially stratified? What are the rules? Whom might the rules disproportionately impact? Are the rules equitably enforced?

Figure 1
R-CHAT Framework Visualization



Methods

This paper presents findings from one case in a more extensive comparative case study (Yin, 2018) of racial meaning-making in doctoral coursework. I collected data in three Ph.D. courses at an R-1 university in the Chicagoland area in the Fall of 2021. Because I was interested in understanding how faculty's racialized identities and their perceptions of the salience of race to their course content might inform their pedagogy, I sampled based on those criteria. The final sample included a Black woman sociologist, a Native woman and White man learning scientists, and a White woman political scientist. While all faculty appreciated how race and power impact their fields, the faculty Women of Color expressed explicit commitment to critiquing racism in their teaching. In contrast, the White faculty were more agnostic about how race and racism informed their pedagogy. Additionally, there were 29 student collaborators across all three courses, with great diversity in students' race, gender, and nationality.

Site & context

This manuscript focuses on the International Law and Politics course taught by Dr. Berr, a tenured white woman professor in the Political Science and Legal Studies departments. Having served as a professor at her institution for over 20 years, Dr. Berr is an internationally recognized scholar of international law and politics, capitalism, and the global economy. This doctoral-level seminar was offered as an in-person, 3-hour per-week elective course in the Political Science department. The course enrolled seven students: four in the Political Science Ph.D. program, two students from a local university, and one visiting scholar who was auditing the course. All seven students identified as men. Interestingly, and perhaps appropriate for an international relations (IR) course, students were from all over the world: Argentina, Canada, Palestine, India, and Kazakhstan, to name a few places. In fact, only the instructor and I were from the United States.

Data collection

To gather thick and rich descriptions of how race talk unfolded in the moment-to-moment joint activity of classroom learning, I focused on three primary data collection approaches: faculty interviews, classroom observations, and student interviews.

Faculty interviews. I engaged in two interviews with faculty – pre-interviews and think-aloud interviews. I conducted pre-interviews the summer before observations, which allowed me to sample with the faculty's teaching philosophy and course design/structure in mind. These pre-interviews not only supported the final case selection but they also informed the development of observation protocols for each course.

In March 2022, I conducted 30-minute retrospective think-aloud interviews with three of the four faculty members I observed (2). Faculty and I reviewed video clips of their teaching where I asked them to interpret what was happening in each clip, provide insight into their pedagogical moves, and reflect on what, if anything, they might do differently in the future. Overall, these interviews allowed me to highlight the interpretive frames that faculty collaborators used to make sense of how their pedagogical moves mediated racial meaning-making. These data were an essential complement to the observation data and boosted the trustworthiness of my analysis.

Classroom observations. With consent from all faculty and student collaborators in the political science course, I attended and audio-/video-recorded approximately 22 hours of classroom teaching and learning throughout the semester. I used one camcorder to capture all class discussions. I chose to record class sessions because video constitutes a robust information source for ethnographic and microanalytic studies of teaching and learning (Jordan & Henderson, 1995). Using video sources as data in my study allowed me to gather a repeated and up-close analysis of joint activity in doctoral coursework. I also took detailed fieldnotes during class sessions, paying particular attention to how faculty leveraged tools like the curriculum, multimedia, and guest speakers to mediate learning and racial meaning-making, as well as the social organization of racial meaning-making in classroom discourse. Observations were spread throughout the academic term.

Student Interviews. I conducted interviews with students across the courses I observed. While all students were invited to participate in a focus group, I employed purposeful sampling techniques to ensure racial and gender diversity. Of the nine total student learners enrolled in the course, five students agreed to participate in one-on-one interviews. During these conversations, I prompted students to share their perceptions of faculty's equity-minded praxis. I asked students to describe their faculty's teaching philosophy and their overall learning experience in the class. I also inquired about whether and how issues of racial meaning were being generatively taken up in classroom practice.

Data analysis

For data analysis procedures, I drew specifically on interpretive traditions stemming from studies of classroom discourse analysis and ethnography traditions (e.g., Cazden, 2001; Erickson, 2004). I began by coding all the interview data. I coded the interviews thematically using critical narrative analysis (Souto-Manning, 2014) in NVivo, a popular qualitative research software. Critical narrative analysis uses key principles from critical discourse analysis (van Dijk, 1989) and narrative analysis (Wortham, 2001) to study how discourse becomes real and enacted in people's lives. For this study, I am particularly interested in how faculty and students' discussions of race have implications for doctoral student learning and socialization.

I utilized the constant comparative approach to data analysis (Fram, 2013), going through cycles of open, axial, and selective coding. I conducted close, line-by-line readings of all transcribed data to arrive iteratively and inductively at my coding scheme. Then, I refined extant codes into concepts during axial coding by aggregating some codes and theorizing relationships between other codes. As I digested collaborators' rich reflections, I wrote analytic memos while coding to keep stock of ideas and connections throughout the data analysis process. Before creating broader case narratives through the selective coding process, I switched my attention to video analysis.

I ultimately took a narrative approach to video analysis in which the "[researchers'] aim is not to make the complex simple, reducing data to theorem. The aim is to make the complex understandable" (Derry et al., 2010, p. 12). I selected relevant clips for analysis by reviewing my fieldnotes and memos across class sessions to identify instances I previously noted as moments in which I perceived racial meaning-making was occurring. Once I noted a few salient instances of racial meaning-making in each course, I reviewed all video footage of the class session in which that moment took place. As I watched the recordings, I created content logs featuring a detailed breakdown of the discourse and interaction in the class session in 2-minute chunks. The content logs supported cycles of interaction analysis, enabling me to identify "hot spots" of activity and choose the final focal events upon which I focus my findings (Jordan & Henderson, 1995, p. 43). Notably, I used R-CHAT to illuminate the interactional dynamics of racial meaning-making in each video. Then, I turned to a finer grain of analysis—the focal events.

Focal events are "stretches of interaction that cohere in some manner that is meaningful to the participants." (Jordan & Henderson, 1995, p. 57). In my study, focal events are short moments of interaction—particularly intervention—by the faculty member that facilitates (or sometimes impedes) racial meaning-making. I identified one focal event in the Political Science course, then I transcribed the dialogue and began analysis by creating playscripts (Goodwin & Heritage, 1990). I sought to understand and appropriately re-story collaborators' shared sensemaking, recognizing it as a collaborative endeavor—a critical emphasis in interpretive research.

Findings

We enter at Week 6 of the academic term, where the topic of the class session was the Racial Foundations of International Law. Students voted to choose the focus of the last four weeks of the academic term from a list of potential topics. Many students were excited to discuss readings on race and international relations and international law (IR/IL) because the discipline, broadly, has not seriously contended with this topic. Lin, a visiting student taking the course through a partnership with a local university, told me, "Usually, when we're talking about international relations and international law, the scholarship was mostly Western-dominated. Race was not really an issue that they wanted to talk about. They focused more on the generic principles like justice and the role of law." Dr. Berr also mentioned in an interview that the discipline of international law "is very clearly extremely Eurocentric, very associated with empire." Moreover, as Daniel, a Ph.D. student in political science and a self-identified critical scholar, shared, "…in political science, the expression in the U.S., the dominant epistemological framework is that of positivism, and the way in which questions are framed, using a positivist framework is—often erases the kinds of concerns that I have and many others completely out of view."

In summary, there was broad agreement that the role of whiteness and the legacy of white supremacy in the field generally get taken for granted by many IR/IL scholars.

According to the syllabus, this class session was designed to interrogate "…whether the entire international legal and political system is predicated upon sustaining a racial divide." Students read six articles focusing on race and IR/IL and came to class prepared to engage in discussion. As class began, Dr. Berr sat in her usual spot at the head of the table in the seminar room. After doing their routine get-to-know-you icebreaker, Dr. Berr began her lecture rather unusually – with hesitation. In our pre-interview, I asked her to describe her teaching philosophy. She quipped, "I am opinionated, as all academics are." Then she elaborated with a sense of deep assuredness:

> I do feel that I create room to disagree with me, but I'm not gonna not—you're gonna know where I stand on issues. That's a pedagogical choice. That can also—I've got the authority. I've got the power. I have the knowledge. I have a huge amount of knowledge. This is totally in my area of expertise so disagreeing with me is really hard.

Nevertheless, Dr. Berr begins this lesson on racialization in IL/IR by telling students, "This topic…it's not like I'm…it's pretty new to me, too, [1-second pause] it shouldn't be, but it is, and so I thought, 'Gosh, I should've asked if you guys wanted to lead a session." This discursive move suggests a sense of hesitation regarding her experience, and by extension, her expertise, with talking about race in IL/IR. Moreover, the second part of her statement seems to yield the role of expert to students. There was one student in particular whose research focused on racialization and colonialism in IL/IR, and Dr. Berr repeatedly referenced his expertise throughout the class session – a move that the student noted as being peculiar.

To spark conversation, Dr. Berr posed a provocation to students: "I wanna learn what you guys learned, discovered, revealed, talked for the first time about the racial foundations of the stuff we've been talking about for five weeks now. That's never mentioned – the racial foundation. It's in there, but we haven't talked about it at all." After listening to some students' reflections on racial capitalism and the pervasiveness of racial inequality in the international order, she made an intervention using a particular pedagogical move – to play devil's advocate. MacDougall and Baum (1997) defined a devil's advocate as "a person who tests a proposition by arguing against it" (p. 536). Notably, people who play devil's advocate generally do not agree with the position they are arguing. Instead, it is used as a tool to test the strength of an argument. Dr. Berr interjected in the discussion to say:

1	>I think I'm gonna be the devil's advocate.<
2	That's how I'm gonna do it,
3	because I want you guys to address how it's important to name the racial foundations.
4	To do that,
5	I'm going to tell you that there's <u>no</u> racial foundation to this.
6	It's not that international law for a long time has not denied that it has its civilized/uncivilized-
7	<in fact,> it was written in, and in terms of barbaric-
8	and that international law was civilizing.
9	That was the legitimating narrative,
10	that all involved told themselves that they were doing.
11	It's not just that it permitted, it <u>legitimated</u> imperialism.

She then turned to mention slavery, telling students,

13	The other thing to say is slavery also existed in a non-racialized form.
14	>I mean<, the Vikings used slavery.
15	The spoils of war were that you won, and everybody became a slave.
16	You won against your European neighbor, and they all became a slave.

In line 13, Dr. Berr argued that "slavery also existed in a non-racialized form." This move to position slavery was a direct attempt to separate slavery from race and racism, thus preempting the use of slavery as a marker of racial foundations of IR/IL. From a CHAT perspective, this move effectively created a rule that the reality of slavery c was no longer a form of 'evidence' that students could use in their argument. She then restated her question, "why is it impossible not to think about the racial dimensions of [international law] and important to bring it in?"

Admir, a Political Science student, tried to answer this question. He told Dr. Berr:

> I feel that there is a difference of treatment that is obvious if we try to look and actually compare which countries are poor, which countries are suffering. There was, for example, a—just as a hypothetical, would the international reaction to South Africa be in the form of economic sanctions if it was a Black majority dominating a white minority?

Dr. Berr at first empathized saying, "I hear you saying that," but then she went back into character and rebutted:

> I can see that you're saying that the pattern is self-evident, but what is the problem with ignoring the pattern? Because I can give you alternative facts—alternative narratives…I don't wanna call 'em alternative facts—alternative narratives that actually are true. I think they're true. They just are whitewashed.

Putting aside the revelatory nature of first accidentally calling alternative narratives "alternative facts," Dr. Berr emphasized that those narratives are still true (read: legitimate forms of argumentation) despite being whitewashed. Admir nodded and said, "True, but that is the problem with whitewashing is that there is less recognition of what is actually driving—" At that moment, Dr. Berr quickly cut Admir off to ask, "Why do we have to name the racial foundations of international law?" Admir then let out an exasperated chuckle and responded:

> Because then that is not the causal variable that is actually influencing what is happening. It's not like internal process of law that's influenced this. It's also an implicit structural understanding of race that influences your decision with various—we all are here in that monocausal goal, but I feel that recognizing that is important if you wanna actually understand the consequences of policy.

Note that at this point, Admir leaned on a postpositivist framing to make his argument – pointing to the efficacy of a causal variable. Still, Dr. Berr seemed to be unsatisfied with his argument. The focal event ended with her cutting Admir off again to embody the role of the devil's advocate by saying:

> I can tell a whole Iraq story that doesn't have race in it. It's about not having nuclear weapons. Why aren't we invading North Korea? Because they have nuclear weapons, and they could conventionally destroy Korea. I can tell a whole narrative that doesn't have race in it.

Throughout the analysis of this focal event, I highlighted how Dr. Berr's choice to take on the role of the devil's advocate functioned to shift the object of learning for students. Although the initial premise of the conversation asked students to articulate why the racial foundations of international law could not be avoided, as the conversation unfolded, Dr. Berr made clear that what constituted legitimate forms of engagement was narrowly conceived. Rather than the object of joint activity demanding that students deeply contend with the importance of naming the racial foundations of their field of study, it became an exercise of argumentation. Where the rules for what counted as evidence of a persuasive argument were arbitrated by Dr. Berr. Multiple students shared with me in interviews that there was often an expectation of what Dr. Berr expected students to leave the class believing. Reflecting on his own experiences of discourse in the class, Admir shared:

> It was often very clear to me where Dr. Berr stands and what kinds of answers…. I felt that there was a particular range of acceptable thought that was clear to me that I could say, and it would fly. I was very aware of the kinds of things that might not…and it caused a lot of back and forth.

Although Admir found those exchanges entertaining, it caused him to wonder when it is best to be completely transparent about his beliefs about the reading versus when to "take a middle-of-the-road approach."

Indeed, Dr. Berr admitted in an interview that she believed that argumentation is "the name of the game and social science, I mean…Most of the interesting stuff in politics are about argumentation and putting together persuasive evidence and believing it when you're confident you believe, because you believe it." Moreover, argumentation for the purpose of persuasion was key, especially for graduate students who are learning the field. She continued, "When they go on the job market, they're going to have not a hostile audience, but a lot of people who are going to be poking holes. And so, they have to get practiced in how to come back when someone pokes a hole." Centering the activity of persuasive argumentation rather than more expansive forms of knowing was a pedagogical move that also re-established Dr. Berr's role – as she previously described to me – as the one with authority, power, and a vast amount of knowledge and expertise in the classroom community.

Discussion & conclusion

I have argued that within the context of doctoral education, coursework is a socializing context. As my findings elucidates, the classroom is an environment where faculty introduce students to key scholars, histories, and debates in the field. It is also a space where students learn (implicitly and explicitly) whose voices are respected, which types of research questions are (de)valued, and which writing styles and argumentation conventions are validated. This type of learning is not a passive process. In this focal event, we witnessed a conversation between Dr. Berr and a student about the racial foundations of international law. They discussed why it is important to name explicitly that there *are* racial foundations to the field. What is most remarkable about this intervention, however, was that Dr. Berr took on the role of a devil's advocate to do it. By giving students a direct argument to contradict, she turned the object of activity away from prioritizing racial meaning-making and towards traditional conventions of persuasive argumentation. I wonder about the implications of rendering racialization, a deeply significant part of people's lived experience, as merely a topic of argumentation.

Faculty play an active and agentic role in student socialization. Although faculty-student interactions are known to shape doctoral student learning and socialization (Anderson & Anderson, 2012; Felder et al., 2014), classroom practice and faculty pedagogy remain a black box in doctoral coursework. Borrowing Walker and colleagues' (2008) language, if doctoral education is the formation of scholars, the field must take seriously that the classroom, and the bustling interactions that take place within it, is a necessary site of empirical inquiry.

I developed Racialized Cultural-Historical Activity Theory (R-CHAT) as a model to explore how racial meanings are constructed and organized in the everyday unfolding of classroom joint activity. R-CHAT is a transdisciplinary framework that allows researchers to situate racialization, or the discursive (re)production of racial meanings, not only as an outcome of learning, but as constitutive of the learning process itself. A striking feature of R-CHAT is its focus on faculty subjectivity that positions faculty as whole as dynamic people instead of reducing them to a monolith. It also honors their active and agentic ways that faculty (acting as stewards of their discipline) facilitate learning and racial meaning-making within their classroom context. It is clear that doctoral students enter into spaces and interactions that are racialized (and too often racist) during their time in graduate school. Yet, few scholars have explored the dimensions of how these spaces and interactions are *racializing*—learned and negotiated in the context of joint activity. Given faculty's own socialization into the norms and routine practices of the discipline, I found that the racializing dimensions of faculty's pedagogy also took on a disciplining character. This paper demonstrates how Dr. Berr's embodiment of devil's advocate effectively legitimated "whitewashed" perspectives about racialization. In their paper detailing the dangers of "both sides" argumentation, Vea and colleagues (forthcoming) posit that "Through repetition, harmful perspectives without an evidentiary base become normalized as reasonable, which effectively shifts the range of viable political possibilities" (p. 4). Towards the construction of more just learning experiences in graduate education, it is my hope that scholars will employ R-CHAT to enrich deep sociocultural and microanalytic studies of racial meaning-making within and beyond the context of doctoral coursework.

Endnotes

(1) Racial meaning-making is the interpretation of racial differences.
(2) The fourth faculty member temporarily fell ill and was unable to participate in the think-aloud interviews.

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Sharing the Responsibility for Learning and Attentiveness to Student Data: Lenses for Equitable College STEM Teaching

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Abstract: To improve equity in STEM higher education, it is critical to support instructors in learning and adopting inclusive teaching practices. This study advances the conceptual foundations for two lenses on pedagogical change, the Responsibility for Learning Lens and the Data Lens. These lenses can serve as mechanisms that support the adoption of equity-oriented pedagogies, such as Adaptive Equity-Oriented Pedagogy (AEP). Using preliminary findings from a randomized controlled trial of STEM instructors, we elaborate on how these lenses aid in distinguishing low- and high-growth instructors on equity-oriented practices. We conclude by arguing that without application of these lenses when making pedagogical decisions, instructors can run the risk of reinforcing a racialized status quo of individualistic and competitive learning cultures prevalent within STEM. This work has implications for improving faculty development, encouraging instructor self-reflection, and reducing systemic barriers to student success through equity-oriented pedagogies.

Introduction: Problem statement and research questions

Research shows that the quality of college teaching directly impacts student achievement and retention in STEM, especially for underrepresented students (URM; Weston et al., 2019). To improve STEM teaching, we studied adaptive equity-oriented pedagogy (AEP). Previous randomized controlled trials found that compared to an active learning control course, STEM instructors applying AEP improved mean student achievement by over a letter grade and narrowed achievement gaps for all students (Phuong & Nguyen, 2019; Phuong, Nguyen, Vo, et al., 2022).

This study extends previous work by examining how pedagogy courses teaching AEP principles can support STEM student-instructors' implementation of inclusive pedagogies. For simplicity, we use the term "instructor" for graduate and undergraduate students who teach and are enrolled in the pedagogy courses. The term "facilitators" refers to the pedagogy course instructors. 129 instructors participated in a treatment or control AEP pedagogy course where they completed a teaching portfolio that included written reflections, evidence of student learning, and feedback on their teaching. The treatment course was adapted weekly based on instructors' written reflections, whereas the control was not. Using qualitative methods, this study focuses on treatment instructors because the treatment course was more effective at increasing AEP competencies over time (Phuong, Nguyen, Vo, et al., 2022).

We focus on the research question: In the treatment, how do low- and high-growth instructors on AEP competency differ with respect to their data use and responsibility for learning lenses?

Background context: AEP pedagogy course design

The AEP pedagogy courses teach instructors about the key AEP principles. AEP is a framework for adapting teaching to address equity barriers to learning based on student data (e.g., formative assessment, observations, surveys) (Phuong et al., 2017a). AEP practice is characterized by instructors' use of 6 competency elements:

(1) Clarify learning outcomes and prerequisites, and build equitable course policies (e.g., adjust course policies and practices based on students' needs and contextual challenges, can include elements of grading for equity (Feldman, 2018))
(2) Align formative assessments and activities with outcomes
(3) Identify students' competencies, interests, and needs
(4) Understand equity barriers and contextual challenges to meeting outcomes
(5) Adapt teaching practices based on students' needs and barriers
(6) Iterate: Reflect upon pedagogy to support continuous learning, adaptation, and growth.

Unique element of treatment: Facilitators modeled and applied the 6 AEP elements explicitly as a tool for instructor learning by using weekly instructor reflection data to continuously adjust pedagogy course discussion and activities. Applying AEP, the facilitators adjusted the treatment based on instructors' reflections of their cultural perspectives and backgrounds, which include their lived experiences, racial experiences, discourse, and STEM department culture (e.g., what is valued methodologically and epistemologically).

Conceptual framing

We are interested in the reasons that drive instructors to learn and implement pedagogical changes. We are inspired by the notion of professional vision (Goodwin, 1994), which refers to developing ways of seeing phenomena that reflect growing levels of expertise. We focus more specifically on *lenses for pedagogical change*, which include the following: instructors' values around the types of data sources used for instructional decision-making and where they place the responsibility for learning. These lenses, or mechanisms, allow us to address content-specific and non-content specific teacher noticing skills (e.g., stereotype threat, imposter syndrome) (Phuong, Nguyen, Vo, et al., 2022; van Es & Hand, 2017). We build on the teacher noticing literature to examine how instructors adapt teaching based on more than unaided classroom observations, but also on information such as data on student equity barriers. We define 2 lenses below: Data Lens and Responsibility for Learning Lens.

Data Lens. The Data Lens is defined as the kinds of knowledge and data that are important and relevant in an academic and socio-organizational culture (Phuong, 2021; Phuong et al., 2021). Here is a question that one may consider when reflecting on the Data Lens: Do I value certain kinds of practices because they are tested using data sources and methods that are important to me or my field (Hammer, 2005)? The Data Lens considers the sources from which instructors can make determinations about student competencies. An instructor can use the Data Lens to understand student perspectives and learning processes. This lens can be useful for diagnosing student needs and adapting teaching.

Prior research suggests that data is an important mechanism for promoting instructor pedagogical change (Birt et al., 2019; Phuong et al., 2021; Reinholz et al., 2019). In thinking about disciplinary and organizational culture, we plan to obtain a better understanding of how disciplinary epistemological traditions impact how instructors learn and adopt equitable pedagogies. Therefore, we argue it would be important to focus on how instructors value and use data to motivate pedagogical decision-making. For example, we are interested in whether and how instructors value and use different data sources (e.g., observations, clickers, formative assessments, surveys, summative assessments) to understand and address equity barriers and patterns in student learning. Thus, the Data Lens can help instructors notice more aspects of their students' perspectives and less visible equity barriers. We hope to examine whether the use of this lens motivates the adoption of equitable pedagogies. In this study, we are interested in examining whether low- and high-growth instructors value qualitative and/or quantitative data sources, which can provide insights on instructors' epistemological values.

Responsibility for Learning Lens. The Responsibility for Learning Lens refers to how the instructor views their role and the student's role in learning. Here are some questions to reflect on: Whose responsibility is it if a student doesn't learn a concept? Are the "good" students the ones who teach themselves or don't need help? (Phuong, Nguyen, Vo, et al., 2022). This lens contributes to scholarship on reflective college teaching since it accounts for the systems, structures, and/or beliefs that foreground individualistic notions of learning that have contributed to STEM students leaving the major because they felt under-supported and isolated in a competitive environment (Jackson & Cobb, 2010; Phuong, Nguyen, Vo, et al., 2022; Seymour & Hewitt, 1997). This issue can be intensified for low-income, first-generation, and minoritized students who have less support from home.

The Responsibility for Learning Lens would account for the beliefs, or logics, that can support and prevent adoption of equitable pedagogies. Identifying this lens in reflections would be beneficial in professional development programs to understand instructors' beliefs, values, and what is driving how they think about their role in their students' learning processes. For example, instructors may hold a faulty logic that the "good students" are the ones who teach themselves, do not need help, and/or do not ask for help. We argue that such a belief can echo the Protestant work where students are asked "to pull yourself up by the bootstrap", which elevates middle- and upper-class European cultural values as the standard for success (Markus & Conner, 2013). Adopting this racialized standard and belief (Bonilla-Silva, 1999) could inhibit the adoption of equitable teaching practices because instructors may not believe that their role is to be responsive to students' learning needs because students are supposed to teach themselves. Curating learning experiences that enable instructors to interrogate these beliefs is important for shifting instructors' logics and promoting pedagogical changes.

Prior literature has been focused on students' internal motivations, mindsets, and management to learn new skills (Broadbent & Poon, 2015; Heikkilä & Lonka, 2006). Other literature has focused on identifying an educational structure that is in the middle where students have some support, but not too much (Brennan, 2020).

In this study, we focus on conceptualizing what it means to share the responsibility for learning; we specifically focus on the role instructors can play in mitigating student learning and equity barriers.

Sharing the responsibility for learning means that all the following themes co-exist in an instructor's reflection response:

- The "It's up to me" theme refers to instructor responses that suggest instructors themselves should take responsibility to mitigate the impact of these barriers on student success. The instructor believes in their responsibility to proactively understand their students' questions, barriers, needs, interests, and experiences. They see an important part of their role to be proactively addressing student learning needs and equity barriers.
- The "It's on my student" theme refers to instructor responses that suggest the student should play a proactive role in advancing their own learning.
- The "It's something else" theme refers to instructor responses that indicate another contextual factor (e.g., equity barrier, stress on the community or family) plays a role in impacting student learning.

We hope to examine the extent to which the lenses, or mechanisms, above can explain the differences between low- and high-growth instructors on AEP competency. Identifying these lenses in reflections is beneficial for supporting instructors' learning of equitable pedagogies. Facilitators can focus on expanding instructors' critical consciousness so that they recognize the importance of using multiple forms of data and sharing the learning responsibility with their students. Using multiple forms of data and considering various factors that impact learning can enable instructors to have a more holistic view of their students, which is important for adapting instruction to respond to student needs. We hope to introduce these lenses to better understand how instructors can collect student data to design, iterate their pedagogies, and become more responsive to their students' learning needs.

Methodology

129 STEM instructors at an R-1 public university participated in semester-long AEP pedagogy courses for first-time instructors, where they completed a teaching portfolio. The pedagogy courses primarily served instructors who taught computer science, data science, math, and statistics courses. Instructors participated in either a treatment or control pedagogy course. The treatment and control courses were co-led by the same facilitators who employed exemplary active learning activities and provided an AEP curriculum. Instructors were randomly assigned to the treatment or control condition.

Using qualitative methods, our research question focuses on treatment instructors because the treatment course was more effective at increasing AEP competencies over time (Phuong, Nguyen, Vo, et al., 2022). For the purpose of this study, we want to understand how low- and high-growth instructors on AEP competency differ with respect to their data use and responsibility for learning lenses.

As explained in Phuong, Nguyen, Vo, et al. (2022), all instructors completed baseline, midterm, and final AEPC assessments. Each AEPC assessment elicits evidence about teaching philosophies, written reflections on teaching and assessment practices, evidence of student learning, student gain score visualizations, media, and peer/student feedback on their teaching. The AEPC assessment contained reflection questions that asked instructors to provide evidence of demonstrating AEP competencies. The scale was 0-22, with 3 items being scored 7 points each and 1 item being 1 point. A detailed rubric (See Table 1 for a summary) was applied independently by two researchers to blindly score assessments. Higher positions on the rubric imply that criteria of lower positions have been met. Based on partial credit Rasch modeling (Masters, 1982), the AEPC measure has high reliability (0.94), has strong validity based on Wilson's (2005) strands of validity framework, shows no gender or URM bias, and correlates significantly with researchers' review of teaching and pedagogical materials (Phuong, Nguyen, Hunn, et al. 2022; Phuong, Nguyen, Vo, et al., 2022).

Table 1
AEPC Scoring Rubric 0-7, originally reported in Phuong, Nguyen, and Vo et al. (2022)

Item Score	Learning Progression Level	Description
0	0	Provides an irrelevant answer, does not apply any elements
1	Low	Applies AEP element 1 and/or 2 (described above) Element 1: Clarifies learning outcomes Element 2: Aligns formative assessment with learning outcomes
2	Moderate	Applies elements 1-3: Diagnoses student learning competency ***Or*** Diagnoses interest

3	Moderate	Applies elements 1-4: Diagnoses learning competency and interest ***Or*** Diagnoses learning competency and learning barriers
4	High	Applies elements 1-5: Adapts based on full diagnosis, not only based on diagnosis of learning competency
5	Very High	Applies all 6 AEP elements
6	Very High	Applies all 6 AEP elements citing instructor and student evidence
7	Very High	Applies all 6 AEP elements with supporting instructor/ student evidence and explains how their practice impacts the student ***Or*** Applies all 6 AEP elements with instructor/ student evidence and explains rationale for how practice impacts student

We provide the AEPC scores in the treatment over time on a scale of 0–22 points: The pre-semester AEPC score was 0.12 points (SD=0.33) and the post-semester AEPC score was 20.65 points (SD=1.61). As noted in Phuong, Nguyen, and Vo, et al., 2022), this growth observed in the treatment was significantly greater than the growth in the control condition.

We drew from instructors' teaching reflections to identify the mechanisms that motivate instructors to learn and adopt Adaptive Equity-Oriented Pedagogy (AEP) in higher education. Specifically, 10 low-growth and 10 high-growth AEPC instructors, as determined by quantitative analysis, were selected from the treatment condition. To accomplish this goal, the bottom 25% (n=16) and the top 25% (n=16) of the 65 instructors were identified by the magnitude of the change in their AEP competency from pre- to post-semester. Next, all minoritized instructors in both of these groups were selected for inclusion. Finally, a different member of the research team randomly sampled additional instructors to create sets of 10 in the low- and high-growth groups.

On a scale of 0-22, the mean low-growth group AEPC growth score is 18.31. By contrast, the mean high-growth group AEPC growth score is 22. We selected 11 reflection questions from the end-of-semester AEPC assessment. These questions ask instructors to describe their teaching philosophies and values, what they have done, their evidence of demonstrating AEP competency, and their reflections on how they have adjusted their perspectives and pedagogical practices to advance student success.

When coding the data, we anonymized the instructors' names, condition, and whether they were in the low- or high-growth group. We deductively coded reflections using a codebook, tracking frequencies of codes, and exploring self-reported mechanisms for learning AEP (Saldana, 2011).

Findings

Data lens

Two subcodes under the Data Lens include "I value quantitative data" and "I value qualitative data." In the treatment, we examined the co-occurrence of "I value quantitative data" and "I value qualitative data" subcodes, which refers to instructors invoking the two subcodes in a response to a given question. All ten high-growth and three low-growth instructors were identified as representing both subcodes. Based on these findings, we found evidence that the Data Lens reflected major differences between low- and high-growth instructors.

As high-growth instructors make pedagogical decisions to advance student success, they value "qualitative" and "quantitative" approaches more often than low-growth instructors. This consideration of both data approaches may suggest that high-growth instructors have more inclusive epistemological values than low-growth instructors. In other words, high-growth instructors recognize the value of both numbers and lived experiences as sources of data for understanding where their students are at in the learning process.

Consequently, we also noticed that the high-growth instructors do not solely characterize students based on their test scores, cultural background, or equity barriers. Instead, the high-growth instructors are using multiple data points to address students' interests, strengths, and learning needs. This may suggest that high-growth instructors are looking at their learners more holistically as human beings, which is a more humanistic approach to teaching.

Responsibility for learning lens

An instructor who fully shares the responsibility for learning recognizes that the instructor, the student, and other factors each play a role in advancing student learning. Accordingly, in our qualitative analysis, sharing the responsibility for learning means that the following subcodes co-exist in an instructor's response:

- The "It's up to me" subcode refers to instructor responses that suggest instructors themselves should take responsibility to mitigate the impact of these barriers on student success. The instructor believes in their responsibility to proactively understand their students' questions, barriers, needs, interests, and experiences. They see an important part of their role to be proactively addressing student learning needs and equity barriers.

- The "It's on my student" subcode refers to instructor responses that suggest the student should play a proactive role in advancing their own learning.
- The "It's something else" subcode refers to instructor responses that indicate another contextual factor (e.g., equity barrier, stress on the community or family) plays a role in impacting student learning.

Based on preliminary qualitative analysis, all the high-growth instructors, but only one low-growth instructor, expressed fully sharing the responsibility for learning. Therefore, the Responsibility for Learning Lens appears to distinguish low- and high-growth instructors.

Discussion

Consistent findings with a previous study. In a recent study, Phuong, Nguyen, and Vo et al. (2022) examined the top and bottom 25% of the 129 instructors on AEPC growth in the treatment and control condition. There were 32 instructors in the low-growth group and 32 instructors in the high-growth group. We provide some context on these low- and high-growth groups from Phuong, Nguyen, and Vo et al. (2022): "For the bottom 25% of instructors (n=32), the average growth on the 22-point AEPC scale was about 9.22 points (*SD=1.93*) and all these instructors were from the control group. The top 25% of instructors (n=32) had a mean AEPC growth of about 21.84 points (*SD=0.37*). For the top 25%, we found that at least 31 instructors were from the treatment" (p. 4).

Ten instructors were randomly sampled and qualitatively analyzed from the bottom and top 25%. We quote a table below from Phuong, Nguyen, and Vo, et al. (2022), which provides frequencies of qualitative subcodes for *responsibility for learning* and *data lenses* that were expressed by instructors in their reflections. Our analysis of the treatment instructors is relatively consistent with these findings from Phuong, Nguyen, and Vo et al.'s (2022) analysis of the top and bottom 25% of the combined treatment and control conditions.

Table 2
Frequency of selected responsibility for learning (RL) and data lens subcodes in bottom and top 25%, originally reported in Phuong, Nguyen, and Vo et al. (2022)

Sub codes in instructors' written reflections	Bottom 25% Frequency (%)	Top 25% Frequency (%)
1. Indicates student is responsible for proactively addressing learning challenges (*RL* subcode)	10 (100%)	10 (100%)
2. Indicates instructor is responsible for proactively addressing learning challenges (*RL* subcode)	0 (0%)	10 (100%)
3. Values and cites multiple forms of data to adapt teaching (*Data* subcode)	0 (0%)	10 (100%)
4. Gives an example and rationale for how adapting teaching will improve student learning based on data (*Data* subcode)	0 (0%)	10 (100%)

The sample size of 20 instructors is limited, and future research can explore additional reflection responses and a larger number of instructors in other college contexts.

Expanding Notions of Expertise and Standards for Success. We challenge simplistic conceptions of learning and expertise that focus on the progression from dependent to independent learning. Taking a sociocultural perspective on learning, we contend that learning is and remains inherently social. Many experts work independently and are nonetheless dependent on a range of resources (e.g., online forums, YouTube) and actors (e.g., mentors, managers, peers) that support their ongoing learning and success. Because we recognize that learning is social and distributed, we argue that educators need to play a role in the learning process by sharing the responsibility for learning when supporting the success of novice and advanced learners.

Furthermore, certain conceptions of independent learning echo the Protestant work ethic of "pulling oneself up by the bootstraps" and place white, middle- and upper-class Eurocentric norms as the standard for success (Markus & Conner, 2013). Elevating independence as the standard perpetuates whiteness in educational and performance evaluation standards. We therefore argue that equating expertise solely with independence is racialized, since it is a remnant of an archaic Protestant tradition rooted in white, upper-middle class norms.

The Protestant work ethic has been used to reinforce the myth of meritocracy, under which any success is attributed to hard work and any failure to the lack thereof (Markus & Conner, 2013). Faculty have echoed the Protestant work ethic by expressing that students, including minoritized students, who cannot succeed in STEM are not “cut-out” for STEM since they did not work hard enough (O’Leary et al., 2020). In some of our other preliminary research, instructors have applied this logic to primarily teach to the higher performing students, as these are the ones perceived to be working hard. Such logic does not account for the systemic and contextual barriers that students face, including minoritized students. Bonilla-Silva (1999) and Sears and Henry (2003) highlight that the Protestant work ethic of individualism reproduces symbolic racism and can be detrimental to equity.

We argue that elevating individualism as the standard of learning (e.g., through a “teach-yourself” model) can reproduce racialization and social inequities. For example, Stephens et al. (2012) documented that there can be a cultural mismatch for first-generation students with respect to individualism in higher education. They found that first-generation students tend to express more interdependent motives than continuing-generation students (Stephens et al., 2012). Moreover, Goode (2007) found that individualistic discourses were disempowering for international graduate students in higher education. In addition, Nguyen et al. (2022) found that first-generation, low-income, and minoritized students achieved greater success towards their personal and professional goals in higher education when they had educators who worked in partnership with them and had a “let’s do this together”, equity-oriented approach. Prior social capital interventions in higher education have been shown to increase first-generation and minoritized students’ sense of belonging, achievement, and retention (Rasco et al., 2020; Schwartz et al., 2017). Instead of focusing on assimilation, it is important to acknowledge, support, and engage the different kinds of capitals and strengths that students bring (Yosso, 2005).

Moreover, individualistic models of learning have also marginalized those who have less access to resources. We found that individualistic approaches to learning have contributed to persistence and retention challenges for all students, including minoritized students. Students cite learning alone, the lack of alignment of instruction and assessment, and curving down as part of the top five reasons for leaving STEM (Weston et al., 2019). In fact, curving grades down has been well documented in promoting competition over collaboration among students in STEM courses and other disciplines. Elevating individualistic norms and performance criteria for learners not only inhibits the transformative opportunities for social learning, but has also led to students being weeded out of STEM fields. We argue that these racialized norms of individualism and pervasiveness of whiteness in educational standards perpetuate cycles of inequity, opportunity gaps, and a lack of diversity in STEM. In sum, we contend that equating expertise and development with independence is racialized and can create barriers to learning and the development of social-emotional competencies for both instructors and students.

The Adaptive Equity-oriented Pedagogical Competency (AEPC) model combats the ramifications of racialized conceptualizations of expertise and development. In the AEPC model, an expert shares the responsibility for learning and draws on multiple data sources to develop as a scholar and practitioner. These two lenses advance anti-racist practices because they encourage ongoing critical reflection on the racialized systems and structures that reproduce systems of power that limit opportunities for students from minoritized and underrepresented backgrounds. We argue that expert instructors work both collaboratively and independently within a learning environment to continuously seek feedback and improve their practice. Part of this work includes expanding one’s critical consciousness to better understand the privilege and lack of privilege that students experience when they enter higher education learning environments. Furthermore, by collecting data on students’ lived experiences and circumstances, instructors can strengthen their social-emotional competencies in social awareness skills such as perspective taking and addressing areas for growth.

Within a higher education STEM context, our conceptual framework prioritizes equity in the teacher noticing process, which is grounded in a sociocultural perspective of learning (van Es & Hand, 2017). In particular, the AEP framework adds an equity perspective to teacher noticing as it seeks to create a culturally responsive community of reflective practitioners. The AEP framework further contributes to the teacher noticing literature by providing a framework with different pedagogical practices that encourage instructors to reflect and respond to their students’ socio-cultural context and equity barriers. Phuong et al. (2017b) argue that taking students’ perspectives is important for promoting student success for all students. Accordingly, part of being an equitable instructor entails using data to reflect on one’s own pedagogical frameworks and student perspectives in order to challenge unconscious biases and design for all students. We argue that relying solely on intuition to make pedagogical decisions can result in instructors being affected by unconscious biases and assumptions.

We want to broaden notions of teaching and learning that are common in STEM. We challenge the pernicious belief that the good students are the ones who teach themselves and do not need help. It is important to foster instructors’ efforts to take different perspectives when they are making pedagogical decisions and policies. An expert instructor under the AEPC model would not solely shift the responsibility for learning onto a student, tutoring center, counselor, or diversity officer. Furthermore, with respect to faculty development, the current findings suggest that it can be beneficial to support instructors in sharing the responsibility for learning and using multiple data sources to adapt teaching and advance student learning. As documented by Phuong, Nguyen, and Vo, et al., (2022), this approach expands instructors' critical consciousness since it asks them to rethink common cultural norms, values, meritocracy, and larger systems (e.g., structural racism) that reproduce inequities, where students from underprivileged backgrounds may not have equitable access to resources and opportunities that enable them to teach themselves. Therefore, critically interrogating the individualistic notions of STEM learning, the myth of meritocracy, and beliefs about self-reliance is key to advancing more equitable and anti-racist pedagogies.

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Contradictions of Decolonial Literacy in an ESL Writing Space

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Abstract: In the last decade scholars have called out the colonial elements of English language arts in order to move towards decolonial literacy practices. But what does decolonial literacy practices entail? I look at some ethnographic data from a online writing project to explore the notion of decolonial literacies. Youth from the Santhal community in a remote village in India participated in this work as students. For this paper, I analyze the process and products of two focal students Saroj and Manoj through the lens of contradictions within the decolonial literature. I show how these contradictions enabled them to simultaneously work with and against the standard conventions of English language and persuasive writing. The paper submits that one aspect of developing decolonial literacy is learning to negotiate with the contradictions it generates. The findings have implications for designing decolonial learning environments.

Decolonizing Language Arts

In the last few decades, scholars have investigated the norms and conventions of English language Arts, exposing their colonial and racial history(Flores & Rosa, 2015). Some common mechanisms of enforcing a colonial pedagogy within English language arts are monolingualism, native accents, standard grammar, genre conventions and subsumption of all kinds of difference as 'inappropriate.' To decolonize literacy is to make epistemic connections that comes with languaging(Cushman, 2016).Two prominent ways through which connections between literacy and epistemology is forged are Translanguaging and culturally relevant texts. Translingualsim challenge the colonial notion that languages are separate distinct entities with neatly defined borders and embrace the fluidity of the full linguistic repertoire of students. . Translanguaging is intended as a decolonizing project, revealing how bilinguals/multilinguals inhabit a world with different knowledge bases and linguistic/cultural practices(Wei & García, 2022). In addition to translanguaging educators have increasingly employed culturally authentic texts for minority groups. By culturally authentic texts I means inclusion of literature that speaks to the cultural reality and background of students. Student produced culturally authentic texts includes counter stories, testimonios, autoethnographies, literacy autobiographies and other versions of personal stories that centers the lived experience of students (S Canagarajah & Matsumoto, 2017;(Kelly, 2017)(Saavedra, 2011). Though there is much theoretical work on decolonization of language arts, we don't have many empirical studies that look at- What does it mean for students to actively develop decolonial literacies? What novel challenges are generated when designing for decolonial literacies? This paper claims that engaging with local languages and local knowledge systems in an ESL writing space creates contradictions for students. These contradictions enable students to develop novel strategies to not just negotiate dominant knowledge conventions but also to refashion them.

Contradictions within decoloniality

Decoloniality is considered a move beyond the apparent transparency and universality of the zero point of knowledge, by embracing the geopolitical and biographical politics of sensemaking(Mignolo, 2000). In that sense, a decolonial literacy practice is to read/write the world from 'somewhere.' But postcolonial scholars, like Spivak rejects the idea that there is an uncontaminated space 'outside' the hegemonic structure(Andreotti, 2007.). Therefore, rather than a simple rejection of colonial literacies, decolonial literacy is an act of negotiation from within. But how does one negotiate from within? What does such a negotiation mean for students? Scholars have pointed out that contradiction marks the existence of postcolonial subjects. The metaphors of being 'here' and 'there' or experiencing a split within one's own desire is a classic postcolonial condition(Asher, 2009). In such a situation, De Sousa Santos invites decolonial thinkers and practitioners to make use of the fertility of a contradiction by working with and through it(Santos, 2015). In my findings, I will show that two students experienced contradictions in engaging with the conventions (coloniality) of English language and persuasive writing. These contradictions enabled them to construct novel strategies to push the boundaries of what is persuasive writing and English language.

Context of the writing project and research question

In the Global South, English language was used as a colonizing tool and scholars argue that the imperial effect of English language is far from over(Phillipson, 2009). India has lost around 220 languages in the last 50 years, and over 500 are considered endangered (Mohanty, 2020). On the other hand, in a society where educational opportunities were reserved for some, English has become a tool to bypass the upper class/caste hegemony and is associated with economic opportunities(Chakraborty & Bakshi, 2016). Therefore, English is placed in a complex matrix viz a viz linguistic and cultural minorities in India(Babu M T, 2015). It was in this backdrop that this study was designed under one of the projects run by my not-for-profit organization in India. The project connects young volunteers from urban colleges to rural youth for skill development. For this particular research project, our goal was creative writing using English language. Students ended up writing fiction, nonfiction, and different kinds of personal narratives. Their writings were guided by the translingual and culturally authentic texts they read in class. We also invited some Santhali writers to conduct workshop with them. Overall, the goal was to write an article on any topic and genre, and if possible, get it published online. 12 young adults (18-21 years) from the Santhal community participated in the project and 6 mentors from different cities worked with them. I was one of the mentors and all of us designed this curriculum together. All the sessions were online, and they happened 2-3 times a week. The questions that guided our study were: What are the challenges that students faced in the development of their writing? How were these challenges engaged with?

Data

I collected three kinds of data for this project- interviews, Zoom recordings and written artifacts of students. I used an artifact-based interview that centered student's final writing to understand their composition process. I started with open coding the interviews. I was particularly stuck by some challenges that students mentioned in their interviews. I say so because they were challenges that related to the two design elements of Translanguaging and writing about one's cultural context. I had assumed that these two features will have great affordances, but when I discovered that they created new problems, I pursued them and wrote some memos. As a next step I became more sensitive to not just challenges but also strategies. By challenges I mean explicit statements in the interview like- " I was confused about this" or " I had great difficulty in doing this". By strategies I mean interview segments where students explained the decisions regarding selection of topics, how they started writing, what kind of openings they made, linguistic choices, etc. Going forward I refined my codes and organized them into five categories (Table 1). I developed a sense that the most prominent challenges were around the categories of 'Navigating Languages' and 'Development of content'. The first category deals with all codes that relate to the challenges and strategies of navigating *how and when to use the multiple languages* in their writing. The second category deals with all codes that relate to the challenges and strategies of navigating *what to write* within a topic to build its content. The frequency of codes in each category helped me develop a sense of what challenges were the most prominent. Next, I looked at classroom moments to get a sense of how and when these challenges and strategies were generated. Finally, I looked at the final writing of students to get a sense of how some of these challenges were dealt with. For this paper, I selected two students Manoj and Saroj, who exemplify the two prominent categories of challenge I described above(Stake, 2008). I have organized their cases as cases of enabling contradictions. This means that I established their challenges as a kind of contradiction which helped them generate certain rhetorical features in their writing.

Table 1
Code categories and frequency for challenges and strategies

	Navigating Language	Development of Content	Arrival at Topic	Structure	Text Comprehension
All	**62**	**44**	40	28	14
Saroj	**11**	3	5	3	3
Manoj	23	**14**	8	6	0

Findings

The central assertion of this paper is that decolonial literacy practices that engage with local languages and local knowledge systems creates enabling contradictions. To support this claim, I provide two cases. My first case is about Saroj (20, F) and her contradiction is organized around the challenges and dilemmas involved in navigating multiple languages. My second case is about Manoj (21, M), whose contradiction is organized around his challenges and dilemmas around the legitimacy of what is to be written. Both Manoj and Saroj (pseudonyms) come from the Santhal community, which has a historical background of socio-economic marginalization. In formal educational spaces, their local language Santhali is not used, hardly understood, and often looked down upon. In presenting both cases, I will first establish their challenge as a contradiction. Then I delve into classroom moments that encapsulates their contradiction. Finally, I look at their writing to highlight how their contradictions enabled them to develop novel rhetorical strategies.

Focal student Saroj: How to write?

Saroj is 20-year-old woman, and she wrote an article on her father's practice of local herbs. Her languagescape is diverse and English is her fifth language. She felt most challenged by the aspect of navigating her multiple language. By navigating multiple languages, I mean two things. First aspect consists of the challenges specific to English, the language of desire and intimidation. In her interview Saroj mentions- "*When I had to translate from Hindi to English then I used to face some difficulties, how to frame sentences? Which word will be translated into what?* The second aspect of this navigation relates to how, when, and why to use languages other than English in her article. In some situations, the first aspect of the challenge was mediated by the second. For instance, in her interview she mentions, "*I cannot write correctly in English, so I wrote it(article) in mixed language and then published it.*" So, one function of 'mixed language' or translanguaging was to improvise and compensate for current competence in English. In another instance of her interview, when asked about her Santhali usage, she mentions "*I wanted to make people aware of my language also, they should know that this word in Santhali means this.*" In that sense there was no single use or rationale for using multiple languages and she had to navigate diverse choices, often changing her stance, and sometimes feeling confused about how she should write. On the one hand she was pulled towards the conventions of standard English and on the other hand she was open to her other languages. This is the contradiction she experienced, which I will elaborate below through several classroom moments.

Saroj chose to write about her father and his practice of treatment with local herbs. She started by writing a few paragraphs in Hindi using Google documents and its default Roman script. Using the Roman script for writing in other languages is a popular practice due to social media communication and WhatsApp messaging in India. However, even at the vocabulary level her 'Hindi version' did contain some Santhali and English words, indicating the organic nature of translanguaging that the community is used to (1). After a few classes she was asked by her mentor to start writing some of what she has written using English.

> *1 Santhal samaj ke log anek prakar ke jari butiyo dawai banate hai.*
> *2 Santhal society ke people very very jari butiya medicine make.*
> *3 Santhal Samaj ren hor ko ayma lekan jaru buti ran ko benawa.*
> *(Taken from Saroj's google doc)*

Line 2 captures her first attempt at writing 'with' English. I say 'with', because she retains the sentence structure and even some of the grammatical features of Hindi language from Line 1 but transplants a few English words like- 'society', 'people', 'very very', 'medicine' and 'make'. Eventually, the mentor asked her to write the same line in Santhali (Line 3).

> *1 Mentor- So, how are you feeling after making your first translation? (Referring to line 2)*
> *2 Saroj- I am feeling kind of okay I guess (said with some skepticism and smile)*
> *3 Mentor- Okay, keep going-*
> *4 Saroj- I feel scared-*
> *5 Mentor- Don't worry, it's coming out well… So, why do you think I asked you to write in Santhali?(Line 3)*
> *6 Saroj- Maybe we have some people who will read this in Santhali*

In this conversation, Sarita is not very confident (2) about her performance in Line 2, which may relate to her skills in English. She is also not sure about the purpose of the third line and at best imagines an audience that would read in Santhali. As I mentioned above, all three lines can be categorized as translanguaging, one more implicit than the other. At this initial level, the nature of translanguaging is shaped by cultural habits, the apparatus of google doc and her limited sense of English grammar and vocabulary. Further down this conversation the mentor inquires if she has ever read texts which use multiple languages, to which she says- "*I have read some, where they use Hindi and English together, but not one where they mix Santhali.*" In the next few classes, the mentor brings some translingual texts and discusses them with her.

> *1 Mentor- This is his Facebook post, let's look at it, this is called Santali marriage and in brackets he has written Hor Bapla. So, you see he has used a lot of names for the marriages, which are in Santhali, why do you think he mentions these terms, instead of just writing about them in English?*
> *2 Komal- I know three kinds of marriage- love, arrange and chadwi*
> *3 Mentor- So I think chadwi is the one listed at number 10, okay, so as a reader how do you like this, with these Santhali words or would you prefer it in complete English?*

4 Saroj- Both are okay, with Santhali we get to know a little more about them…

The mentor text presented above is a more intentional version of translanguaging, where the author uses some very specific Santhali words that highlights cultural differences and complements the subject of his writing. But the students are not very clear about this usage in this interaction. The author has used some Santhali words that are not used in their particular region, and they are unable to recognize them. In this interaction, Saroj does not feel any strong preference for either mixing languages or using exclusive English (4). Although she does appreciate the text for learning some new Santhali terms, a move she makes in her own final writing. A big concern that translanguaging or non-conventional English poses is the challenge of comprehensibility. In our own study, when students started writing, they often wondered- "Am I making sense?" To test this internally, the mentor invited students to read and make sense of each other's writing. In the following interaction, another student (Student 2) is reading a paragraph written by Saroj.

1 Mentor- So do you understand what is written?
2 Student 2- Since we have discussed here writing for so long, so I can get it, but the sentences are not clear in the middle, so if someone else reads it, who is a stranger, I feel it will not be clear for them
3 Mentor- So how can we improve this?
4 Student 2- So, 'jari butiya', can be there as it is…but for instance 'Ke tree" is something which is not looking well…she could have used either Santhali word or full English there instead…but at the moment it's confusing.
5 Mentor- What do you think of this Saroj? How should we go about it?
6 Saroj- Lets go towards more English. As he said, some words I will retain and make more sentence in English

In this interaction we see a negotiation of understanding, as the student reading Saroj's text feels that a new reader may not be able to follow(2). He recommends less hybrid structures (4) and Saroj immediately feels that she should use more English (6). In response to Saroj's inclination, the mentor presented more examples of online writing, which was mostly written in English, not necessarily using standard grammar.

1 Mentor- Is this a good example for you, Saroj? It is mostly in English.
2 Saroj- But what about for those who don't know English?
3 Mentor-So should we have separate articles for the audience, or should we have one article but with mixing?
4 Saroj- Lets mix. But I think English should be separate, yes, so this version should be mostly English and the other with more mixing, maybe we can also put in brackets what is the English name for Munga.

In this interaction, Saroj feels a pull towards her other languages and expresses her concern for non-English readers (2). She is deliberating upon the possibilities of how she can 'mix' and yet have a 'mostly English' version (4). These pulls were elevated at different moments in the classroom. In another discussion she was part of, some other students highlighted the fear of being judged poorly if they mixed their language. Even though they do practice translanguaging in everyday life, they felt that translanguaging in writing will be perceived positively only if done by people who are already experts in English. Saroj moved between her position of translanguaging as a form of asserting her language and an improvisation for her inability to form full English sentences. This is the central contradiction that her case presented. Let's now turn to her final writing to look at what her contradiction enabled. Let's begin by looking at the evolution of the very first line she wrote, from its first draft to its publication.

Santhal samaj ke log anek prakar ke jari butiyo dawai banate hai.(1)
Santhal society ke people very very jadu butiya medicine make (2)
Santhal society people make many types of Rehe Raan (jari buti) medicine. (3)
The Santhals make many types of 'Rehe Raan' ('jari buti' / medicinal herbs) medicine. (4)

Line 1 is where she started, and Line 2 is her first attempt with English. Line 3 is what she eventually submitted for publication. It has mostly English words (like she wanted) but not necessarily in the conventional form or order. It has a Santhali word *Rehe Raan*, which is the local word for herbs. This strategy to translanguaging reflects how some cultural key words are to be articulated in Santhali, an understanding possibly shaped by continuous classroom discussions. So, she works around all her languages, her desire for English, comprehensibility, and inclusion of different readers to create line 2 But what gets published on the platform is Line 4, as the editors use their publishing standards to intervene. They restructure the first few words of her sentence and adds the word medicinal herbs next to Hindi word 'jadi buti'. There are many instances in her article where the editors changed her language to match their convention. This move by the editors underscores the place of convention in writing, and that sometimes resolution to Saroj's contradictions were decided externally.

> *♫♫Hane dular koyog mese bir buru sona disom haire. Bai Bai te Nana hunar dare nari ujar cabakan.*
> *Somaj tala re ayam hor do rehe raan ko badaiya .bir buru re ayam lekan rehe ran ko mena .*
> *bir buru dare nari re nidir do lago wen.*
> *cedam japetak ebhen me ♫♫*
> *♫♫Look friends, the forest mountain in our country is so lovely. Slowly, slowly many types of trees are getting finished. Santhal society people know many types of indigenous medicine. Forest is getting cut. Why are you sleeping? Arise and get up!♫♫*
> *(First part of the song that introduces Saroj's article)*

Saroj decided to open her article with a Santhali song. In Santhali culture, songs are one of the key mediums of persuasion and knowledge transfer. The strategy of opening with a Santhali song not just speaks of her desire to include Santhali audience, but also to address them first. The song, though appears in the start of her article, was actually the last thing she added to her writing and in some ways is a poetic culmination of her journey. In the interview she mentions, "*I started with a song because songs are my favorite and I wanted to make people aware about the gradual decline of the greenery, mountains and our beloved nation via the medium of the song."* The song captures the essence of all the paragraphs that follows it, persuading the readers with the evocative imagery of community in " Slumber" and a need to "Arise and Get up!" Working across multiple languages also enabled Saroj to engage with the 'mostly English' sections better. For her five paragraphs Saroj went from Hindi to English, but for the song she attempted a direct translation from Santhali to English. This indicates her increasing confidence with English. The song translation was the segment where she made the most agentive decisions regarding what English words really convey what she wants to say. For instance, Saroj went through several phrases like 'Stand Up', 'Get Up', 'Wake Up', before settling for "Arise and get Up"! She also overturned some word suggestions made by the mentor in favor of what she thought fits better. Reflecting on this process she said, *"The way in which I have written my article I had never done before…through the article I got the opportunity to learn English."*

I argue that her contradiction enabled her final article to embody both a sense of convention and a place for her whole personality. The convention is visible in the five paragraphs that follow this song, which is somewhat modeled after a Hindi article she read in class. She writes the five paragraphs 'mostly in English' and retains Santhali words for significant relationships, names of medicine or diseases. On the other hand, the song represents her existing expertise and inclination in her writing(Lee, 2003). I say this because, after the publication of this article, the mentor discovered that Saroj has sung some Santhali songs that have over 250,000 views on YouTube. This is one reason she felt most at ease when writing the song. In her interview she recollects- "*It didn't take much time; I easily thought about this and wrote it."* Eventually, Saroj's contradiction enabled her to indigenize English language and push the boundaries of persuasive writing by infusing in it the orality of Santhali music.

Focal student Manoj: What to write?

Manoj is 21-year-old man, and he wrote an article on the changing food habits of his community. Unlike Saroj, he has some exposure of living in a big city as a migrant labor, which adds to how he looks at his community life. Manoj wanted to write a persuasive nonfiction piece about the significance of non-cultivated forest food. In the standard conventions of persuasive writing, assertion should strongly align with evidence. But for Manoj the most prominent challenge was to make a persuasive case for his traditional food practice in the face of lack of 'conventional evidence'. For him the central contradiction was in asserting his traditional knowledge on one hand and the skepticism around its legitimacy on the other. In talking about the writing process in the interview, Manoj recalls several doubts he had. *"It was still difficult to write on this topic, there were many kinds of doubts, for instance, what exactly we are writing about the food, its nutritional status, what we are writing, is it true or not."*

Most of the non-cultivable forest food of Santhal community has not been written about and there is very little research around its nutritional status. Manoj and his mentor could not find a simple blog-like article that could model his writing. To develop the content of his writing, he relied mostly on his interactions with community elders and some existing practices of his community. But 'is it true or not' is something that he continuously wrestled with. His own confidence about his community's knowledge around food went through some shifts. The following interaction is from a class when he first discussed his topic.

> *1. Manoj: Yes, I don't care whether people do it or not. People never talked about madua (millet), but 20-25 years later they've started talking about madua.*
> *2. Mentor: Why do you think people have started talking about madua,..why are they talking now?*
> *3. Manoj: People were not valuing it.*
> *4. Mentor: Why were they not valuing it?*

> *5. Manoj: When people like you will come and tell us, people who've studied at good colleges, are government employees or doctors, are certified, are well educated, or earns a lot or are researching, that would be more credible.*

In this interaction, Manoj uses the example of *madua* (millets), which was historically consumed by the community but was socially looked down upon. Eventually the community stopped eating it and used it as animal fodder. But then large-scale campaigns were conducted by the government to revive millets for its nutritional benefits, something he refers to as 'they have started talking about it' (1). This notion of value and where it comes from is best characterized by his elaboration (5) on institutional validity. In this interaction Manoj not only looks confident about the significance of local food, but he also points out the politics of legitimacy and that sometimes conventions are late in catching up with local knowledge. Few sessions later, as shown in the following interaction, we can see a shift from his personal indifference to an exploration of why his community members may be turning away from local food items.

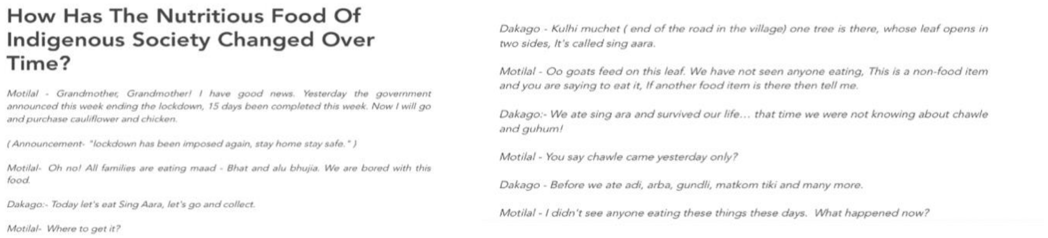
> *1. Manoj: Even though there is so much nutrition in Sahejan (local available green vegetable), the doctor would rather recommend spinach that is available in the market.*
> *2. Mentor: Why is that? No one is aware of these food items?*
> *3. Manoj: They are not aware about the vitamin content, like it's not in some books or google, so they are not confident about it.*
> *4:Mentor: So, you think people used to eat these items without any research.*
> *5. Motilal: They would have known this by some method or daily usage.*
> *6. Mentor: But how do you think they figured this out ?*
> *7. Manoj: yes, they didn't research but they would have found somehow, there are so many plants in the forest, but not all are consumed, so there must be some way to test.*

Manoj is still speaking with some confidence about the local food but brings up that the authorities on health and nutrition (doctors) do not recognize it (1). He attributes the decline of the local food items to lack of support from conventional sources of knowledge, as 'it's not in some books'(3). Therefore, lack of conventional evidence comes out as a strong factor that may be dissuading the consumption of local food. When the mentor poses a question about how the community generated this knowledge and its own form of evidence, Manoj feels that there must be a method of discernment within the community. There are two important points here. One is that this other way of knowing, and this other kind of evidence (7) suggests a tension in presenting indigenous knowledges in conventional forms of representation. The second point is about 'not being confident'(3), which if read from a structural perspective, can become a case of rendering some people underconfident. Later in the project, in another class, Manoj reads an article about 'natural medicine' as practiced by indigenous community, which makes him more skeptical about how confidently community knowledge is presented. In this class, the mentor directs Manoj's attention to the "Note" that the author had included at the top of his article, which recommends that people consult a doctor before consuming these medicines mentioned in the article.

> *1. Manoj- This (note) is written because these medicines are only based out of experience, and there is no research, so maybe it is not confirmed, because it is based only on experience, so this is just used by Adivasi community, so that is why maybe the author is recommending that doctor should be involved before its usage.*
> *2. Mentor- The title however does not look tentative. What do you think?*
> *3. Manoj- Yes, the title does not have it. When people see this title, they may get curious to know about such medicines, they would want to explore it, but then they have put this note.*
> *4. Mentor- Do you agree with the choice of the note being here?*
> *5. Manoj- Yes*
> *6. Mentor- if the article was written without a note, do you think it would have made any difference?*
> *7. Manoj- Maybe some people may have questioned this knowledge, not everyone knows about this , people just know that there are some traditional medicines, but what is its actual impact they don't know, I am actually not sure…*

Manoj interprets the "note" as the eventual deference to the validation of doctors' over lived experience of the community(1). If the article is written without the note, he can imagine some objections because 'not everyone knows about this' and its 'actual impact'(7). Eventually he connects this need to write a note to the lack of confidence in the community as discussed in the previous interaction. His own agreement to the choice of including that 'note' (5) can either be read as his pragmatism about the convention of publishing articles of this nature, or it could be indicative about his own skepticism about the status of community knowledge. There were classroom moments where the status of community knowledge on food was not in question, only the acceptable form of evidence was doubtful. But there were also moments when Manoj slipped into doubts about the knowledge itself. Manoj felt the need for confirmation in the way it appears conventionally for regaining cultural confidence in local food. Having a mentor who does not share his cultural background and practice may have alleviated the confusion about this topic. Eventually, Manoj developed the content of his article and published it. So, let's turn our attention to how his contradiction enabled certain rhetorical strategies in his final writing.

Figure 2
Opening segment of Manoj's article



How Has The Nutritious Food Of Indigenous Society Changed Over Time?

Motilal - Grandmother, Grandmother! I have good news. Yesterday the government announced this week ending the lockdown, 15 days been completed this week. Now I will go and purchase cauliflower and chicken.

(Announcement- "lockdown has been imposed again, stay home stay safe.")

Motilal- Oh no! All families are eating maad - Bhat and alu bhujia. We are bored with this food.

Dakago:- Today let's eat Sing Aara, let's go and collect.

Motilal- Where to get it?

Dakago - Kulhi muchet (end of the road in the village) one tree is there, whose leaf opens in two sides, It's called sing aara.

Motilal - Oo goats feed on this leaf. We have not seen anyone eating, This is a non-food item and you are saying to eat it, If another food item is there then tell me.

Dakago:- We ate sing ara and survived our life… that time we were not knowing about chawle and guhum!

Motilal - You say chawle came yesterday only?

Dakago - Before we ate adi, arba, gundli, matkom tiki and many more.

Motilal - I didn't see anyone eating these things these days. What happened now?

Manoj decided to have a title that has a quality of both asking and telling in the same gesture, which encapsulates both the process and product of his writing (Figure 2). He includes 'nutritious food' in the title and chooses not to provide any disclaimer or note, suggesting his confidence in what he is presenting. His strategy to open the article with a conversation he had with his grandmother during the covid lockdown is an interesting choice. Though this is an actual conversation he had, he retells and possibly refashions it. In this conversation, he positions himself as an outsider to this knowledge system, possibly representing the young people of the community, looking forward to "purchasing cauliflower and chicken" as soon as the lockdown is over. When his *Dakago* (grandmother) suggests eating *Sing Aara* (a local green vegetable), he is not just unaware of what it is, but by calling it a "non-food item" is also outright dismissive. He is making several rhetorical moves in this section that reads as a dialogue between local knowledge and convectional evidence. His voice embodies an acute sense of skepticism that he experienced in the classroom. The paragraph after this conversation entails a description of old food items and habits. These details are generated by what he calls, 'research at the *Aatu*(village)'. His voice moves back and forth between a distant sociological tone to that of personal lived experience. In support of these traditional and locally available food items, he writes- "*Old men says that 50 years ago eating fruits and leaves used to keep their bodies healthy and energetic. My grandfather is healthy and strong compared to the new generation.*" In attributing the first sentence to 'old men', he creates a distance between that claim and himself. But in the next line he presents evidence of that claim from his personal experience. The nature of evidence for the value of traditional food habits is not presented through a nutritional breakdown, but rather through an observation of his own grandfather's health.

> *When we are sick, then our community and doctor have not told us to take nutrition food like sahjan, sing arah, siti, and many more available in villages and forests. There is huge unawareness around nutritious indigenous food. These foods have more nutrition yet are left out. One reason for this neglect is also that experts and our community people are not taught about indigenous food knowledge. The people of the villages are also less educated and less knowledgeable about indigenous food nutrition. This is just self-knowledge and not published or recorded anywhere.*

From the standard conventions of persuasive writing that encourages a unidirectional claim backed by evidence, Manoj's writing may feel to be moving in multiple directions and sometimes undercutting its own stance. I would argue that the contradiction Manoj experienced between asserting his local knowledge and the skepticism around it, enabled him to develop a critical yet intimate voice that moves in many directions. This critical intimacy not only allows him to move between his admiration and critique of his own culture, but also provides him a space to both critique and respect conventional evidence. He implicates both the 'community' and the 'doctor' for 'huge unawareness around nutritious indigenous food'. As much as he claims that 'these foods have more nutrition', he is also mindful that 'this is just self-knowledge'. Finally, it allows him to move between a version of himself that comes across as ignorant and indifferent in the introductory exchange to a version of himself willing to take responsibility, as presented in the last few lines of his article. *"I also share with people about the food we find around our home. So that everyone knows and becomes aware about natural food. If we try to increase the awareness, then people will change."* Therefore, I argue that the contradictions enabled Manoj to creatively navigate the need for conventional evidence and his love for community food. He turns around his confusion into a playful rhetorical strategy of adopting multiple positions that gives a deconstructive edge to his writing. In the process, like Saroj, he too pushed the limits of persuasive writing. If a conventional template of persuasive writing, supports a clear assertion, his writing structure embraces complexity and contradictions.

Implications

In this paper I presented two cases of enabling contradictions from my study of decolonial literacy. One way to think of enabling contradictions is to think- what does it enables us to do? We can say that it is enabling us to transform the knowledge systems from within. In this case we saw how students constructed novel ways to push the boundaries of what is persuasive English and English language. Therefore, the study has implications for classrooms that want to engage with decolonial designs in general and more particularly with Translanguaging and culturally authentic texts. I want to mention two limitations of this work. First, in my data there were moments where the contradictions were confusing and demotivating for students, which highlights the pedagogical care required to work with decolonial frames. Second relates to the metacognitive awareness of students in the strategies they employed, some they articulated explicitly but some were inferred by me. Finally, I feel that contradictions were not internal states of students, but rather a distributed experience, that worked across students, teachers, and the mediating artifacts. But for this study I have privileged the perspective of students.

A broad implication from this study is that decolonial educational designs that are inclusive of alternative epistemological stances, create contradictions for students that are potentially enabling. For different contexts and different subject domains, different design elements and conventions will activate these contradictions differently. However, regardless of context and domain, the process of struggling through contradictions has the potential to deconstruct dominant knowledge systems. Therefore, in designing decolonial literacy spaces one can design *for* contradictions and also *for* the mediating processes that mentors, and students will use to engage with it productively.

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Socially Constructive Interaction for Fostering Teacher Learning

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Abstract: In order to clarify the structures of successful teacher interaction for learning about the relation among lesson, student learning and technology, this paper analyzed a case of three elementary school teachers trying out six lessons of collaborative learning and lesson studies during five months in the COVID-19. The teachers first felt failures in their online collaborative lessons and attributed them to the technology, but later changed their views focusing more on student learning and lessons with the help of colleagues and technology. Our analysis revealed that the successive role-exchange among teachers contributed to inducing constructive interaction, indicating such mechanism of socially constructive interaction needs to be built in the community with the sharing and accumulating technology of the processes of lesson study.

Introduction

Responding to the conference theme of “Building knowledge and sustaining our community”, this paper aims to clarify the structures of successful teacher interaction that supports teachers in changing their views on the relation among lesson, student learning and technology. The COVID-19 pandemic forced many teachers to adopt new technologies into classrooms, even when they lacked appropriate *technological pedagogical content knowledge* (TPACK; Mishra & Koeler, 2006). Such situation tended to yield failures in lessons and invite the them to attribute the failures to the technologies. Even in that situation, it is desirable for teachers to acquire *principled practical knowledge* (Bereiter, 2014), which helps teachers go beyond what is required for solving practical problems such as recovering from failures, but little is known about how they build this kind of knowledge in what mechanism.

Countless studies of professional development indicate that it is important for teachers to experience designing lessons, conducting and reflecting upon student learning repeatedly in a professional community (Fishman, Davis & Chan, 2014). The *lesson study* approach, originated from Japan and known as an effective form of professional development, constitutes practices in which a group of teachers plan lessons, observe live classroom lessons, collect data, and analyze such data (Lewis, 2002). Recently, the technology-mediated lesson study is proposed, which uses the same cycle of lesson study but uses technology resources that allow teachers to interact and learn together when not co-located (3D-RST, 2023). If we combine this type of lesson study with the introduction of technology into classrooms, we would be able to offset or at least reduce disadvantages caused by the technology, since it keeps a record of student interactions for teacher reflection. As the first research question, therefore, we examine if the combination of technology with lesson study would help teachers change their views on lesson and student learning, even after they feel that their lessons have failed.

If this is the case, we then identify its mechanism. The lesson study, we hypothesize, enables *constructive interaction* (Miyake, 1986), through which each participating individual deepens her or his own understanding. The theory of constructive interaction explains that a role exchange between a *task-doer* who proposes solutions to a shared problem and a *monitor* who reflects upon such proposals contributes to deeper understandings. Saito and Miyake (2011) expanded the notion of the two-person constructive interaction into *socially constructive interaction* in two senses: first, the interaction takes place in the situation involving more than three persons, and second, the interaction occurs not only among individuals but also groups. It was observed in their case of science class by third graders that in the whole class discussion, a small group of active members engage in a long-heated discussion as a *task-doing* group, which is *monitored* by the other members. As the second research question, we examine if we could identify the socially constructive interaction in the teacher interaction during lesson study.

In order to answer these two questions, this paper analyzes a case in which three elementary school teachers of a town tried out six lessons of collaborative learning and lesson studies during a five-month period in the year 2020. We first explain a research field, and schemes of collaborative learning and lesson study, the latter of which emphasizes a pre-lesson study to make hypotheses about student learning explicit (Iikubo, Shirouzu & Saito, 2022), and then the board of education (hereafter BOE) of the town, teachers and lessons in the Method section. We analyze the case by tracing not only the lesson that was actually taught but also a pre- and post-lesson study and other lessons to retry that lesson and considering the learning outcomes not only of the main teacher but also of her or his colleagues in order to reveal the socially constructive interaction during lesson studies.

Method

Research field: Consortium for Renovating Education of the Future (CoREF)

As the research field, we focus on a learning sciences project led by the institute, CoREF, initiated by the University of Tokyo in 2010 and taken over by the Nahomi Institute for Learning Sciences from 2021. CoREF has been collaborating with twenty-nine BOEs distributed across Japan, hundreds of schools, and 1,305 teachers with the vision that the teachers as well as the administrative leaders at the schools and BOEs are learning the sciences of learning, not in an abstract form but through implementing them.

CoREF assumes that the learning processes are too diverse and complex for teachers to design lessons, listen to student dialogues and understand their processes without any common *constraints* (Norman, 2013). CoREF built on the theory of constructive interaction (Miyake, 1986), assuming that a key condition for the interaction to take place is sharing the desire to solve a challenging problem. Thus, CoREF introduced an instructional framework, the “Knowledge Constructive Jigsaw” method (hereafter “KCJ”) not only to bring the constructive interaction into classrooms for students but also for teachers to be involved in practical research of how to design lessons and reflect on student learning according to this framework as their shared problem.

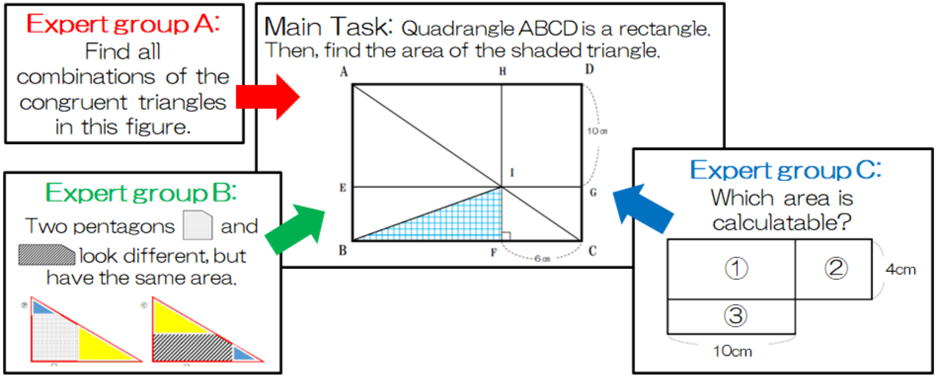
Framework of practices: Knowledge Constructive Jigsaw (KCJ)

The KCJ serves as the instructional framework as well as the stage for the collaborative reflection of teachers. It consists of five learning activities for students: (1) writing an individual answer to the day’s given problem using a rule of thumb, (2) an expert-group activity which allows each student to accumulate some (three in most cases) pieces of knowledge relevant in solving the problem, (3) a jigsaw-type activity where students from different expert groups get together to exchange and integrate the pieces of relevant knowledge and form an answer, (4) a cross talk activity to exchange their ideas for solutions across groups in the entire class, and (5) writing down an individual answer again to the same problem and newer questions (Miyake, 2013).

Figure 1 illustrates a KCJ lesson schematically. The main task is challenging since students need to find the area without knowing exact the lengths of side BF and side IF. Thus, they learn expert materials and integrate pieces of knowledge in the jigsaw activity: find three combinations of the congruent triangles (Expert A), subtract the areas of triangles AEI (AHI) and IFC (IGC) from that of triangle ABC (ADC) to find that the area of rectangle BFIE equals that of rectangle DGIH (Expert B), calculate the area of rectangle DGIH as 60cm^2 (Expert C), apply it back to the rectangle BFIE (Expert B), and divide the area by 2 and get 30cm^2 using the congruence between triangles BFI and BEI (Expert A). The students challenge these kinds of tasks, and teachers assess student learning through the improvement between the two answers to the same question at the beginning and the end of the lesson. They also utilize students’ dialogues during the expert, jigsaw and cross talk activities in order to understand what kind of interaction deepens understanding of each.

Figure 1

Example of the Knowledge Constructive Jigsaw lesson (Math, Grade 5)



Lesson study approach

The KCJ motivates teachers to engage in lesson study; as being only a framework, it requires teachers to design the learning content, that is, the “problem (main task)” and “learning materials (for the expert activity)” and to be proactive in discussing the content prior to the lesson. For this purpose, the project used a mailing list for online discussion on the planning and reporting of KCJ lessons in each subject group across the schools and the BOEs from the initial year 2010. When consulting others, the teachers have a shared understanding of the framework, which aids in making the discussions more efficient and pertinent. In addition, CoREF devised a common format of the teaching plan and the reflection sheet, accompanied by the teaching materials (e.g., worksheets, readings), which makes discussions even smoother. At the end of every fiscal year, CoREF published the annual report which includes sets of plan, material and reflection sheet of tested practices. This resource is not intended to guarantee a success of the lesson to other teachers, but to provide them with chances to retry or modify it to listen to and learn about the dialogues of *their* students. In this way, the community as a whole helps the participating teachers, experienced as well as novice ones, work together to take turns practicing the lesson as the main teacher (task-doer) and observing it (monitor), in order to make constructive interaction occur among teachers.

A remaining issue is what knowledge teachers need to acquire or build through such interactions. CoREF revised the lesson study approach with putting more weight on the pre-lesson study to turn the cycle of lesson study as the *hypothesis-formation and testing cycle* and accumulating its records by the two tools given below.

Hypothesis-testing lesson study

A "hypothesis-testing lesson study" combines hypothesis formation (*how students will learn*) and testing (*how they have learned*), where teachers participate in the following activities: (1) engage in the *simulation activity* of experiencing the lesson as students, anticipating the learning processes of students, and comparing their anticipation (hypothesis) with that of the main teacher, or just listen to it prior to the lesson, (2) observe the same student group together with multiple teachers during the lesson, (3) share and discuss observations, particularly on the learning processes of target students compared with the hypothesis of the main teacher, (4) make recommendations on the lesson design, (5) listen to the self-reflection of the main teacher and (6) write down their findings from the lesson study. As is evident from the activities, the word "hypothesis-testing" is not meant as the generalization, or *high-level abstraction* of causal relationships found between a specific teaching method and its learning outcomes, but the careful anticipation and reflection of *each* practice as in steps 1, 2, 3, 5 and 6 in order to extract hypothetical practice guidelines called "design principles" as in steps 4, 5 and 6 through dialogue among the participants involved. The hypothesis-testing lesson study differs from a typical lesson study in two senses: focusing more on student learning and letting not only the main teacher but also the participants take the role of task-doing of imagining what they would have done based on the reflection upon learning processes.

Learning note

A "Learning Note" system collects and categorizes the emails posted on the discussion list by lesson topic, displays posts with attached files in chronological order, enables searches using keywords and recommends related topics (IIkubo et al., 2022). All the teaching materials published in the annual reports were added to the system with links to the discussions. The members are able to download files to replicate and modify a lesson and read the discussions from where the lesson developed, as if to unpack the accumulated cycles of lesson study in which they have not participated. The system is equipped with a database page of 1,096 teaching materials, a topic page that discusses 1,893 lessons, and three "unit-map pages" which visualizes the structures of the learning units of social sciences, math and science of elementary and middle school and their relation to the KCJ lessons.

Online and hybrid lesson study

Although CoREF adopted various digital technologies as above, the KCJ lessons for students and lesson studies for teachers were mostly conducted via face-to-face. The COVID-19 pandemic, however, interrupted this practice. In Japan, all schools were closed at the end of February until May 14, 2020, but the participating teachers continued to create "undated lesson plans" for a time when their students would come back to school. Moreover, even when they became able to resume collaborative learning in the classrooms, they had to enforce social distancing such as by using a web-conference system. This is somewhat an additive usage of technology, not being situated in their socio-cultural context, which might intervene smooth interactions among students.

On the other hand, such use of an online platform, for example, Zoom's Breakout Rooms for the KCJ group activities enables a safely-distant, convenient lesson study, since other teachers and researchers outside the school and the BOE are able to sneak into the student group when the students engage in online discussions during the expert and jigsaw activities, followed by a post-lesson colloquium directly after the lesson. This style of lesson study is also innovative in the sense that the observers are able to chat online or discuss the points directly with one another during the lesson, which would have been impossible in an on-site observation where the observers would have been positioned right next to the students. We call it *online lesson study* when all the observers participate remotely and *hybrid lesson study* when both online and face-to-face observers are included.

Board of education: Akiota municipal board of education

Akiota municipal BOE participated in the project above from the initial year as one of the most proactive BOEs despite its disadvantaged conditions in terms of education (e.g., low SES, small population) and tried the online collaborative learning and lesson study at an early stage of the COVID-19 pandemic in 2020. The BOE has faced a problem of how to enable teachers to learn from other colleagues and experts outside the town due to its small population. A superintendent set a vision of participation in the CoREF project for the purpose of teacher professional development, while sharing the basic vision of reform for children. Under his leadership, the BOE set a standard requiring each core teacher teach a KCJ lesson at least three times every year. He also secured a budget to send core teachers to the University of Tokyo, not in the way of sending different teachers every year but selected teachers to engage in in-depth learning, who then returned to the town to act as a hub of innovative practices as well as a facilitator of lesson study. In 2020, there were two middle schools and four elementary schools comprising 305 students and 70 teachers. Three elementary schools, Schools TT, TG and KD had combined classes where one teacher taught two grades. Before COVID-19, the BOE provided these schools with chances once per semester to assemble students of the same grade to any one school, enabling a group learning with more members than usual, which served as a basis for the online collaboration.

Lessons in target

Table 1 summarizes the target for analysis: six lessons using the KCJ and their post-lesson studies conducted from June to November 2020. Although Teacher KO had been a teacher for 20 years, Teachers YN and KN had been teachers only for four and five years respectively. KO belonged to the elementary school TT, YN did to School KK, and KN did to School TG. In the fourth trial, students from the three schools assembled on Zoom. Although there were other KCJ lessons than these lessons during this period, we selected six mathematics lessons. The third trial by KN was a replication of the second trial by YN and the fifth trial by YN was a replication with some modification of the fourth trial by KN in turn. The first and sixth lessons were taught by Teacher KO to the same students, which makes an analysis of the development of the teacher and students easier. Lessons and lesson studies were conducted in various ways, drawing many teachers and researchers outside the schools.

Table 1
Summary of six lessons and lesson studies

Trial	Teacher	School/Grade	Unit in math	Lesson	Post-lesson study
1st	KO	TT/ Grades 5, 6	Congruence (Grade 5) Ratio (Grade 6)	Via Zoom (Combined class)	Online (27 teachers and researchers)
2nd	YN	KK/ Grade 4	Concept of "Times"	Via Zoom	Online (25)
3rd	KN	TG/ Grade 4	Concept of "Times"	Face-to-face	-
4th	KN	TG, TT, KD/G4	Round numbers	Via Zoom	Hybrid (33)
5th	YN	KK/ Grade 4	Round numbers	Face-to-face	-
6th	KO	TT/ Grades 5, 6	Area (Grade 5) Basic statics (Grade 6)	Via Zoom (Combined class)	-

Case analysis and results

We first report each case (lesson) in detail by using the data of posts on the mailing list, activity logs of the Learning Note, video recordings of lessons and post-lesson studies and the reflection sheets written by the main teachers, along with anecdotes reported from the BOE. We then present two analytical perspectives with the results of analysis: first, comparison between the interpretation of each lesson by the main teacher directly after the lesson and that after the lesson study, and second, identification of the successive role-exchange among teachers, that is, who made such interpretation and reinterpretation in a series of six lesson studies.

Case: Development of the six lessons

The first trial: "congruence" (grade 5) and "ratio" (grade 6) lessons taught by teacher KO

On June 17th, Teacher KO attempted the online KCJ lesson for the first time in the town, since she did not want to give up collaborative learning despite the pandemic and the pressure to cover mandatory content.

The lesson for six 5th graders was the "congruence" lesson shown in Figure 1, which had been devised in 2014 by a teacher belonging to another BOE. Teacher KO found the material on the Learning Note and considered it as a good review of students' learning about the area of rectangle as well as preparation for learning the area of triangle. She posted her plan and material on the mailing list on 28th April during school closure, followed by seven posts made by researchers SI and MS, a supervisor KM and a teacher KK of the town (see Table 3). The discussion centered on the expected dialogue for the students, especially the dialogue with drawing diagrams on the worksheets to find congruence. Teacher KO revised the material once before the lesson.

The lesson was conducted in fifty minutes. Her students sat down in a school format, apart from each other, and engaged in group discussions using Zoom Breakout Rooms. Since it was the first time most children used Zoom, they repeatedly asked each other "Can you hear me?". The functions of screen sharing and whiteboarding did not work well, preventing them from thinking and explaining while drawing and instead forcing them to communicate with only words. In addition, the class lost the Zoom connection due to the traffic overload, but the children were strong and flexible minded enough to raise mini-whiteboards at hand up to a distant classmate with speaking loudly. Both the two jigsaw groups did not reach a sound explanation at the beginning of the cross talk. Teacher KO invited one group member in front of the blackboard to let her explain a part of the answer, draw two combinations of the congruent triangles (AEI and AHI; IFC and IGC), and calculate the area of rectangle DGIH, which made some students notice the congruence of the two biggest triangles and the "part that had different shapes but the same area" with the rectangle DGIH. Although all students solved near-transfer problems correctly after that lesson, not all students created complete explanations.

Directly after the lesson, Teacher KO regretted, "If it weren't for the problem with the technology!". Twenty-seven observers participated in the online lesson study of one hour that covered the steps 3 to 6 of the hypothesis-testing lesson study. First, they shared and discussed observations of the student group in small groups via Breakout Rooms, and then shared what they had discussed among groups. For example, a representative of one group, Teacher FI reported, "Because one student said, 'The diagram of the main task looks like that in the material of Expert C', I thought they could deepen their understanding along this line of thinking. Right after that, however, he said, 'We can't find the area of rectangle unless we know the vertical length,' and a group eventually started thinking in terms of the length, not the area".

A week after the exchange of these careful observations and ideas for future lessons in the lesson study, KO submitted the reflection sheet to the mailing list, followed by three posts (see Table 3). KO still complained about the technical difficulty in monitoring conversations, but she focused more on the *cognitive difficulty* for children in reinterpreting the same figure from different perspectives, what the Expert B material required (Figure 1). The following discussion seconded her finding, with proposing various scaffolds for such perspective shifting.

Space does not permit us to detail the "ratio" lesson for five 6th graders. Teacher KO found the material on the Learning Note that asked students to decide which juice tasted the same using the concept of ratio. The 6th graders, facing the same technical issues as the 5th graders, solved the problem only by calculation without justification. Similarly, the online lesson study eased KO's feeling of failure with reports on observations of students' struggle to think.

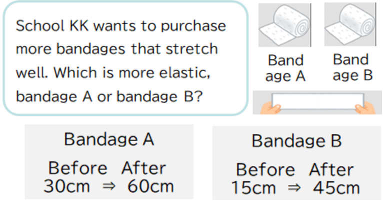
From the second to the third trial: "times" lesson (grade 4) taught by teachers YN and KN

Teacher KO's attempt and the lesson study encouraged other teachers to try the KCJ lessons online. On September15th, Teacher YN tried the online KCJ lesson in a computer lab for seventeen 4th graders. The unit "Times" had been newly introduced into the national curriculum of this grade and intended to connect students' understanding of multiplication and division with the concepts of ratio and proportion. The main task, which Teacher YN had chosen from the textbook, tells what the unit was about, as shown in Figure 2. In order to know the nature (elasticity) of the bandages, his students needed to use not subtraction but division and compare *double* (Bandage A) with *three times* (Bandage B), which was the first time they compared *two ratios*.

Twenty posts on the discussion list prior to the lesson focused mostly on the content of expert materials and the goal of mathematical understanding in this lesson. While Teacher YN revised his plan twice, the materials changed from the mere explanation of the correct solutions to the inquiry into why and when to use subtraction and division, as YN deepened his own understanding of the ratio. The final version expected his students to reach understanding of two points: first, subtraction was suitable when the basic amount for comparison was the same between two objects, but unusable when the basic amounts differ between the two, unless they made them the same, and second, division was applicable when the basic amounts differ using the concept of ratio or "times".

Although this lesson was the last lesson of the unit through which his students should have become proficient in seeing things in terms of *times*, and the students perceptually judged that Bandage B was more elastic, they stuck to the solution of subtraction throughout the lesson. At the end, 15 out of 17 students still wrote this solution, being unable to decide which bandage was "well-stretched" since the difference (30cm) was the same.

Figure 2
Main task for the 2nd and 3rd trials (Math, Grade 4)

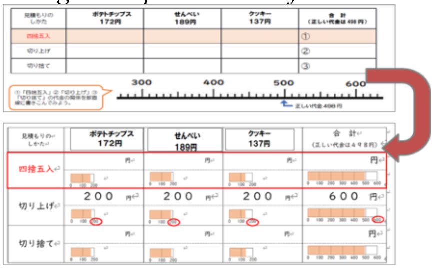


School KK wants to purchase more bandages that stretch well. Which is more elastic, bandage A or bandage B?

Bandage A	Bandage B
Before After 30cm ⇒ 60cm	Before After 15cm ⇒ 45cm

Figure 3

Change in Expert material from the 4th to 5th (Math, Grade 4)



見積もりのしかた	ポテトチップス 172円	せんべい 189円	クッキー 137円	合計（正しい代金は498円）
四捨五入				①
切り上げ				②
切り捨て				③

見積もりのしかた	ポテトチップス 172円	せんべい 189円	クッキー 137円	合計（正しい代金は４９８円）
四捨五入	円	円	円	円
切り上げ	２００ 円	２００ 円	２００ 円	６００ 円
切り捨て	円	円	円	円

In the online post-lesson study, he attributed the failure to the usage of technology, since it actually took longer time than planned to give the students instructions through Zoom. The observers, however, helped him change this interpretation by sharing comments on student learning such as complexity of expert materials and difficulty in understanding the difference between "stretchiness" and "stretched". From these observations, Teacher KN as a group representative proposed, "It would be a good start for the lesson where most of the students know the answer but are unable to fully explain the reasons", the hypothesis of which she tried in her own lesson.

A month later, Teacher YN submitted the reflection sheet to the mailing list with writing, "The *comparison* means subtraction (difference) to the children, and it is still unnatural for them to consider the ratio. …When given the real bandages, they naturally cut out them to make the basic length the same, but did not use that idea when solving the problem on paper", implying that he had learned from the lesson and got closer to student thinking processes.

In September, Teacher KN modified learning activities with the same teaching materials as YN's so that her students were able to grasp the main task more clearly, and tried the lesson at School TG via face-to-face. At the beginning of the lesson, all the students understood that Bandage B was more elastic and all what they have to as the main task was to justify the answer. The lesson worked so well that all groups adopted the solution of division and the idea of ration at their cross talk, Teacher KN countered, "Is it impossible to use subtraction to solve?" and the students replied, "If we make the basic amount the same, we can solve it by subtraction!" Although the post-lesson study was not conducted, Teacher KN posted report and reflection on the mailing list with gratitude to Teacher YN, writing that she would never have confirmed the answer at the beginning of the lesson, if she had missed YN's lesson study. She further proposed an idea of narrowing the content of materials down.

From the fourth to the fifth trial: "round numbers" lesson (grade 4) taught by teachers KN and YN

On October 22nd, Teacher KN taught the online collaborative lesson by assembling eighteen 4th graders from the three schools on Zoom. She found the material for the unit "round numbers" on the Learning Note, which was devised by a principal HH of School KK eight years ago. The main task asked children which rounding was appropriate for particular situation (e.g., to know if ready money is enough for shopping), rounding up, down or off. Teacher KN also used HH's reflection sheet as reference, which reported that the lesson itself had not met HH's expectation, but number lines had greatly improved students' understanding in the next lesson. Upon the discussion on the mailing list with nine posts including Principal HH (see Table 3), the expert material was revised as shown by the upper figure in Figure 3. It included the number line below the table to visually compare the original sum of prices of three items with that of calculated by rounding off, up and down.

As both the teacher and students had adjusted to the various technologies in October, the lesson went smoothly. The hybrid lesson study was conducted simultaneously, permitting the in-person participants to talk with each other about what they observed. For example, they noticed that the students rarely used the number lines provided as hints for thinking, but simply filled in the tables and thought about the answers to the questions. Although all the student groups were able to choose the correct approximation method at the cross talk, sufficient explanations were not shared as to why they chose that method.

In the post-lesson study and the reflection sheet, Teacher KN commented, "Since we listened to key expressions such as 'Rounding up makes estimation safer' and 'It leaves the leeway' during the cross talk, I wanted to solicit such verbalization more by grounding their thoughts on easier materials to understand".

On November 18th, Teacher YN, in turn, tried this lesson via face-to-face. Having learned from KN's lesson, he modified the expert materials as shown by the lower figure in Figure 3 to include the number line (or bar chart) in every item with the guide of how to use (number and red circle in the figure). He also added detailed procedural instructions in case students got lost. As a result, the students managed to achieve his teaching objective. In his reflection sheet, Teacher YN wrote, "New ideas are born more and more after the lesson was over".

The sixth trial: "area" (grade 5) and "basic statics" (grade 6) lessons taught by teacher KO

On November 18th, Teacher KO and her students tried the online collaborative lesson again. The fifth graders attempted to invent a formula of the area of a triangle using their knowledge of the areas of a rectangle and parallelogram; the sixth graders examined two datasets by calculating central values and reading histogram and plot diagrams. Both activities required physical externalization of their thoughts and reinterpretation of perceptual objects, but her students, having got accustomed to Zoom, reached the expected learning outcome. Although the combined class made monitoring of student learning hard since two lessons were proceeding simultaneously, KO switched two headsets attached to the computers fluently in order to listen to the group conversation of different grades. She reported that one student who had little confidence in the face-to-face communication used the whiteboarding tool to let his drawing creep onto the board as if to jump in the conversation without a word.

Analysis of socially constructive interaction among teachers

Table 2 summarizes how the main teachers felt about their lessons and changed their interpretation, especially attribution of the failure, in addition to the information of who participated in the lesson study, or *monitored*.

As seen in Table 2, the main teachers expressed their feelings of failure and frustration about the lesson and/or the technology in the first, second and fourth trials. However, the post-lesson study and writing of the reflection sheet revealed that they put their focus more on student learning and the improvable points in their lessons as in the three trials. The results indicate that, even when the main teacher felt that she or he had failed in teaching the lesson due to problems with the technology, the colleagues gave feedback to change her or his focus from the technology to student learning. The improvement from the first trial (failure) to the sixth trial (success) demonstrates that the same teacher came to cope with the technology for implementing the lesson as she liked.

Table 2 also shows the role exchange pattern. By focusing on the role of the main teacher, we found that the role exchange happened twice between Teachers YN and KN. Teacher YN practiced the second lesson as the main teacher (task-doer), while Teacher KN monitored it and took the role of practicing the modified lesson in the third trial. Teacher KN practiced the fourth lesson in the new unit with making Teacher YN the monitor, who then took the role of task-doer in the fifth trial. As the theory predicted that the monitor grasped the situation from a slightly broader perspective (Miyake, 1986), both Teachers YN and KN reflected more objectively including not only the factor of technology but also that of lesson design when they took the role of monitor in the second and fourth trials. In addition, the two teachers formed an active *task-doing group*, which were *monitored* by Teacher KO who took the role of task-doer first and last. In sum, these results indicate that the teachers learned from others' lesson and lesson study on how students learn, came up with their own hypotheses, or *design principles* (*principled practical knowledge*), and tested them with their own students in their own classroom.

The socially constructive interaction took place at the finer level than the one above. Table 3 represents who posted on the mailing list in what order by their initials (those in italic mean the main teacher at each lesson). The gray cells mean the posts after the lesson including the submission of the reflection sheet. All members were teachers other than two researchers (SI, MS), two managers (FI, HH), and two supervisors (KM, MK).

Table 2

Interpretation, reinterpretation and monitoring of six lessons before and after lesson studies

Trial	Teacher	Lesson	Interpretation after lesson	After lesson study	Monitors
1st	KO	Online	Failed	Reinterpreted	YN/KN
2nd	YN	Online	Failed	Reinterpreted	KN/KO
3rd	KN	F2F	Succeeded	-	-
4th	KN	Online	Failed slightly	Reinterpreted	YN/KO
5th	YN	F2F	Succeeded	-	-
6th	KO	Online	Succeeded	-	-

Table 3

Role-exchange patterns of posts to the mailing list for six lessons

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1st	*KO*	SI	KM	*KO*	MS	KK	*KO*	*KO*	FI	MS	KM											
2nd	*YN*	SI	HH	SI	FI	*YN*	*YN*	KM	SI	FI	*YN*	FI	HH	YS	*YN*	FI	YS	FI	MO	*YN*	*YN*	SI
3rd	*KN*	SI	*KN*	SI																		
4th	*KN*	SI	*KN*	KM	HH	*KN*	KM	KK	HH	MK	FI	*KN*	HH									
5th	*YN*	SI	*YN*	SI	*YN*	SI	*YN*	SI														
6th	*KO*	SI	*KO*	SI	*KO*	SI	*KO*	SI	*KO*	KM	SI											

As seen in Table 3, various members were involved other than the main teacher and researcher, up to eight. In every lesson, Researcher SI responded to the post by the main teacher before anyone else, but the exchange between them (as if they were the task-doing group) invited others to further discussion, especially when the main teacher tried new things (1st, 2nd, 4th trials). In contrast, the discussion of replication and modification did not last long (3rd, 5th trials), as if the lesson study of the original had served as the *pre-lesson study* for these lessons, indicating a succession of lesson design cycles. Space prevents us from detailed content analysis of the posts, but the teachers, whether the lessons were successful or not, almost always found new things, as Teacher KN proposed newer ideas after the third trial and Teacher YN did so after the fifth trial.

Discussion

In a series of six lessons and their accompanying lesson studies, the three teachers first felt failures in their online collaborative lessons and attributed them to the technology such as getting to grips with Zoom, as the use of technology tended to come to the foreground in the COVID-19 pandemic. However, they later changed their views focusing more on student learning and lessons with the help of other colleagues' observations, comments, and the actual process data of student learning, all of which were also enabled by technology. When we compared the discussion before and after the lesson in all trials, the teachers, whether they were main teachers or not, almost always built some pedagogical practical knowledge about student learning to go beyond such practical problems as recovering from the failure. This long-term accumulation of experiences moved the technology from the foreground to the background, letting the teachers think "critically about how to use technology" (Mishra & Koeler, 2006), especially understand the role of technology to share and keep a record of the learning processes.

Our analysis revealed that the successive role-exchange among teachers at both individual and group levels contributed to inducing constructive interaction to change their views. The lesson studies, especially when coupled with the usage of mailing list, Learning Note and hypothesis-testing lesson study, made the hypotheses of the main teachers more explicit to compare them with the observations, preventing them from deviating from the lesson and student learning and causing constructive interaction more effectively. In addition, as five out of the eight lesson materials were taken from the Learning Note system, the teachers appeared to *stand on the shoulders of giants* while learning from the development of each material as if *monitoring* the discussion of the *active task-doing group* across time and space. All these results imply that the sustaining community for teachers' knowledge building needs to build the mechanism of socially constructive interaction in the everyday practice with the sharing and accumulating technology of the processes of lesson study.

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Storytelling “in Theory”: Re-imagining Computational Literacies through the Lenses of Syncretism and Translanguaging

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Abstract: This inquiry is guided by a curiosity around the stories that teachers tell about their students, content, and pedagogical approaches focused on data and computational literacies. We present a form of storytelling *with* theory as we apply theories of syncretism and translanguaging to empirical vignettes about teachers' sensemaking. We also present a form of storytelling *of* theory, drawing on teachers' stories to help us better understand how these theories are related to each other. We bring two teachers' stories into conversation: one from the Writing Data Stories (WDS) project and the other from the Participating in Literacies and Computer Science (PiLa-CS) project. Both projects utilized translanguaging and syncretism in their conceptions and designs, working with teachers to design for expansive forms of data-based and computational literacies.

Introduction

Theories of syncretism and translanguaging highlight that people use diverse language, culture, and literacy practices to make sense of the world (Gutiérrez, 2008; Vogel & García 2017). Translanguaging and syncretic forms of design and pedagogy afford educators ways of leveraging learners' existing sensemaking resources to disrupt power dynamics that mark (or leave invisible) certain forms of sensemaking as unacceptable (or normative). Our past work has explored the potential for syncretism and translanguaging to inform more expansive forms of learning within computing and data science education (Ascenzi-Moreno et al., 2020; Lopez et al., 2021). These domains are often presented as objective, neutral, and only interpretable according to Western logics. Translanguaging and syncretic pedagogies suggest that computing and data can be presented to students as additional literacies that can work alongside and in interaction with students' existing linguistic and cultural practices to help express themselves and understand the world. While our focus has been on bi/multilingual students, these pedagogical approaches are meant to engage a diversity of students who have been marginalized or othered in typical school settings.

In this paper, we analyze data from two teachers' engagements with these theories and pedagogies, as we heard in their storytelling reasoning about disruption, improvisation, and attention to students' culture and language. We contend that even as teachers leverage power to disrupt boundaries, the work of equity does not end there. Along with inviting student voice, culture and language, re-listening helps to negotiate trust and power and helps inform how knowledge and language practices become unmarked. Additionally, we also interrogate how teachers' stories attend to student language and culture and contribute to theoretical and pedagogical understandings of syncretism and translanguaging in computing education. Undergirding our methods and analysis is an interest in storytelling. As learning scientists, we seek to expand accounts of learning that consider historicity, social practices, and culture, and to do so in humanizing ways. Storytelling affords creative ways to share nuanced and complex meaning and emphasizes the salience of literacies in STEM spaces. As researchers, we work to co-construct stories that help inform understandings of the nature of learning and the power of equity-oriented pedagogy. To do so, we focus on pedagogical design, such as the reorganization of academic and everyday literacies, to explore teacher sensemaking.

Theoretical framework: Theories as story

We bring theories of syncretic and translanguaging into conversation with each other in a rather syncretic way, to highlight points of alignment and tensions. Rooted in theorizing the experiences of multilingual and nondominant learners, both theories emphasize how language and culture are fluidly negotiated in meaning making.

Syncretic theories of literacy originated in the field of linguistic anthropology to examine the non-deterministic relationship between language, culture and literacy and debunk long held beliefs about multiculturalism such as language indicates culture, and people can only inhabit one culture at a time (Duranti & Ochs, 1997). These scholars demonstrated that literacy practices are complex, socially situated, and draw on a multiplicity of language and cultural practices: "when different cultural systems meet, one rarely simply replaces the other," (p. 173). In conversation with Duranti and Ochs, Gutiérrez was inspired by the ways language-minoritized speakers drew on a multiplicity of powerful literacies and extended these ideas to contend with critical perspectives of learning (personal communication). She felt compelled to show the expansiveness of *syncretism*, the bringing together of two or more ostensibly contradictory or distinct domains, in opposition to Vygotsky's (1987) use of syncretic as the most underdeveloped form of learning. Drawing on the multidisciplinary history of syncretism, Gutiérrez demonstrated the rigor and generativity in migrant youths' literacy practices, actively resisting deficit narratives that these ways of knowing were in any way underdeveloped (2014).

Consistent with the boundary-defying orientation of syncretic theories, translanguaging theory describes how language use defies social categorizations of languages (Otheguy, García, & Reid, 2015). *Translanguaging* (Vogel & García 2017) demonstrates that named languages (e.g., "Arabic", "academic" or "vernacular") are social and political constructs, not cognitive ones. As one of the most notable translanguaging scholars in the US context, García developed her conceptualizations of translanguaging from the work of Welsh educationalist Cen Williams who developed the term to describe the use of Welsh and English in the same school lesson to counter colonial monolingual efforts to erase Welsh (Lewis, Jones, & Baker, 2012). García's work on translanguaging in the US was influenced by the context she was researching in, engaging in descriptive inquiry in bilingual classrooms with bilingual teachers (García & Traugh, 2002). Descriptive inquiry with teachers emphasized understanding students' sensemaking in relation to their friends, adults, and various contexts, looking at the student as a full person to understand their work. This humanizing research in conversation with the language politics highlighted in the Welsh origins of translanguaging laid the groundwork for García's work on translanguaging theory in the US context, focusing on the expansiveness and fluidity of bi/multilingual speakers' language practices.

The pedagogies derived from these theoretical perspectives foreground how teachers can disrupt barriers between learners' lived experiences in and outside of classrooms. Syncretic pedagogies (Gutiérrez, 2008) recognize that hierarchies between academic and everyday knowledge are also socially and politically constructed and resist this hierarchy by emphasizing and privileging hybridized forms of knowledge that emerge. Translanguaging pedagogies resist the social construction of named languages by encouraging learners to openly leverage their full linguistic repertoires. These pedagogies encourage students to use their full linguistic and knowledge repertoires, developed across home and school contexts toward more equitable and consequential learning (Radke et al., 2022).

Methods

Storytelling across contexts

This paper brings together stories about teachers across two projects–WDS and PiLa-CS–that both worked with teachers to support bi/multilingual students' learning in computing related subjects. Partner teachers were encouraged to design learning environments that supported students to leverage everyday language and knowledge repertoires for expression. Our projects took up constructs from translanguaging and syncretism as guiding pedagogical principles, to socioculturally situate computing as literacies within the multiplicities of literacy repertoires learners can leverage in their expression. These projects illustrate the application of these theories in relatively new domains (computing) and contexts (formal yet interdisciplinary school settings). Situating computing as literacy helps to foreground the ideologies and power dynamics that shape these means of expression, which is often hidden in a depiction of computing practices as objective logics to acquire. As expansive theories of learning and language, syncretism and translanguaging challenge these a priori conclusions.

WDS and PiLa-CS have both helped teachers develop projects where computing is integrated as an expressive and sensemaking resource within other disciplines (e.g., math, language arts, and science) through the facilitation of online summertime teacher learning communities (TLCs). In both TLCs, teachers were encouraged to incorporate authentic discourses and personally relevant programming and data science tasks for their students. WDS's TLC took place in summer 2020 and focused on introducing teachers to the data analysis tool CODAP and reviewing model curriculum units concerning nutrition and climate using large-scale data sets. PiLa-CS's TLC occurred in summer 2021 and focused on sharing an approach to designing which encouraged teachers to juxtapose literacies students might have developed at home or in their communities, with literacies from disciplines and computing communities as they designed a unit for the upcoming school year. Our analysis involves sharing stories from two focal teachers across these projects: Calli and Sandy (pseudonyms). Both teachers participated in a summer TLC and then extended their work into the following school year by implementing new units they designed. Calli extended the nutrition unit in CODAP from the WDS TLC to a new unit about candy advertising and Sandy implemented a unit she designed around the ethics of hacking that she initially designed during the PiLa-CS TLC.

Data collection and analysis

Data collected from both projects were used for this analysis including 1) observations and recordings from both TLCs, 2) pre- and post-interviews with Calli and Sandy, 3) artifacts teachers made in planning their lesson, and 4) student work from Calli's lesson. We used this data to develop empirical vignettes (Gutiérrez et al., 2019) demonstrating how teachers reflected on their pedagogical designs and learnings. This method foregrounds the power of storytelling as a form of analysis that broadens how we talk about data and computational literacies.

Authors 2 and 1, postdocs on WDS and PiLa-CS respectively, met weekly over an 8-month period to develop these empirical vignettes about the focal teachers. The initial vignettes consisted of three parts: (1) an introductory story about each teacher, (2) analysis of what each story revealed about syncretism, and (3) translanguaging. The aim in empirical storytelling was not to evaluate whether or not teachers "got" these theoretical concepts as evidenced in their narrative. Rather, in "sister team meetings," the authors identified translanguaging and syncretic elements that surfaced in (1) how these focal teachers talked about the design of their lessons (2) what teachers shared about implementing these lessons, and (3) what clues these teachers' pedagogies provide us about how these theoretical traditions are related to each other. The history of these theoretical traditions became a salient part of this analysis, supported especially by the intergenerational analysis with senior PIs on the projects and foregrounding the human and historical contexts of theory building that often remain hidden in scholarly writing.

Findings: Stories with theory

Vignette 1: Calli, data analysis, & lived experience as data

Calli was a middle school STEM teacher who identified as Mexican-American and bilingual (Spanish and English). She participated in the TLC with WDS with the goal of having her students "look at data meaningfully and feel comfortable using this tool [CODAP]." For Calli, issues of racial justice and equity were integral to teaching STEM; she described science as "a social endeavor that involves institutions with systemic inequities and historical racism" and reported that she "[has] felt uncomfortable with how little culture has been integrated into science education." She framed data literacy as "so important for [students'] critical thinking and also advocating for themselves and their community." Calli took up WDS's use of CODAP, data visualizations, and nutrition-related content to design a unit for her students around a seasonal topic, Halloween, so they could analyze *and* construct a data set. Her storytelling–across both her learning design and the implementation–lifts up her sensemaking about data literacy.

Calli's storytelling about the learning design

Drawing from her experience in the TLC, Calli designed a Candy Ad unit, which she taught in the fall of 2020. She wanted to make ideas from the TLC "more festive" and used a Halloween theme. In the unit, students discussed their favorite candies, how they were introduced to them, and how professional marketing teams use focus groups to sell products. At the time, all instruction was online and Calli described the unit as an "opportunity for students to connect with others" including their own cohort and people in their households. These connections traversed boundaries of school and home in a time of remote learning and social distancing.

Along the same vein of boundary-crossing, Calli invited students' lives as data into their practices of data collection. In her "hook" or "launch" activities that introduce new topics, questions, or themes, Calli "[collected] data from students' own experiences." She stated that "no matter who you are, you're bringing in knowledge, you're bringing in your own data and connecting that to new understandings," which she believed can "support student knowledge and self-esteem in STEM areas." Calli echoed this support in a later interview:

> The reason why I've stayed engaged is because of the actual name of the project [...] and also the the mission in a sense of the project, which is–which I interpreted as teaching our students to not–to build confidence in reading data, becoming data analysts in themselves, and being becoming familiar with each step, of developing an inquiry question, figuring out a way to collect data that can possibly answer it, revising if it's if it's clunky, and then being thoughtful when making conclusions about it.

Calli repeatedly emphasized students' agency in the practice of data literacy. For example, her language around "confidence" and "becoming data analysts themselves" was also reflected in her desire for students to "be researchers themselves and they're not passive about it."

The Candy Ad unit allowed students to engage in disciplinary practices of data literacy for statistical inquiry (Wild & Pfannkuch, 1999). Students were asked to identify candy that would sell best in their local context. Students' planning included developing questions for focus groups of eighth grade peers, friends, and family. Then, using Google Forms, students designed a survey to generate data. For analysis, teachers imported the Google form data (.csv file) into CODAP for students to visualize and interpret the survey results. Students then shared observations and inferences as evidence for their claims and wrote a Claim-Evidence-Reason (CER) statement "explaining why they think their candy would sell successfully at a local level based on their CODAP analysis." Calli designed this unit to counter "what usually happens" in STEM classrooms, where students use "expert-collected data from a professional." Instead, Calli "wanted them to go through the process of being a researcher…being someone out in the field collecting information and collecting input."

Language emerged as a theme in Calli's storytelling about her design. In the TLC, Calli critiqued her school's "focus on English as the only way to communicate information in our classroom" and emphasis on English monolingualism to prepare students for high-stakes testing. In contrast, she argued that "disruption" can happen "at the classroom level when you allow students to reflect and share their knowledge in other languages, or you know discourses, with each other in other languages." For her, this practice "support[s] learning even if it's not in English." She contrasted her expansive approach to language with less productive approaches. Calli reflected:

> Providing opportunities for either more casual discourse, or discourse in their native language, I think does the opposite of limiting, right? It opens up opportunities for them to describe things that maybe they don't have access to in …academic language …yet. So instead of saying "well if you're not going to communicate in this way, I'm not interested in hearing it." Rather than that, we're going to support that skill, but at the same time provide you opportunities to share those observations that maybe you're not ready to, or not as accessible to you…without shutting it down.

She reflected on her students' language practices both in and out of the classroom, emphasizing that students have wide repertoires of language that they should be allowed to access. She affirmed that students translanguage all the time, and that limiting their communicative repertoires amounts to "shutting down" their ideas. These reflections connected to the focus on audience in her design, which she found important for data literacy: "that's such a huge component–who's your audience and how are you getting them to buy in on your claim for this dataset?" Students shared a link to the survey with family and friends via social media or email. However, if the survey was "not in the language that they read," teachers offered strategies to "get around that" like administering the survey "interview style" in a different language, then manually "fill[ing] out the form to submit" it to the class dataset.

Calli's storytelling about the implementation

In her implementation, Calli found that students did not use the data in their ads in the way she anticipated, identifying the candy most people enjoyed and advertising for it. Instead, Calli found three distinct approaches:

> Number one we had students who said, "Hey I'm going to just go off the data. What the data says is the most popular, I'm going to go with that." The second group of students was like, "Everyone is not in their right mind. They don't know what's good. I'm just gonna go with what I know everyone actually wants and not our focus group. Our focus group is wack, that data is wack. I'm not going to go with it." And then the third group were the ones that were like "Yeah, this and that, but I just want to be a creative mind, and I wanted to do what I want." So they were funky. You know, the funky creative minds are like, "I want to do something weird. I want to do something unique."

Calli acknowledged that "sometimes there was a contradiction with [students'] C-E-R paragraphs and their ads." Rather than evaluating their work as wrong or unsuccessful, she affirmed her students' sensemaking: "They're like, 'okay well if I were to go off the data, this is what I would say, but if you give me the opportunity and say it's whatever I want, I might not go that route.'" Students drew different conclusions and used different rationales to make sense of their data across assignments. While their C-E-R paragraphs might have taken on a more traditional "majority rules" logic, students took up the ad space more expansively by integrating scientific practices of data literacy (data generation, planning, analysis/trends) with their everyday knowledge of candy and their audience. Calli designed for students' lived experience to be used in data collection and came to see how students leveraged these experiences in their analyses. In doing so, she ruptured boundaries between the scientific and everyday by positioning students' cultural repertoires and everyday knowledge as generative for data-related sensemaking.

Vignette 2: Sandy, hacking, & centering student language

Sandy was a white, monolingual English speaker working as a librarian in an elementary school with predominantly bi/multilingual Asian and Latinx students. As a librarian Sandy saw each student at her school once a week for a library and technology class and joined PiLa-CS to learn more about translanguaging because, “I don’t really understand it yet. But I do work with, with a large enough population, and I can see it being very helpful for them.” In the TLC, Sandy co-designed a unit on hacking for 3-5th grade students that she implemented that fall. In the unit, students developed a hacker’s code of ethics for their classroom community. This syncretic text put students’ hacking literacies into conversation with those of computer scientists. Sandy’s pedagogical reasoning and her students’ engagement illuminates generative tensions in centering student language and ideas in academic spaces.

Sandy’s storytelling about the learning design

During the PiLa-CS TLC, Sandy and her fellow teachers were asked to design curricula that incorporated literacies from computer science (CS), the teacher’s disciplinary home (e.g., library), and students’ home communities. Sandy grounded her unit in students’ home literacies that had frequently been brought up in her class. Sandy shared how her idea for a unit on hacking came from students’ contributions in her class.

> [This] is the inspiration of the conversations my students were having that made me want to design this unit. Basically, every time I, if I mirror my screen onto their devices or if we're remixing a project in scratch and I change something that is that they think they owned and created and it's safe, and then I go in and change it, it's always a kind of, it turns into was a huge disruptive conversation of like, “Oh, you’re hacking me.” “Why are you doing that?” “How are you doing that?” And then it turns into how maybe their family members got hacked in there, in the game play Roblox. This is about 3rd to 5th grade where these conversations are happening. So, since they happen so consistently, with every lesson almost that we do, it almost always comes up, I thought it would be a good idea to design a unit that really gets into, “What is hacking? How does it look in our community and do you think it belongs in our classroom?” So that students can really get a realistic view of what they're talking about. The PiLa-CS approach to designing the unit really helped me to try and address all layers of the student learning experience. So having their initial interest in this topic and then bringing it into the disciplines of the classroom was a very, a very gratifying way to design the unit for them because I feel like they're going to be engaged right from, right from the beginning. It feels like they’re designing the lesson instead of me.

Addressing hacking was a deliberate and consequential design choice. Sandy had previously positioned students’ comments about hacking as ancillary to the focus in her class, but they became the content focus for the unit. Thus, she centered language and ideas students regularly brought into her classroom that had previously remained at the margins. Sandy shifted from positioning students’ conversations as “a huge disruption” to seeing them as productive to the point of commenting “it’s like they’re designing the lesson for me.” She quickly and confidently identified regularity in students' comments about hacking, sharing numerous examples like, “‘Oh you’re hacking me.’ ‘Why are you doing that?’ ‘How are you doing that?’” These comments are examples of students translanguaging, using home language practices to make sense of classroom activity. When Sandy took control of their screens, it reminded them of being hacked, hacking someone, or observing hacking in a video game. In their comments students raised concerns about hacking and issues of control over digital spaces. Sandy previously saw these utterances as unrelated to her class, which is why she felt the need to control students’ screens to focus them on the content at hand.

Sandy’s unit engaged students in the question “What is hacking?” through a collective defining process. In doing so, she elevated her students’ knowledge and ideas about hacking. By asking “How does [hacking] look in our community and do you think it belongs in our classroom?” she recognized that students believed that hacking was happening in their classroom and had strong beliefs about whether it belonged. Since the topic had previously been dismissed, students had not been given a chance to shape how hacking operated in their classroom. Sandy moved from observing translanguaging in her classroom to implementing pedagogy that supported translanguaging. By centering the unit on a topic brought to her attention by student language practices, Sandy signaled to her students that their full language repertoires were welcomed and their ideas about CS were consequential.

Sandy’s storytelling about the implementation

When Sandy implemented this unit in her classroom, however, her expectation for having students “engaged right from, from the very beginning” did not match the ease of feeling like they were “designing the lesson instead of me.” In fact, during Sandy’s follow up interview a year later, she shared that there was some initial push back from her students when she first wrote the word “hacker” on the board:

> Even the word hacking. When I first put the word hacker on the board, they thought they were in trouble. They thought I was gonna be trying to say “someone hacked somebody's iLearn account and now you're in a lot of trouble.” Like but they would kind of timidly uh approaching the idea, because they also, it was like, “I don't really want her to know what I know, because I feel like what I know is gonna get me in trouble,” you know, like, “I don't want to get in trouble for hacking someone else's account because I thought it was funny.” Or, “I don't want to get in trouble for knowing what hacking is when I change the code to this game, because then they're not going to let me play it anymore.” So, it kind of, it took a minute.

Sandy saw that students had knowledge of hacking, but initially they did not want to share it in class for fear of getting in trouble. They were hesitant to engage with the initial goals of the lesson: to build off of students’ knowledge to develop a hacker’s code of ethics for their classroom community. While Sandy made the syncretic move to attend to her students’ translanguaging practices and center their thinking about hacking in an academic space, her students did not yet trust that they could engage openly and honestly.

Sandy worked to gain students' trust in multiple ways. One way was asking students questions that made hacking the object of study and analysis rather than “spotlight them” or draw attention to their previous hacking activity: “I wouldn't use the word ‘you’ I wouldn't say. ‘What did you do?’ [...] I would say, Ah, ‘Based off of the video, What does hacking mean?’” Sandy described taking the pressure off students to reveal things about their experiences with hacking that they were uncomfortable sharing by asking them to reason about other people’s hacking practices. Focusing on what other people did and what her students might do in the future kept the responsibility off of youth in the present and only put it on them for speculative, future actions. This finding highlights tensions that can arise with the implementation of syncretic pedagogy. Students may contest how and what is a viable and safe unit of analysis in a classroom. Putting different literacies in conversation together can bring up unanticipated conflict and illuminate other assumed relations necessary to engage in this work, like trust.

Based on these interactions, Sandy identified an emergent goal for this unit: to create a “safe environment.” When asked what made the unit feel successful, Sandy shared, “bringing the idea of hacking that they saw as a bad thing, and, and teaching them how to talk about it and learn about it in a safe way, I think was a success overall.” Getting past students’ hesitancy to engage was an important outcome for Sandy. She started by noticing students' peripheral translanguaging practices in her classroom as students called her out for hacking them. This led her to leverage syncretic literacies in her class by bringing students’ home hacking practices into conversation with computer scientists’ hacking practices. Thus, in response to her students *calling her out* for hacking them, she *called them in* to share what they knew. As the unit progressed, she shifted the spotlight from her students’ hacking experiences to developing (previously taken-for-granted) trust with her students.

Conclusion & discussion

How these vignettes help build stories with theory

We share these vignettes because we want to learn about equity-oriented pedagogy from our focal teachers. By identifying how theoretical histories of syncretism and translanguaging were reflected in how these teachers talked about their pedagogical designs and classroom implementations we saw 1) teachers disrupt barriers between language practices inside and outside of school; and 2) tensions arise that teachers had to negotiate when students were given new opportunities to openly translanguage while developing computational literacies.

In both cases, while teachers’ syncretic moves afforded pedagogical opportunities, they also presented pedagogical tensions. Both teachers’ stories emphasize a goal of lessening barriers between learners’ lived experiences inside and outside of schools (everyday and academic). Calli’s data literacy design positioned student experience as an important source of data alongside normative constructions of what constitutes data. It brought together scientific practices (survey design, CODAP analysis, statistical rendering) with the everyday (family talk, candy, culture). Rather than engaging in data literacy as limited to pre-determined datasets shared by the teacher, students were invited to leverage their own cultural experiences, communities of participation, and voice to practice statistical analysis. Course activities and ideas were organized around student interests and experiences, which led to students incorporating their values and language practices as part of their analytic process. Sandy, on the other hand, engaged student language and home practices as a way to expand learning about computational literacies. Rather than limiting what might be seen as disruptive behavior for students, Sandy engaged their talk about “hacking” to lead to enriched learning experiences that engaged new relevant disciplinary content.

Both teachers’ stories also highlighted tensions that emerge when boundaries between academic and everyday knowledge and literacies were disrupted. In Calli's case, a tension arose as students' sensemaking with data did not appear to align with canonical forms of reasoning in the leading discipline (statistics). For example, disciplinary ways of understanding might encourage a "majority rules" approach to determining the "best" candy to advertise for, yet students' sensemaking drew upon other resources that might not have been captured in the data, namely their own experiences. They repositioned data beyond what existed in the dataset they generated, instead using it as a tool for imagining what could be (i.e., their original candies and successful advertisements for an audience). As Calli made sense of what seemed to be a disconnect between students' CER paragraphs and their candy ads, she validated students' moves as productive expressions of student skills, knowledge, and values, and not "incorrect" data reasoning.

Sandy faced an unexpected tension as she invited her students' language practices and interests into the lesson. When the topic of hacking was brought from the margins to the center, students hesitated to respond to this reorganization drawing from their understanding of boundaries between what was "okay" and "not okay." Hacking was not something that had been sanctioned as discussable in school previously, and students did not immediately welcome or trust breaking that boundary. Sandy approached this tension improvisationally, shifting from asking students to share about their own experiences with hacking to what they thought about others' hacking practices. What emerged was the creation of a new syncretic artifact–a Hacker's code of ethics–that focused on ethical considerations for students' future–not past–actions. We learned from these cases that designing and implementing equity-oriented pedagogy that disrupts disciplinary, academic, and linguistic boundaries can generate new tensions when teachers work to unmark certain ways of knowing and speaking. These tensions can generate opportunities to expand what and how we reason about disciplinary concepts. In the context of computational literacies, these stories present compelling examples of how to broaden what we mean by computational literacies (e.g., hacking) and towards what ends we use them (e.g., imagining new possibilities).

How these vignettes help build stories of theory

Inasmuch as these vignettes represent how we build stories *with* theory, they have also been insightful in constructing stories *of* theories of syncretism and translanguaging. These two lineages, each with their own history, are rooted in descriptions of fluid ways of being, knowing, and drawing on repertoires of language central to sensemaking. Yet humans' semiotic resources are also marked by social structures that may impede their full exercise. In classrooms, including monolingual ones, students' ability to foreground a full range of communicative practices is governed by unique boundaries of power and appropriateness. Similarly, while students draw on wide knowledge and experience to make sense of content and information in classrooms, certain forms of knowledge are routinely more welcome than others. Teachers leverage power to invite or reject students' cultural repertoires as aligned with their conceptions of the boundaries of relevant knowledge. The vignettes presented in this paper offer insight into teachers' syncretic pedagogical moves as related to translanguaging–a practice that is always happening but not always marked, sometimes more hidden, sometimes more visible.

Resonant with the lineages of this work, we also position teachers as theorists of their own practice, and reflect on how their stories add to the stories of translanguaging and syncretism. Both Gutiérrez (2008) and García (2002) worked closely with teachers as they began to theorize about syncretism and translanguaging respectively, collaborating with teachers as co-theorists to better understand and reframe bi/multilingual learners language practices as a generative asset for learning and not a deficit. Gutiérrez (2008) demonstrated how teachers brought students' language into a *third space*, where the official classroom discourse and unofficial discourses in the classroom met. Further, García and colleagues' (2002) descriptive inquiry enabled teachers to see possibilities for engaging students' use of unofficial discourses, which would create what we see as third spaces. These theoretical beginnings situated both teachers and students as initiating moves to create third spaces in classrooms where multiple ways of knowing, being, and (trans)languaging could intersect.

The two vignettes shared in this paper show that there are different ways of leveraging teacher power to co-create a syncretic third space (Gutiérrez, 2008) through practices of re-listening. Classrooms represent spaces where sanctioned language and knowledge are implicitly unmarked as norms. However, as illustrated by our two focal teachers, syncretic pedagogical moves can help unmark unsanctioned ways of knowing and doing. Both stories demonstrate that unmarking language and knowledge practices can be an iterative process that is negotiated with students as they accept or resist these invitations and involve teachers' re-listening as an important response. For example, Calli's candy ad unit design emphasized the importance of students drawing on their experiences and relationships in the construction of a data set for analysis. This design reflected a conjecture that opening up sensemaking resources in the construction of a data set would support students in leveraging traditional methods of data analysis. However, Calli noted that some of her students' conclusions countered traditional forms of CER because they drew on their lives and values as data outside of the dataset they had constructed. Not all students decided "what the data says is the most popular I'm going to go with that [in my ad]." In this case, unmarking the ways students might construct data resulted in a push for Calli to unmark their data analysis practices as well. Students extended Calli's pedagogical offering, widening the third space she invited them into in her classroom, and in validating their analysis she in turn re-listened to what students had to say about valid data-analysis practices. In contrast, Sandy's invitation to bring in students discourses around hacking, to unmark their language practices about a topic of interest they shared, was not initially reciprocated by her students. Sandy's story demonstrates how theories of syncretic pedagogy involve more than just invitations, but also require re-listening as a humanizing effort to reframe students' computational literacy practices. Re-listening involves identifying topical connections within students' discourse, and also recognizing ideological implications of language and concepts and how those might intersect with student engagement. In inviting hacking as a valid topic, Sandy attempted to unmark what could be talked about, but students' initial responses revealed that unmarking knowledge and practices is a process to negotiate *with* students. The act of naming alone does not mean students will publicly engage. Instead, relational trust needs to be built between students and teachers because language and concepts are powered and politicized.

Ultimately, the analysis presented across our two empirical vignettes forefronts how opportunities to support syncretism and translanguaging in classrooms can be taken up as humanizing pedagogies. This occurred in moments when teachers unmarked previously irrelevant or unwanted language and knowledge practices and attended to how students responded to these invitations by-relistening to student contributions. Bringing these stories and theories together help us understand how teachers' work to disrupt language and cultural boundaries in service of expansive student sensemaking can create new forms of disciplinary practices, in this case computational literacy practices, when negotiated with students' acceptance and resistance to such invitations.

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Refiguring the Positioning Through Tabletop Game Redesign: What it Means to Engage in Culturally-Sustaining Learning as a Family

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Abstract: In this paper, we present our approach to culturally sustaining learning, enabling the contribution of non-dominant voices and cultural resources to collective learning activities. In our study, we proposed activities for families to redesign tabletop games with ideas, categories, and processes that reflect their interests and culture on their own time during the global pandemic. We collected data through online video communications and families sharing their own artifacts (e.g., photos, videos, and blogs). We describe how families expressed what matters to their members individually and collectively and how this was intertwined with shifting family members' relational positions.

I don't think it was as easy to relate to what was going through the minds of each creator of the game pieces…all of us had probably very different perspectives. Even within a family unit, it is probably really hard to even get on the same page because sometimes I am like, I don't get it, what is going on?
The mother of Family 1, during the final interview

Introduction

The above excerpt was taken from the final online interview with a Canadian family (the parents and both daughters have Chinese ethnic background) who redesigned a tabletop game together. The mother shared her experience of recognising and reconciling the diverse perspectives within their family. In conceptualising this work, we were concerned about how Canada's public institutions perpetuate dominant cultures' deficit perspectives toward minority languages and cultures, despite being a pluralistic society with over 200 spoken languages and cultural origins. We introduced tabletop game redesign to family learning contexts to harness how tabletop games are played across generations (e.g., *Mancala* in Africa) and reflect cultures. Previous research has shown that game play and design position learners as individuals who engage creatively and critically with disciplinary ideas. In exploring culturally sustaining pedagogy of pursuing linguistic and cultural pluralism (Paris, 2012), we sought to address the deficit perspectives of seeing difference as incorrect and focusing on fixing what is deemed as problematic by exploring culturally sustaining pedagogy supportive of linguistic and cultural pluralism (Paris, 2012). When we moved the learning setting to the family during the global pandemic, we learned that each family not only explored their cultures, but also learned to accept the differences within the family. In this paper, we discuss how redesigning tabletop games (i.e., games with boards, cards or other physical objects) can help participants reposition generational differences, practices, and ideas as resources for their social learning (Ladson-Billings, 1995) as a family, sustaining their varying interests and perspectives. In what follows we introduce the perspectives that we drew on in conceptualising and enacting this work and discuss findings that contribute to advancing our understanding of culturally sustaining learning in diverse learning contexts.

Perspectives on tabletop games and culturally sustaining learning

A tabletop game is a unique design form that deeply engages users as part of its underlying structure to enable game play. Players must make sense of the rules and create mental models of possible moves and dynamics in relation to game elements and other players in the social space of play (Pearce, 2006). Simultaneously, players become part of the game system, where their personalities and ways of doing (i.e., negotiating the play) come into play (Gatti Junior et al., 2020). Playing tabletop games, players have different experiences each time they play and with different playmates or opponents. Crist et al. (2016) similarly pointed out how tabletop games provide an intimate space of play that can bring people from different ethnic and social and economic backgrounds in contact and offer them new opportunities for engagement and relationship building. We discuss how the literature on tabletop games and their educational significance demonstrates the potential for culturally sustaining learning.

Sustaining and evolving tabletop games

Tabletop games are cultural artifacts that reflect values, beliefs, and interests in their system of rules and aesthetic elements. The ancient game of *Senet*, for example, reflects the value of divination, while players have "a metaphoric race against fate" (Flanagan, 2009, p. 68). The Chinese game *Go* (i.e., its system of layout and unfolding situations) is influenced by cultural norms and beliefs and may be connected to some divinatory practices of using black and white stones for predicting mystical events (Flanagan, 2009). Among other examples that Flanagan (2009) shared, many Japanese games reflected contemporary interests such as educating about the world through travel and contemporary poetry (e.g., *100 Poems by 100 Poets*). From another viewpoint, Crist et al. (2016) described how board games were used to facilitate interactions "across kinship, ethnic and socio-economic boundaries" (p.181), such as for traders to develop amity in Africa and South Asia allowing "individuals from distant regions and cultural backgrounds to interact across real and imagined boundaries" (p. 191). They argued that board games were historically used as "social lubricants" across cultures and were adopted into varying societies by being decorated and reimagined appropriately to their cultures (Crist et al., 2016).

The *Landlord's Game*, created by the activist Elizabeth Magie in the 1900s, is a notable example of how board games reflect their context and convey designers' interests. This game intended to teach the economic consequences of the rent system prevalent at the time, which perpetuated a vicious cycle of enriching the property owners, and to promote the idea of an alternative tax system (i.e., "Single Tax" theory by Henry George (1879), an anti-monopoly economist). Magie's *Landlord's Game* was about an even market competition and the creation of a just society (i.e., against monopoly). Ironically, the game evolved into the board game *Monopoly* by Parker Brothers, which gained enormous success without acknowledging Magie's contribution (Flanagan, 2009). These examples highlight that tabletop games were designed to express and record values and ideas (modeling, altering, or proposing the rules of the society), used to mediate activities (social interactions, disseminate new ideas), and redesigned and evolved to reflect different (sometimes opposing) values and purposes.

The above examples indicate that some aspects of the games communicated across different contexts. Danilovic and de Voogt (2021) saw a formal system, i.e., "coherent (logical) structure of the game" (p. 509), as the reason for these games' dispersion across time and space. The coherent structure is somehow noticed and understood regardless of the players' cultures and provides a common ground to understand the game, participate in play, and interact with the game and other players. When games enter the new context of people with different backgrounds and ideas, players imagine new narratives and rules, and give new meanings to the events and interactions through play (Brown & Waterhouse-Watson, 2016). Scholars indeed saw that game play or similarly playful actions create a space that encourages players or actors to seek alternative interactions, ideas and norms, and imagine and negotiate new possibilities. Such space might be called a liminal space (Crist et al., 2016), Third space (Gutierrez, 2008), or boundary space (Akkerman & Bakker, 2011). The spread of tabletop games across cultures and regions also demonstrates how such boundary-crossing spaces facilitated the redesigns of games, i.e., creating new possibilities. de Voogt et al. (2013) similarly observed that "crossing socio-cultural boundaries has positive effects on rates of innovation, likely as people reinterpret (i.e., translate) rules or other parts of the game from their own local and cultural perspectives" (p. 1728) from their historical review.

Culturally sustaining learning and tabletop game redesign

The scholars of culturally sustaining pedagogy view learning as critically enriching strengths rather than replacing deficits, moving away from aligning with linguistic and cultural hegemony (Lee & Walsh, 2017). In our view, culturally sustaining learning repositions diverse learners as catalysts for interdependence and their cultural and linguistic differences as the basis for understanding the world and creating novel and pluralistic outcomes (S. J. Lee & Walsh, 2017; Paris, 2012; Paris & Alim, 2014; Joyce, 2017). Culturally sustaining learning should involve critical consciousness to identify social structures and positions as well as biases and oppressive constructions against non-dominant groups, and efforts to decenter from the norms of the dominant group (Ladson-Billings, 1995; Paris & Alim, 2014). Repositioning and genuine transformation of positions happen through discursive practices and deepening social relations (Davies & Harre, 1990; Joyce, 2017; Ladson-Billings, 1995).

Our argument for tabletop game redesign as culturally sustaining learning is supported by the cultural-historical significance of tabletop games and how their evolution reflects pluralist outcomes as described above. The evolution of tabletop games through redesigns has happened in local gameplays as the games disperse in new contexts and encounter different cultures and languages (de Voogt et al., 2013; Crist, 2019). While designing games has been shown to engage learners in inventing alternative ways of knowing (Civil, 2002), we believe that *re*designing activities could facilitate enriching and repositioning linguistic and cultural diversity. In a study of students' redesigning the game *Inversé* for mathematics learning, a grade 4 new immigrant from China used his mathematical and cultural knowledge: using gestures and drawings, he demonstrated his reimagined play by adopting rules from the Chinese game, *Go* (*Weiqi*) (Kim & Bastani, 2021). The study showed that culturally-relevant games have the potential to bring historical and cultural contexts to disciplinary thinking (e.g., mathematics; Bayeck, 2018; Bastani & Kim, 2022) while helping learners position themselves as confident contributors and their culture and language as important resources in the learning settings.

Game play and design could encourage novel interactions that challenge established relational patterns. Crist et al. (2016) pointed to a "continuum between order and disorder in games" (p. 180) giving rise to new models and interaction paradigms. Through this interplay, games could encourage a liminal space "whereby people can step outside normal social practices and bend familiar cultural elements and societal structure." Such playful states do not mean to maintain the status quo and can introduce new unconventional possibilities, influencing dominant social and political practices and roles (Crist et al., 2016). They could persuade an borderland where limits of inclusion and exclusion can be revisited. This speaks to shifts in power positions that could encourage non-dominant voices (Davies & Harré, 1990). We see cultures as meanings and practices of the families and other social groups that individuals may belong to, inherited or (being) formed individually and collectively. Individuals' interests and views informed by their background and current practices could impact their ways of contributing to collective practices. When taking new positions becomes possible, individuals bring their cultural and social resources from their practices and views in their different life spaces (McVee et al., 2021). We argue that such negotiated spaces and positions truly bring out culturally sustaining learning opportunities.

Research design

We conducted this study remotely via video communications due to the global pandemic. We recruited six families through digital flyers, inviting them to participate as a family unit with at least one adult and one child. The study focused on the four families who completed most of the activities. We provided general guidelines for the game redesign process and held online video meetings with each family to explore their approach to the project, the game they chose to redesign, their ideas for designing their own game, and their experience of collaborative game redesign as a family. The researchers also brainstormed with families on possible changes to their selected games. The meetings were recorded with permission, and families shared their work through written descriptions, visual data (photos and/or videos) from their in-progress designs and final artifacts, and/or blog posts. The final games were exchanged among the families, to play another family's redesigned game and provide feedback.

The initial aim of the study was to investigate how families as collectives could use their cultural and linguistic resources in their game resign project. However, the researchers observed that individuals' differences within the family had a significant impact on the design processes. Therefore, the analysis shifted from a macro-level focus on the family as a collective to a micro-level focus on how family members' diverse backgrounds and perspectives influenced the development of ideas and artifacts. The researchers paid attention to how each family member's unique interests and viewpoints contributed to the game redesign process.

Analysis: Tabletop game redesign as culturally sustaining learning

The shift in research focus led us to explore the following: 1) how the family members engage in social learning through redesigning tabletop games (i.e., games with boards, cards or other objects), and 2) how they reposition generational differences, practices, and ideas as resources for their collective design and learning process.

Relational positions and social learning. Game play and design could encourage shifts in relational positions through discursive and somatic exchanges. Repositioning is intertwined with perspective taking/making, leading to a third problem space, whereby new collective possibilities could emerge (Davies & Harré, 1990; McVee et al., 2021). Game redesign builds on conscious game play, such as noticing others' strategies and interpreting the emergent situations in the game. The explicit requirement of evaluating an existing game structure could change the individuals' position from players to critics of games and the assumptions that back their system and narrative. We had access to family members' reflective accounts through online conversations. We looked for any indications of developing a critical stance towards the norms, expectations, and ways of being, implied by dominant voices in the tools and media of our shared activities.

Shared projects within families and other social groups often involve intergenerational collaboration. Critiquing familiar structures (i.e., games we play) and inventing new participation structures (i.e., redesigned game play) by families could invite family members' different forms of contribution stemmed from their various interests, backgrounds and different roles in and outside the family, i.e., bringing in their various cultural resources in shared activities. In analysing the interviews and artifacts, we also attended to how they evaluated the different aspects of games as the media familiar to both kids and adults. How they could make explicit their understandings and ideas in relation to other family members and how they were able to encourage new relationships and collective possibilities. Put differently, we examined how they might have actively engaged in refiguring their positionings within the family, and how they crossed established boundaries, developing self and mutual understandings, and engaging in creating hybrid spaces where "ingredients from different contexts are combined into something new and unfamiliar" (Akkerman & Bakker, 2011; p. 148).

In our analysis, we reviewed our notes and online meetings' recordings and identified how the participants worked as families and how they formed redesign ideas. We traced the evolution of family discussions and design practices (Barab et al., 2001). We identified the critical episodes of their redesign reflected in our online conversations and the designed artifacts they shared with us. These episodes showed development points, such as how they chose the game to be redesigned, the evolution of family members' participation (e.g., who takes the lead, etc.), and how they determined new objectives and strategies for their redesign. We also explored the playtesting opportunities within the family and the feedback they received from other families after exchanging their games. This led to identifying some overall themes and patterns in families' game redesign practices, including families' sharing critical perspectives on existing games, expressing their interests and attending to one another's perspectives, and connecting the game content with their interests and topics in school and life. We also looked for emergent patterns, such as how the family members' voices reflected in our online conversations and the redesigned games, and the changes in family members' relational positions. The analysis involved examining families' artifacts (i.e., their games, play-recordings, photos, blogs, feedback notes) to understand what connections they were making with their disciplinary and cultural practices and family members' interests.

Tabletop game redesign by families

Each family had an adult contact person, but who led the game design differed among them. The families' unique circumstances influenced their approach to the project, such as the age of their children. Some families used a child's interest to guide their game design, while others had an adult member who encouraged the diverse interests of their family members or sought to create a disciplinary learning experience. During our meetings with families, both adults and children identified the shortcomings of existing games, such as the lack of cooperation among players and the use of stereotypical gender roles. They also compared their cultural gaming practices to those that they played in their home country (if they were immigrants) and reflected how intergenerational relationships and social occasions impacted the games they played. Despite this, we noticed that the redesigned games and rules did not necessarily display overt cultural markers from the participants. Instead, culture was manifested in the decision-making process itself, which influenced the games and game design as a practice. Through this process, the families were able to explore and understand their own cultures and what mattered to their family members as they negotiated their views and interests through play and design. Below is a brief description of each family and their game redesign project. Pseudonyms are used for all names.

Family 1 (with a Chinese background) decided to redesign *The Game of Lif*e board game. The family had four members: Hailey (mother), Patrick (father), Alia (in 5th grade), and Eira (in 7th grade). They chose to redesign the game to make it more relevant to their current context and future expectations by altering the game's theme and introducing new choices, such as career options. Family 2 (Caucasian) chose to redesign the card game *Love Letter*. The family included four members: Katie (mother), Josh (father), Ellie (in 5th grade), and Aiden (in 1st grade). Ellie took the lead in redesigning *Love Letter* to align it with her current favourite book series, *Warriors* by Erin Hunter. Family 3 (with Chinese background) redesigned the board game *Mice & Mystics*. The family comprised three members: Kenny (father), Erika (mother), and Eden (in 1st grade). Their design goal was to integrate coding and logical thinking into the board game. Family 4 (Mexican immigrants) redesigned the board game *Survive*. The family included Lisa (mother), Diego (father), and Elena (in 7th grade). Their goal was to create a cooperative version of the originally competitive game *Survive*.

Positioning children's thoughts as resources for evaluating existing structures

Families considered various elements of a game before selecting one to redesign and while assessing what aspects they will want to change. During this process, families reflected on their goals for creating a new game and took critical perspectives towards the cultural norms, gender roles, and hegemonic ideas that shaped the original games' narratives and dynamics. Family 1, who chose to redesign The *Game of Life,* expressed the most explicit cultural critique of the original name. As a family who played the game often, they believed it represented Western life choices and wanted to create a game more reflective of their Chinese cultural context. Patrick, the father said: "when you play, it is definitely a very Western culture. You go to school, you pick where you want to go school or you just get a job. But if you fill in something more traditional like my Chinese background, it could be something totally different where you can maybe, you know, maybe your parents make you go to school ((laughing)) and you have to achieve a certain mark before you can start picking another career or something like that…there's a lot of cultural influence in there" (the first interview). They also criticized the limited options in the original game and how a redesigned game could reflect a different belief system. Patrick mentioned, "the careers, ...that path can be very different... In *Game of Life*, the more kids you have the better, maybe in the new modern China, too many kids may not be good". This process of rethinking the game's narratives allowed them to exchange and expand their perspective on culture and life choices beyond their game redesign project. In subsequent interviews, they pointed to their conversations on alternative career paths, such as if education is needed to pursue a career and how education could contribute to career choices or pathways. Hailey mentioned how Alia and Eira challenged the limited options for players to progress: "the pathway (in *The Game of Life*)… was ((you get)) married and then you have children. It was also interesting that they (kids) had noted ((this point))". They also discussed how they were going to adjust the game to include more diverse pathways: "((having)) children was one of the pathways we were going to adjust because…there's other ways to have a child" (Hailey).

Family 4 also discussed gender roles while playing the game redesigned by Family 3. Diego, the father, discussed their daughter's disappointment with the limited gender roles portrayed in the original game, *Mice & Mystics*: "She ((Elena)) wanted a different female character. There were only two female characters and at the beginning you could only choose one and she didn't like that female character". She wanted to play a female fighter, which was male in the game's option, not a healer, which was female in the game's option. "We learned that from ((her saying)), 'I want to be a fighter, I want to be a magician, I want to be something very powerful'" (Diego, Interview). In both Family 1 and 4, they used cultural background and children's ideas to critically evaluate the structures and expectations depicted in the original games.

Noticing different ideas and interests within the family

The families chose to redesign games they often played together as a family. This common goal of redesigning the game led them to explicitly evaluate and critique this familiar medium as discussed above. On the other hand, we observed that family members expressed their interests and ideas informed by their different roles in various life spaces. For example, Kenny, the father in Family 3 initially had the idea of redesigning a game representing Chinese cultural elements, using accurate historical stories and cultural aspects. As they progressed, they decided to redesign *Mice & Mystics*, the favorite game of their six-year-old son, Eden. In our interview, Eden discussed how he enjoyed playing with the game's figurines that model the characters. The parents mentioned that they found this cooperative game fun since Eden does not handle losing in competitive games well. They decided to use *Mice & Mystics* as their base game and integrate elements from other games. Kenny, who works at a tech company, and Erika, who has a background in Chemistry, wanted to create a STEM-related game. They did not think highly of trivia games labeled as STEM learning, and since Eden was interested in hands-on activities like playing with robot toys, they wanted to engage Eden in logical thinking and coding. They also saw programming as a skill he would need in the future. Kenny posited, "I think the idea of robotics…obviously at his age and skills…he can't really build a robot. But maybe this ((board game)) gives an idea of what might be possible in the future. I mean, it's very simple programming, logic and stuff, but he's gotta start somewhere, I guess."

They implemented the mechanics used in the game *Mechs vs. Minions* to replace the dice-based random moves in *Mice & Mystics* with command cards, allowing each player to program their characters' moves. They called their final game *Minions' vs Mystics* (Figure 1a). They coined the term "boardgramming" to describe their new game, and created rules that use game pieces and boards from both games. Kenney remarked on Eden's creativity, saying, "my son's never done a boardgramming kind of game, programming at all. That, uh, how he took to thinking about the logic was kind of what surprised me" (Interview).

Figure 1

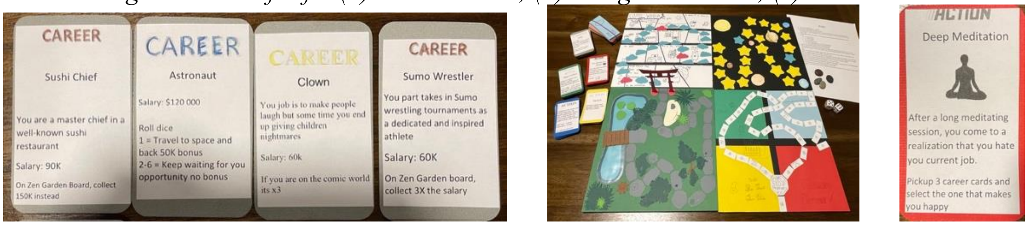
Redesigned games: (a) Minions' vs Mystics setup; (b) Warriors game cards

(a) (b)

Family 2 decided to redesign the card game *Love Letter* because it was a favorite game of Ellie and her father Josh. The design process was led by Ellie after Katie suggested that she "re-work the cards of *Love Letter* to correspond to [her] current favourite book series, *Warriors* by Erin Hunter. This book series follows a variety of clans of feral cats" (blog post). In our conversation, they discussed how there are parallels between the renaissance courting theme of *Love Letter* and the hierarchal nature of the *Warriors* series' characters: "((In)) *Warriors* there's different ranks. There's a leader, a deputy and medicine cat or you're, um, kind of an apprentice" (Ellie, online meeting). The initial design process focused on incorporating the characters from the first arc of the series from an aesthetic perspective. Once the aesthetic choices were formalized, Ellie considered whether the card text/rules needed to be adjusted to reflect the changes to *Warriors*' characters, such as its hierarchy of "kits, apprentices, warriors, and medicine cats" (blog post). They crafted cards to play-test the game as a family (Figure 1b) to see how the game worked and to adjust the rules. The rest of the family members had not read the *Warriors* series and found the backstory complicated. Nonetheless, supporting the redesign process and playing the redesigned game provided an opportunity for the family to learn about the literature that Ellies was invested in.

Family 1 decided to redesign *The Game of Life* board game based on their two daughters' (Alia and Eira) interest. The parents (Hailey and Patrick) and the kids went through multiple brainstorming cycles to come up with alternative life paths. Hailey found the process of choosing the careers particularly interesting: it allowed her to learn about the careers her kids knew about and discuss other careers that they were not aware of. As a result, they created the set of career cards that reflected the interests and values of the family members (Figure 2a). Some of their shared interests, such as Japanese culture were reflected in their career choices, such as Sushi Chef and Sumo Wrestler. They decided to create game boards that reflected each family member's interest, and combined them to create the final game board (Figure 2b). Haily commented, "this game sort of allowed us to really showcase things we are interested in. So, I made the space part, Eira made the Harry Potter part, Alia made the newsprint type part and Patrick made the Japanese part. It all actually reflected, very interesting, that it reflected our interest, which actually made it more personal for us to enjoy."

Figure 2
The Redesigned Game of Life: (a) Career cards; (b) The game boards; (c) An action card



(a) (b) (c)

In an interview with Family 4, Diego reflected on their family game play: "we came from Mexico to Calgary. So, we started playing games because we need to spend time as a family." Their family engagement with tabletop games, particularly the insights gained from the cooperative game *Forbidden Island*, led them to consider designing a cooperative version of the competitive game *Survive* (Figure 3). Discussing their interactions during the game play and redesign project, Lisa pointed out how their daughter, Elena, surprised them with unconventional strategies in her game play, while also suggesting very unique game ideas (e.g., incorporating grandmother's interest in physical activities). However, their different ideas often made reaching an agreement challenging. Diego and Lisa's background as teachers influenced their design approach, as they remained open to new ideas and changes, recognizing the uncertain and iterative nature of design process. Elena also believed Diego's math and teaching background influenced their redesign project. Connecting the game design experience to his teaching practices, Diego asserted, "I have been thinking, what are the strategies to talk to my students and get engaged with those. It's quite the same thing. What kind of activities, what kind of rules, you need to put there that make the game engaging to participants in that sense." He also compared his experience of making an educational game to this project: "it's quite different if you interact with your family in the design." The parents also talked about how their shared interest in fantasy literature, such as Lord of the Rings, Star Wars, and some Spanish fantasy novels, inspired them in their game choice and design ideas. The game redesign experience, however, allowed them to recognize differences in how each of them see and engage with the fantasy genre. Diego mentioned that this experience allowed him to better understand his daughter's media engagement.

Figure 3
Survive (Family 4 redesigned the rules only), source - boardgamegeek.com

Family members' shifting positions: Mutual understanding and imagining possibilities

In connection with what we discussed, we observed that the game redesign process changed the relationship between participants and games. Participants shifted from being just players to also being critics. Furthermore, family game play and redesign became intergenerational activities that allowed families to consider each other's perspectives and interests. This family project had an important impact on relational positions within the family. Parents came to see their children as experts and independent contributors, while the children could see themselves as leaders in redesigning a familiar medium (i.e., a tabletop game) of their shared activity. Participants in all families expressed their surprise at other family members' play strategies, design ideas, and methods of contribution, revealing emergent opportunities for learning about each other and refiguring their positioning through this project. The family members' shifting of positions challenged the power dynamics established within the family as everyone was able to negotiate their views, interests, and roles. This highlights how game redesign can not only facilitate communication within the family but also motivate new configurations in family members relations, which enabled opportunities for seeking out differences and children taking a leading role (Akkerman & Bakker, 2011). In Family 3, for example, the 6-year-old child's interest in robot toys was incorporated in their game redesign. While he was not able to guide the project at his young age, his father pointed out how "Eden has started thinking about and suggesting ways we can make changes in board games we play since we did this project." This demonstrates how the family game redesign enabled Eden to take on a new role in relation to games and redefine his position in relation to his parents by offering suggestions for modifying their shared activities.

One significant aspect of the work by Family 1 was how each family member designed individual, yet interconnected boards that incorporated everyone's individual interests in the game. This approached allowed them to appreciate the different perspectives that each family member brought to the project. For example, Hailey remembered how "Alia had the idea of adding other measures of success in life like happiness or experience." They explained that while their boards had similar configuration for player moves, each had a unique theme. The career cards were designed by specific family members to be more advantageous to players moving on the related thematic board, such as the Wizard career card being more advantageous on the Harry Potter board. They also explored how action and chance cards could be similar but also different for each board. Throughout the project, everyone made an effort to attend to each other's viewpoints and figure out what each family member valued in creating their board: "Even though we each individually created our boards, I think it was interesting because each of us had a role to guide one another... to have it all together" (Hailey).

Discussion and conclusions

This study investigated tabletop games as cultural artifacts that convey diverse beliefs and ideas through their systems (Flanagan, 2009). Tabletop games are open to different strategies, fostering diverse forms of engagement (Pearce, 2006) and allowing players to interpret the game situation from their unique perspectives while considering others'. These games often provide familiar and enjoyable spaces for families to interact, as they are suitable for both adults and children. Through analyzing data from four families who redesigned tabletop games based on their shared and individual interests, we explored how such an approach can enable families to invent alternative ways of connecting across intergenerational differences, and disciplinary and cultural practices. Although they did not explicitly explore their cultural or linguistic practices, they expressed what mattered to their family members, both individually and collectively. In all four families, the children's interests, perspectives, and prior engagement with media, including games, influenced the game redesign process. Working with these families, we learned that each family could explore their unique culture and learn to accept and appreciate differences within the family. Through this process, families were able to reposition generational differences, practices, and ideas as resources for their social learning, sustaining their diverse interests and perspectives (Ladson-Billings, 1995). By examining family settings, this study highlighted the multifaceted aspects of culture and language in culturally-sustaining learning. Our findings have significant implications for educational spaces, particularly in urban schools catering to culturally and linguistically diverse students.

Critical consciousness, interdependence and relational positions. The game redesign practices by families included game play and exploring games' structure and narrative. Game redesign provided opportunities for the families to explore and utilize their family culture as a resource for evaluating the underlying ideas, values, and beliefs expressed by the systems of a game. Family members could also make their individual views on the game explicit, and engage children and parents in new relationship configurations. Considering how children's culture, including interests and previous engagements with different forms of media, can influence a child' critical perspectives on games, new ideas, and their relational positions, a similar approach can be extremely valuable in engaging children in the classroom in challenging power dynamics and positioning themselves as leaders of idea development and change making. We believe that learners in educational spaces would be able to recognise the value of diverse cultural perspectives and appreciate the interdependence that accompanies such recognition.

Commonalities, differences and pluralistic outcomes. The families selected games to redesign based on their shared experiences of playing them. Family members' collective goal was to create a more engaging and relevant game for their family. Our findings illustrate how this approach enable us to we pursue commonalities, differences, and pluralistic outcomes, which are crucial for promoting culturally-sustaining learning in educational spaces. Redesigning games that learners play together can facilitate the emergence of shared design language and mutual understanding. By negotiating ideas within this structure, learners from various backgrounds can also express and apply their distinct ideas, goals, and perspectives stemming from their multiple roles, such as being a student, child, cultural representative, game player, and immigrant (Davies & Harré, 1990).

Game design facilitated family members to cross boundaries between their various life spaces. We propose that learners in diverse contexts can undertake similar work: they can establish links between the game worlds and their own, characterized by inherent multiplicity, foster individual and shared understandings, and imagine new possibilities (Akkerman & Bakker, 2011). We believe that the game redesign process can also facilitate intergenerational meaning-making, as demonstrated in our findings, between teachers and students, which is often a formidable task for educators in the classroom.

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Adaptive Dialog to Support Student Understanding of Climate Change Mechanism and Who is Most Impacted

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Abstract: To support ninth graders to take advantage of the ideas, intuitions, and experiences that contribute to their understanding of climate change, we designed an NLP-based adaptive dialog and tested it in a week-long unit exploring Urban Heat Islands. The dialog's guidance prompts were designed to elicit students' ideas about climate change mechanisms. Students interacted with the adaptive dialog twice during the unit. We scored their initial and revised explanations (after engaging with the adaptive dialog each time) using a Knowledge Integration (KI) rubric. A repeated measures mixed ANOVA revealed that students who initially expressed descriptive ideas often rooted in experience made significantly greater gains during the dialog than those who initially expressed mechanistic ideas. The dialog supported all students to broaden the ideas they considered when exploring climate change. Further, a paired t-test revealed that students made overall gains in KI from pretest to posttest (d=.76).

Introduction

The ideas and experiences students express while reasoning about scientific phenomena are productive and powerful resources for developing integrated understanding (diSessa, 2006; Linn, 2006; Hammer, 2000) especially when they are taken up and built upon by teachers (Fulberg & Silseth, 2022). Students' funds of knowledge (González, Moll, & Amanti, 2005) are grounded in their family culture, daily routines, and community interactions and inform their sensemaking in science classrooms. The initial ideas students hold are often a combination of vague, descriptive, and mechanistic ideas (diSessa, 2006). Research shows that when instruction neglects the ideas students hold while introducing new ideas, students develop a fragmented understanding by either dismissing their own ideas within the school context in favor of what is presented during instruction (Carlone, 2015) or holding both perspectives rather than evaluating and making connections across ideas (diSessa, 2006).

We explore the impact of an adaptive dialog that responds to specific ideas detected in student explanations, mirroring an effective teacher responding to and building upon students' ideas. In particular, this study examines the effect of the adaptive dialog on the learning gains of students who initially express primarily descriptive ideas such as those that are vague and not yet clearly linked to an explanatory mechanism as compared to students who initially express primarily mechanistic ideas. Descriptive ideas are less likely to be taken up and built upon during class interactions (Bang & Medin, 2010) than mechanistic, school-based ideas, which the teacher might more easily recognize as relevant to classroom discussion. We investigate the role of an adaptive dialog that recognizes and builds upon students' descriptive ideas.

Advanced natural language processing (NLP) techniques enable detection of individual ideas in each student's written explanation (Riordan et al., 2022) and have the potential to be embedded within science curricula to help students value and build on their initial ideas. However, a recent review of adaptive dialogs in education, also called chatbots, found that few studies were carried out in K12 classrooms. Further, these studies had negligible learning gains (Wollny et al., 2021). Wollny et al. suggested that the lack of impact might reflect that "chatbot development in education is still driven by technology, rather than having a clear pedagogical focus of improving and supporting learning" (p.13).

We draw on the Knowledge Integration pedagogical framework (KI; Linn & Eylon, 2011) with the aim of designing effective adaptive dialog that builds on students' funds of knowledge to promote development of an integrated understanding of climate change. We investigate the impact of dialogs with guidance that is adaptive to students' distinct initial ideas. KI advocates respecting and building on the diverse ideas each student brings to the classroom. KI recognizes that learners hold varied ideas that reflect their lived experiences. The KI pedagogical model supports students to develop coherent understanding by: *eliciting* and valuing the full range of students' ideas; providing opportunities for students to *discover* evidence in a variety of relevant and meaningful contexts; using evidence to *distinguish* among existing ideas and new ideas; and guiding students to *make connections* among their ideas to form an explanation or argument (Linn & Eylon, 2011).

KI informed the design of both the adaptive dialog and the unit under study. The adaptive dialog is driven by an NLP idea detection model that is trained to identify a wide range of ideas, including ideas rooted in experience, vague ideas, and nonnormative ideas. Adaptive guidance prompts are assigned based on the ideas detected and are designed to elicit further details and reasoning about the ideas students initially expressed. The unit in this study aims to *elicit* students' observations of the causes and impacts of climate change and Urban Heat Islands. It guides students to *discover* new evidence and perspectives. It prompts students to *distinguish* among possible mechanisms that explain climate change and to understand who in their community is most impacted by it. And, it supports students to *make connection*s to explain causes and formulate solutions. In this study we investigate how the design of the unit, including the adaptive dialog, supports students to build on their own ideas to understand the mechanism causing climate change as well as who is most impacted by the dialog.

Methods

Participants

The study was implemented in a suburb of a large Western city in the United States with two ninth grade biology teachers and all of their students. The school is racially diverse, has 26% of students eligible for free or reduced-price lunch and 5% of students are emergent multilingual learners. Only students who completed pretest, posttest, and two full interactions with the adaptive dialogs were included in the analysis (N=70).

Curriculum

David and Mary both taught the Global Climate Change and Urban Heat Islands (UHI) unit to their 9th grade biology students. This unit features interactive models, data visualizations, and mapping activities (Bradford et al., 2022). Students first explore how energy from the Sun is transferred and transformed to heat the Earth. Their ideas and experiences are elicited through activities that ask them to make predictions. They use interactive models to discover ideas about the natural greenhouse effect and then investigate how human activities can amplify the greenhouse effect leading to anthropogenic climate change. Students are then prompted to consider the impact climate change has on people. They are introduced to several youth climate activists from their community and are asked to consider whether marginalized communities experience greater effects of climate change than dominant communities. Students explore the UHI phenomenon through investigations of how different surfaces are heated by the sun. Students deepen their understanding by distinguishing how historical, racist policies, like redlining, contribute to some areas becoming UHIs. Students compare historical redlining maps to present day temperature maps to gather evidence of the impact of redlining.

Pre and posttest assessment

Pretests and posttests were administered to students before and after interacting with the curriculum. Two items determined the pretest and posttest scores used in analysis. The *Coal* item prompted students to explain how increased levels of carbon dioxide in the atmosphere might impact the climate. This item examines students' conceptual understanding of the mechanisms of climate change. The *Impacts* item prompted students to explain how the effects of climate change could impact people and whether or not all people are impacted by these effects in the same way. This item measures connections students make between the causes of climate change and the historical policies that have shaped who experiences the impacts of climate change, such as the effects of UHI. Validated Knowledge Integration rubrics were used to automatically score student responses to each item (Liu et al., 2008). KI scores indicate the degree of integration among normative science ideas that students have in their explanations, without penalizing for vague or non normative ideas. The KI scoring rubric is on a scale of 1-5. The scoring rewards students for connecting their ideas to evidence and does not penalize students for expressing vague or non-normative ideas. A score of 1 or 2 indicates the student has not yet connected their ideas to an explanatory mechanism, while a score of three or higher reflects that students have connected at least one mechanistic idea.

Adaptive dialog idea scoring

The interactive, adaptive dialog occurred on the *Car* item (Figure 1) at two points in the unit: early in the unit after completing a lesson about the natural greenhouse effect, and right before taking the posttest. The adaptive dialog was designed to elicit and build upon student explanations about how the temperature inside a car would compare to the outside temperature on a cold, sunny day. This is an analogy for the greenhouse effect mechanism that drives climate change and leads to rising global temperatures. It asks students to connect the same ideas students use to explain the pre/posttest item *Coal.*

To develop the adaptive dialog, we built a *multi-label* NLP model for idea detection. The NLP model used a *token classification* approach for idea detection (Riordan et al., 2020; Schulz et al., 2018). The model was trained to predict an idea category for each word token in the student response data. Consecutive words with the same predicted idea were treated as an idea *span.* Since ideas can overlap, a given word token can receive more than one idea category prediction. The multi-label idea detection model was trained and validated with 10-fold cross validation for hyperparameter tuning and evaluation. To prepare data to train the model, we first created an idea rubric (Table 1) that enumerates the ideas typically expressed in response to the item, including ideas rooted in personal experience, vague ideas, and non-normative ideas in addition to the ideas that comprise the mechanism targeted by the item (for details see Gerard et al., 2022). We generated a set of 24 ideas for the *Car* item which included nine mechanistic ideas, seven vague or personal experience-based ideas, and eight nonnormative ideas. We then human-coded 793 student explanations by annotating spans of text and labeling them with the corresponding idea. The human-coded student explanations were collected at schools serving similar populations to the school in the present study. Prior to use in this study, the idea detection model was evaluated on word-level micro-averaged F-score (harmonic mean of precision and recall, weighted by frequency of idea category). The overall F-score achieved by the model was .592, in line with similar models developed for challenging idea and reasoning detection tasks (Schulz et al., 2018; 2019).

We also build a KI scoring model (using a KI scoring rubric) for the initial and revised responses to the *Car* item, using 1093 human-coded student explanations. The model achieved a Quadratic Weighted Kappa (QWK) of .889. This indicates a high level of agreement between model and human scoring, exceeding the standard threshold of 0.7 for automated scoring deployment (Williamson et al., 2012).

Table 1
Sample from Car Item Idea Rubric and Adaptive Guidance. The full rubric includes 24 ideas across all KI levels and includes both descriptive and mechanistic ideas.

Item prompt: *On a cold winter day, Akbar is walking to his car that is parked in the sun. His car has not been driven for one week. Does the air inside the car feel colder, hotter or exactly the same as the outside air? Explain.*

#	Idea	KI	Assigned Adaptive Eliciting Guidance in Dialog
2	The car feels colder than outside (DI)	2	Interesting ideas! Can you tell me about how you feel if you are sitting inside a car and the sunlight shines on you through the window?
5	Heat (or cold) is conducted between the car and the surrounding area (DI)	2	You’re right that heat energy is conducted between objects that touch each other. Since the Sun is far away, how can its energy warm the car?
8	The sun warms the car directly (DI)	2	Interesting idea! How does the sun make the car warmer?
15	Solar radiation is transformed into heat energy (MI)	3	I think you're saying that energy from the sun transforms to heat energy in the car. What happens to that heat energy?
18	Heat or infrared energy is trapped inside the car (MI)	3	Can you tell me more about why heat gets trapped in the car but solar radiation doesn’t?

Within the adaptive dialog, the idea detection model was used to detect the ideas present in each response the students provided. After their initial response, students received an adaptive guidance prompt based on the ideas detected (Figure 1). Drawing on the KI framework, prompts were designed to elicit more of the students' thinking about the idea they had expressed. Because multiple ideas could be detected in each student response, we developed a prioritization order for which ideas to guide. We opted to guide detected mechanistic ideas before vague or non-normative ideas. In the dialog interface, students responded to the adaptive prompt and then were given a second, non-adaptive prompt that asked them to share an idea they were unsure about. The second prompt was non-adaptive because we trained the idea detection model on full explanations and had not yet determined how it would perform at identifying student ideas in their responses to the first adaptive prompt. After responding to the non-adaptive prompt, students were asked to revise their explanations.

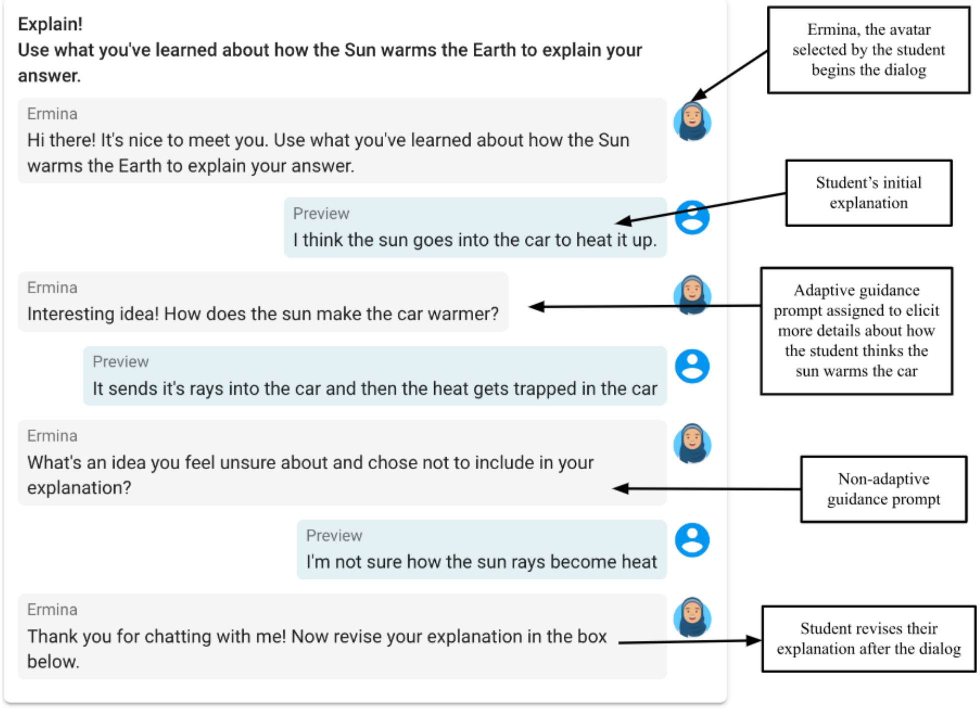
Analysis approach

Descriptive and mechanistic student idea categories

When responding to the Car item, students express a mix of descriptive ideas rooted in everyday experience and mechanistic ideas that are often connected to evidence that they have explored throughout the unit. Because we were interested in how well the unit and dialog supported students to connect their descriptive ideas to an explanatory mechanism, we categorized students based on the kinds of ideas they initially expressed. To assign students to the categories, we considered their performance on both pretest items and on their initial response to the Dialog Item (Car). For each of these items, a score of 3 or more must have at least 1 mechanistic idea connected to evidence, whereas a score of 1 or 2 indicates the use of descriptive or vague ideas not yet connected to a mechanism. We assigned students who had scores of 1 or 2 and not more than one 3 across these items to the Descriptive Ideas (DI) category. We assigned students with at least two scores of 3 or more on each item to the Mechanistic Ideas (MI) category. Thus, students in the DI category started with not more than one mechanistic response across the items. Students in the MI category started with two or more mechanistic ideas. There were 25 students in the DI category and 45 in the MI category.

Figure 1

Example adaptive dialog for the Car item.



Explain!
Use what you've learned about how the Sun warms the Earth to explain your answer.

Ermina
Hi there! It's nice to meet you. Use what you've learned about how the Sun warms the Earth to explain your answer.

Preview
I think the sun goes into the car to heat it up.

Ermina
Interesting idea! How does the sun make the car warmer?

Preview
It sends it's rays into the car and then the heat gets trapped in the car

Ermina
What's an idea you feel unsure about and chose not to include in your explanation?

Preview
I'm not sure how the sun rays become heat

Ermina
Thank you for chatting with me! Now revise your explanation in the box below.

Ermina, the avatar selected by the student begins the dialog

Student's initial explanation

Adaptive guidance prompt assigned to elicit more details about how the student thinks the sun warms the car

Non-adaptive guidance prompt

Student revises their explanation after the dialog

Progress across dialog items

To analyze the impact of the adaptive dialog, we examined the frequency of ideas detected during each round of guidance in each dialog as well as in the revised explanations. We computed the frequency and types of ideas added and pruned between initial and revised explanations for each interaction with the dialog, comparing patterns for DI and MI students. We also use a repeated measures mixed ANOVA to examine the change in students' KI score over *time* (four time points: initial explanation in the first engagement with the dialog, revised explanation after the first dialog, the initial explanation in the second dialog, and final revised response after the second dialog) with student idea category (DI and MI) as a between-subjects factor.

Progress of DI and MI students from pretest to posttest

We assessed students' overall change in understanding by conducting a paired t-test on students' scores on both pretest and posttest items. We computed the gain students made on each item by taking the difference between posttest and pretest scores. We then used a two-sample t-test to investigate whether the gains on either item varied by student idea category, to account for the alignment of the dialog with the *Coal* item and not the *Impacts* item.

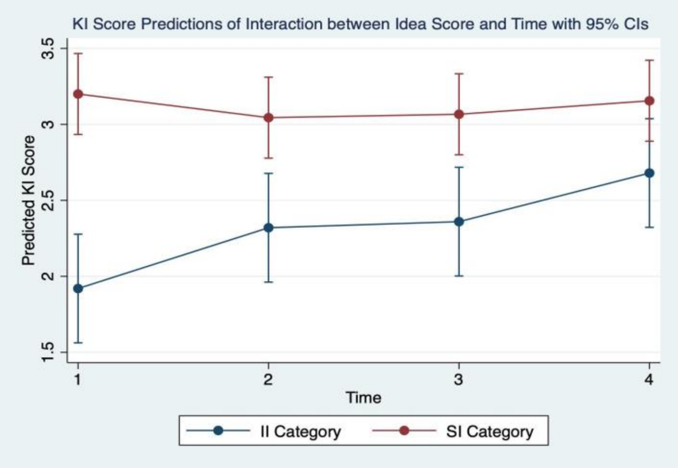
Results and discussion

Progress across dialog items

Across the Dialog items, a repeated measures mixed ANOVA using the Greenhouse-Geisser correction revealed a main effect for both *time* (F(3, 68)=3.41, p=0.022, η^2=0.048) and student *Idea Category* (F(1, 68)=19.8, p<0.001, η^2=0.226) along with a significant interaction between the factors (F(3, 68)=4.51, p=0.005, η^2=0.062). Post-hoc analysis of estimations revealed that DI students made significant gains in KI score at all time points when compared to their explanation at time point 1. The greatest significant difference in KI score for DI students (t(68)=4.17, p<0.001) was between initial explanation (M=1.92, SD=0.75) and final revision after the second dialog (M=2.68, SD=0.80). The KI score difference for MI students was not significant between any time points (Figure 2). Thus, the two interactions with the adaptive dialog on the Car item were more beneficial for DI students than for MI students.

Figure 2

Estimated KI Scores on the Car item at each time point by student Idea Category with 95% CIs



Idea changes during dialog interactions

For both dialogs, students generated ideas in multiple categories (Table 2). We analyzed the overall impact of the adaptive dialog as well as the specific ideas students contributed. We also looked at the ideas generated by students who started with DI and MI ideas.

Advantage of adaptive guidance.

For both dialogs, adaptive guidance elicited more ideas (164) than non-adaptive guidance (52). Specifically, adaptive guidance elicited more mechanistic (99 versus 21) and vague ideas (53 versus 14) than the non-adaptive guidance. Thus, tailoring the first guidance prompt to students' initially expressed ideas motivated them to generate more ideas than did the second, non-adaptive prompt, consistent with prior research showing the value of building on students' prior knowledge and experiences (Zacharia et al., 2015).

Table 2

Frequency of ideas elicited at each round during both interactions with the adaptive dialog. Ideas from the rubric are characterized as mechanistic, vague, or nonnormative. Ideas detected were summed across categories. N=70

Dialog	Round	Mechanistic	Vague	Nonnormative	Total
First Dialog	Initial	89	18	14	116
	Adaptive Guidance	49	26	6	81
	Non-adaptive Guidance	14	9	8	31
	Final Revision	81 (62%)	28 (21%)	22 (17%)	131
Second Dialog	Initial	78	24	16	118
	Adaptive Guidance	50	27	6	83
	Non-adaptive Guidance	7	5	9	21
	Final Revision	103 (65%)	36 (23%)	19 (12%)	158

In both opportunities to engage with the adaptive dialog (Table 2), students in the DI category added more ideas on average from initial to revised explanation than students in the MI category (M=1.08 vs M=0.87 and M=1.2 vs M=1.02). In the first dialog, a greater proportion of these added ideas were mechanistic for MI students (43.9%) than for DI students (33.3%). However, in the second dialog, at least half of the ideas added were related to the mechanism for both groups of students. Specifically, the most frequently added idea during the second dialog was idea 18, the idea that "the car traps heat energy." This is a key part of the mechanism. In both dialogs, students in the MI group pruned more ideas on average than those in the DI category. Additionally, a higher proportion of the pruned ideas were mechanistic for the MI category than for the DI category (Table 3).

Specific changes in ideas

The differences in the frequency and types of ideas that students expressed can explain some of the differences in change in KI score for students in the DI and MI groups. Students in the DI category tended to start with vague or non normative ideas and then integrate mechanistic ideas generated during the dialog into their revised explanations. Students in the MI group tended to start with one or more normative ideas in their initial explanations. The dialog served to elicit additional normative ideas from many of the MI students, however, these students tended to focus only on the new idea in their revised explanations rather than integrating them with their initial ideas.

Table 3

Mean frequency of all ideas (and of mechanistic ideas) that were added and pruned between initial explanation and final revision following interactions with the adaptive dialog.

Dialog	PK Level	Ideas Added/Student	Percent Mechanistic Added	Ideas Pruned/Student	Percent Mechanistic Pruned
First Dialog	DI	1.08	33.3%	0.48	41.7%
	MI	0.87	43.9%	0.82	59.5%
Second Dialog	DI	1.2	53.3%	0.52	46.2%
	MI	1.02	50%	0.88	59.1%

Typical dialog exchanges for DI and MI students were selected from the second interaction with the dialog (Table 4). The DI student initially explains that inside the car is hotter because the sun is "looking right inside" the car. The idea detection model recognizes idea 8, a vague, descriptive idea about how the sun directly warms the car. Based on detection of this idea, the avatar offers an adaptive guidance prompt that asks the student to explain more about how the Sun makes the inside of the car warmer than the outside. The DI student responds to the prompt with idea 18, the mechanistic idea that the car can trap heat energy. In their final revision, the DI student incorporates the idea about the trapping mechanism. The MI student initially explains that solar (electromagnetic) radiation is emitted by the Sun and that some radiation is reflected while some is absorbed. Their explanation also indicates uncertainty about the distinction between solar radiation and infrared radiation. The idea model detects the presence of two mechanistic ideas: idea 13, that radiation comes from the sun, and idea 14, that some radiation is reflected and some is absorbed. Based on the presence of idea 14, the avatar offers an adaptive prompt that elicits additional ideas from the student, namely what happens to the radiation once it has been absorbed. The MI student responds to the prompt with idea 18, stating that some of that energy gets trapped inside the car. In their final revision, the MI student prunes both of their initial mechanistic ideas and expresses idea 18, that the car is warmer inside because it is able to trap heat. Thus, from very different starting points, both the DI and MI students express the same, compelling mechanistic idea.

Progress of DI and MI students from pretest to posttest

On the two pretest/posttest items (Coal and Impacts), students demonstrated significant pretest (M=5.51, SD=1.09) to posttest (M=6.50, SD=1.35) learning gains while interacting with the unit (t(69) = 6.39, $p<0.001$, d=0.764).

Between pretest and posttest, on the *Coal* item, MI and DI students converged on explanations featuring mechanistic ideas about climate change. Each group experienced two interactions with the adaptive dialog that elicited their ideas about the mechanism of climate change. The mechanism students needed to explain the *Car* item used in the adaptive dialogs was the same as the mechanism students needed to explain in the *Coal* item. The DI students showed significantly greater gains (M=0.64, SD=0.91) than MI students (M=0.22, SD=0.95) on the *Coal* posttest item, which targets the climate mechanism (t(68)=1.79, p=0.039, d=0.446). Further, the posttest scores for the *Coal* item were not significantly different between DI and MI students, despite a significant difference at pretest. This suggests that the dialog supported DI students to build upon their ideas to reach the same level of mechanistic explanation as their MI peers.

On the *Impacts* item, which prompted students to connect their understanding of the mechanism of climate change to explain why some groups experience more harmful impacts of climate change than others, there were similar pretest to posttest gains between the MI and DI students. The MI students had significantly higher posttest scores (M=3.49, SD=0.73) on the *Impacts* item than the DI students (M=2.8, SD=0.87, t(68)=-3.55, p<0.001). This result aligns with the lack of attention to policy and social factors in the adaptive dialog. The dialog did not elicit students' thinking about the issues in the *Impacts* item. It is possible that lack of attention to these ideas in the dialog, account for DI students' greater gains and higher average score on the *Coal* item than on the *Impacts* item.

Table 4
Representative examples of the second interaction with the adaptive dialog for students from DI and MI categories. Ideas detected by the model are italicized.

Time	DI Student	MI Student
Initial	It'll be warmer because the *sun is looking right inside the car.*	The *sun uses it's solar radiation to heat the Earth* by infared radiation *getting absorbed into the atmosphere and some reflects off the Earths atmosphere*.
Adaptive Guidance	Can you tell me more about how the Sun makes the inside of the car warmer than outside?	What happens to the energy from the sun when it is absorbed by the car?
Student Response 1	It will be warmer because the *car traps in all of the heat off of the sun*.	Some of the *energy is trapped inside the car* and some is released.
Non-adaptive Guidance	What's an idea you feel unsure about and chose not to include in your explanation?	What's an idea you feel unsure about and chose not to include in your explanation?
Student Response 2	I'm not unsure.	Nothing I'm confident about my answer.
Final Revision	The *car will be warmer* because the *heat from the sun will be trapped in the car making* it warmer than outside.	The *temperature inside the car will be hotter than the outside* because of the *car being able to trap heat* like the Earth does with the sun.

Conclusion and significance

The adaptive dialog shows promise as a strategy for eliciting students' ideas whether they start with descriptive or mechanistic ideas. It seems particularly useful to help students elaborate initial descriptive explanations. We found that students starting with descriptive ideas and starting with mechanistic ideas followed distinct paths during the dialog and achieved similar understanding of the mechanism of climate change by the posttest. The use of eliciting guidance was particularly impactful for DI students, who incorporated new mechanistic ideas into their initial explanations. This aligns with other research that suggests the importance of building on students' funds of knowledge as they construct understanding (diSessa, 2006; Linn, 2006; Hammer, 2000). The eliciting guidance supported MI students to articulate additional mechanistic ideas, which they often prioritized over their initial ideas during revision. Both groups increased their overall KI score at posttest.

The path taken by MI students suggests the potential of leveraging information about the KI score and the presence of multiple ideas when designing and assigning the adaptive guidance prompts. Students who started with one or more mechanistic ideas often articulated additional mechanistic ideas within the dialog. They pruned some of their initial mechanistic ideas to settle on promising final ideas. The KI Framework (Linn & Eylon, 2011) suggests that MI students need further support to distinguish among their mechanistic ideas and connect them into more complex explanations. Future iterations of the dialog could feature new guidance prompts that encourage students to sort out their mechanistic ideas and determine when they apply. This would enhance students' ability to draw connections among their mechanistic ideas to explain the *Car* phenomena.

Although the adaptive dialog was not aligned with the *Impacts* item, students made gains in Impacts KI scores, consistent with the overall focus of the unit. Both MI and DI students made progress in connecting their ideas about the causes of climate change to the social and political reasons that resulted in marginalized communities experiencing greater impacts of climate change. Further research is needed to determine whether an adaptive dialog using an idea detection model for the topics in the *Impacts* item would support greater student learning about the political and social factors that intersect with climate impacts.

Overall, the adaptive dialog was effective at drawing out students' ideas and enabled them to persist in reasoning about their explanations. The wide range of ideas expressed within the dialogs illustrates the value of the unit and dialog design. The dialogs reinforced the classroom culture established by our teacher participants and amplified their ability to both elicit students' descriptive ideas and respond to them.

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Short Papers

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Musical Agency in Experimental Music Education

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Abstract: Although previous studies have revealed the affordances of experimental music and its subgenres (e.g., noise music) in relation to providing students with access to musical agency, this research often overemphasizes individual capacities for musical performance while ignoring other manifestations of agency. In response, I address the following research question: how do learners in a noise music workshop conceptualize musical agency? To do so, I present findings from comparative case study research into two intertwined noise music workshop series. In analyzing interview data from eight workshop participants, I identify three specific elements of these noise music workshops that participants recognize as contributing to the development of musical agency: permission, accessibility, and relatability. This analysis then expands on previous research into the affordances for musical agency within experimental music and provides a framework for engaging agency in other education contexts as well.

Introduction

Within extant music education research, scholars have routinely explored the role of musical agency in learning processes, here defined as an “individuals’ capacity for action in relation to music or in a music-related setting” (Karlsen, 2011, p. 110). For Sutela et al. (2021), this component of musical knowledge development represents an embodied process that incorporates a student’s ability to make creative decisions, interact with others and express their emotions through music, and be seen as capable musicians themselves. Beyond a focus on the individual musician, explorations of musical agency align with learning sciences research that positions the development of agency as a situated phenomenon through which learning contexts either restrict or enable the inherent agency of learners (see Calabrese Barton & Tan, 2010; Cobb et al., 2009). According to Kuuse (2018), musical agency is “determined by discursive boundaries such as constructions of discipline, empowerment, and space” (p. 151) with conceptions of education praxes and the preconceived notions of genre or musical tradition directly controlling whether students feel empowered to act or make choices within musical contexts.

As an example of this situated framing, music education scholars have routinely highlighted the role of musical agency within experimental music, here referring to Gilmore’s (2014) ideological definition that includes all new musical genres that intentionally break from the tenets of Western music (such as rhythm, pitch, and repetitive structure). In particular, the shift away from traditional music skills and knowledges (such as standard musical notation literacy or instrumental performance techniques) allows musicians of all skill levels to participate in authentic experimental music performance contexts, thus embodying a democratic approach to learning through musical production (Kanellopoulos, 2012; Siljamäki, 2021; Wright, 2019). Experimental music curricula therefore challenge the rigid structures and roles of formal music education, allowing participants to reimagine spaces of learning and, subsequently, the medium through which students access musical agency (Small, 1996).

Yet despite the emphasis placed on musical agency in all processes of learning related to music, music education research (both within and outside of experimental music) has overemphasized forms of agency related to instrumental performance. While scholars such as Kondo & Wiggins (2018) routinely acknowledge that performing, listening, composing, improvising, and theorizing within musical contexts all require agency to some degree, studies routinely focus on the agency learners exercise when playing an instrument without exploring these other musical practices. Building on the affordances of experimental music education to address this oversight, I use this paper to explore the following research question: how do learners in a noise music workshop conceptualize musical agency? Noise music, in this context, refers to a subgenre within experimental music that draws influence from punk, industrial, free-jazz and the mid-century experimental composers (Bailey, 2012) and aligns with constructionist approaches to agentic knowledge production (Woods, 2020). To address my research question, I present findings from a comparative case study of two intertwined experimental music workshop series focused on noise music. Through my analysis, I identify three specific elements of the workshops highlighted by participants that contributed to the holistic development of musical agency: permission, accessibility, and relatability. This analysis both aligns with and expands on previous research into the musical agency of learners and provides a framework for developing student agency in other learning contexts as well.

Methods

To explore the role of student agency within noise music, I draw on a selection of data from a year-long comparative case study (Bartlett & Vavrus, 2016) into two intertwined music series focused on noise music: the Experimental Education Series (EES) and the Noise Knowledge Consortium (NKC). Both events took place at community-based arts organizations in Milwaukee, WI in the United States (EES at the Jazz Gallery Center for the Arts and NKC at Brinn Labs), were free and open to the public, and followed a similar format: featured artists at each event would teach an hour-long workshop related to their artistic practice and then perform at a concert alongside other local experimental musicians. The EES took place once every three months while the NKC occurred monthly. Since each featured artist developed their workshop independently and centered their unique approach to making noise music, the subject matter and pedagogical structure of each event differed. These workshops fell into three broad categories: lectures about the artist's work/creative philosophy (6 workshops), interactive workshops about performance or composition techniques (7 workshops), and hands-on instrument building/music technology demonstrations (2 workshops).

For this particular study, I center my analysis on interview data with eight workshop participants who attended a majority of the sixteen events in the series. Participants initially self-identified as being generally unfamiliar with (but interested in) the genre or novice noise musicians who were interested in developing their musical practice. While all participants had previous experience in other music education contexts, with some having received individual instrument training and others completing general music education courses within formal K12 settings, none had experience with experimental music education explicitly. When joining the study, participants were given the option to use a pseudonym or their own name in publications and all participants chose the latter option except for one (who is referred to by the alias of John A. in this paper). I initially recruited five participants through publicly available social media posts and conducted a series of hour long semi-structured interviews aligned with Siedman's (2005) three-interview structure. This included one interview before the series began, one to two mid-interviews during the implementation year, and one interview after the participant attended their last workshop, all focused on their evolving understanding of noise music and their experiences during the events. Near the end of the study, I enlisted three additional participants who had not responded to my initial recruitment efforts but had still attended a majority of the workshops. Although I only met with each of these additional participants after the workshops had ended, I condensed my semi-structured protocol into one single interview. I also conducted participant observations of all workshops and collected musical artifacts (scores, recordings, etc.) created by the participants, thus producing validity via triangulation of data (Denzin, 2012). Field notes were also used to generate further questions during the semi-structured interviews, creating opportunities for participants to elaborate on (or, potentially, dismiss) moments in the workshops I considered meaningful in relation to learning or embodying musical agency.

To analyze the interviews, field notes, and artifacts, I employed an open and iterative approach to both descriptive and pattern coding techniques (Saldaña, 2015) to explore how participants conceptualized learning within the workshops. In line with Karlsen's (2011) definition of musical agency, I coded excerpts from the interviews where participants described moments of feeling capable of acting or making choices of their own volition, focusing on the elements of the workshop that participants recognized as contributing to this emergent sense of agency. In doing so, I constructed three themes that comprise a shared conceptualization of musical agency: permission, accessibility, and relatability. I describe all three in detail in the following section.

Findings

Permission

Succinctly defining the first theme, Andy de Junco explains that one of his big takeaways was "permission to just make whatever you want, literally whatever you want" within a musical context. Rather than having to conform to a specific set of musical traditions or rules, de Junco saw a potential in noise music to create without restriction and still fit within the genre. For John A., the need for permission relates directly to people's preconceived understanding of what musicians need to make music:

> People [have a] tendency to get caught up in, like, "making music is complex and hard and I can't do it. That will take too much time." Those kinds of things. So making noise music is permission to forget all of that. And that is, to me, what's great about the series.

Importantly, John A. draws a connection between noise music as a context and what happens within the workshops. In his understanding, the value comes from participants gaining exposure to and working within the genre itself. Bill Pariso connects to this framing in a personal moment of gaining permission from the experience:

> It's permission when I see other people do it. I shouldn't have to have that, but for some reason I still do. Like, "this blues guy's career is built on that technique so that means I can't try that," versus Eli [one of the artists] rubbing a coffee cup on top of his guitar. He didn't ask for permission; he just did that and it worked.

Again, Pariso connects this sense of permission to a moment in the workshop and the genre itself, drawing a comparison between understandings of technique (and the implicit inclusion of skill) in noise and blues music.

Accessibility

Beyond an internalized feeling of having permission to make music, the learners in this study also found value in the accessibility of music making tools and practices they experienced in the workshops. In terms of the tools being used, Jack Hietpas recognized this during a workshop on experimental vocal techniques: "Amanda [the featured artist] was encouraging us to explore the possibilities of the voice, this amazing instrument that we all have. It gives people confidence in their own voice. I think that's really powerful." Through this quote, Hietpas not only recognizes the power of gaining confidence in one's voice but speaks to the importance of everyone having the ability to vocalize in the first place (one highlighted by experimental music's shift away from a rigid framing of musical technique). Even when the workshops focused on instruments to which someone might not have immediate access, participants discussed the importance of finding easily accessible instruments. De Junco discusses this theme in relation to a tape loop workshop: "It becomes this thing that I can go out and do now. I just need 20 bucks and I just go out and do this thing and make a ton of them," which sits in opposition to the significantly higher financial hurdles associated with buying or renting many traditional Western instruments.

Beyond the tools, the participants also found accessibility to music making practices themselves important. Hietpas weaves this theme into his discussion of vocal techniques ("exploring the possibilities of voice" instead of having to develop a specific technique through training) while Chris Momsen found a similar connection in learning about composition strategies: "it opened your eyes to something that you maybe hadn't thought of or even would be willing to try. Let's take an everyday occurrence, like taking a shower, and make that an actual performance with a sound component." Momsen, in this moment, learns that the actions he takes on a daily basis (and the sounds they produce) can act as the material for noise music, providing an increased amount of access to music making processes and contributing to a sense of musical agency within composition.

Relatability

Finally, the participants also recognized relatability, or the capacity to see the alignment between their own emergent practice and the work of established musicians, as an important part of developing agency. For Momsen, this relational (and externalized) theme involved seeing a similar compositional approach used by a featured artist:

> It kind of affirmed that what I am doing is not as crazy as it sounds in my own head, that one other person on this planet is following a path that I'm following too. It's an affirmation. It's nice to know you're not doing it wrong because someone else is doing it.

De Junco had a similar reaction to the workshops, asserting that, "it just felt super relatable, because that's how I do it and that's how he does it." For both de Junco and Momsen, the value in these specific workshops did not come from learning some new technique or developing their practice in a new way. Instead, the workshop affirmed their already established approach to music making held value because a veteran artist mirrored their practice in some way. In discussing this theme, Jennifer Zamora differed slightly from Chris and Andy by not fully aligning with the featured artist but still finding enough relatability to feel confident in her practice:

> what I took from that is: I know I could do everything that he did because I've worked with those [programs]. It's like, "I know that. I know how to do that." But I don't do it that way because my brain isn't wired that way.

Rather than comparing her practice with that of the teaching artist, Zamora instead relates to a familiar tool being used and recognizes that she has the skill to create work in a similar fashion (even if she does not want to).

Discussion

In producing the three themes described above, my analysis builds on previous research into experimental music education contexts by attending to underexplored aspects of musical agency beyond instrumental performance, such as composing and theorizing (Kondo & Wiggins, 2018), within noise music. For example, while Siljamäki's (2021) research into vocal choirs reveals how experimental music as a learning context legitimized the use of non-traditional performance techniques, Hietpas' comments on the vocal workshop both reinforce that finding but also acknowledge the importance of positioning the human voice as an accessible and embodied tool in legitimizing musical agency. Described through the lens of this analysis, extant research overemphasizes the notion of permission (and, in particular, permission to legitimately make music without conforming to particular performance standards or techniques) within musical agency (see Karlsen, 2011). While the findings in this study do reinforce the importance of permission, they also acknowledge that enabling access to agency within the workshops also relied on both accessibility to instruments or music making tools and finding relatable practices (including composition processes) with veteran artists. This study therefore aligns with previous research that positions student agency within the interplay between the context and the learner (Calabrese Barton & Tan, 2010; Cobb et al., 2009; Kuuse, 2018). More than just the internal ability to make choices while performing, agency remains intertwined with the people, spaces, and materials that define cultural and learning contexts. Moreover, the positioning of the workshops within the context of experimental music allowed participants to build on the democratic (Kanellopoulos, 2012) and constructionist (Woods, 2020) foundations of the genre as they conceptualized musical agency through this musical tradition. The participants in these workshops therefore distribute the musical agency they experience between themselves, the tenets of experimental music, and other artists. Future research into the agency of learners should therefore explore these themes as a framework for accessing agency within a variety of learning environments. In understanding how different disciplinary contexts (musical or otherwise) either restrict or enable permission, accessibility, or relatability, scholars can trace the affordances for and barriers to developing agency embedded within cultural and educational spaces.

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The Impact of Levels of Immersion on Learning: Electrodermal Activity and Eye-Tracking Study

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Abstract: The current study aims to provide insights into the impact of Virtual Reality (VR) immersion levels on students' learning processes and outcomes. A quasi-experimental design was utilized to compare two conditions: a high-immersive VR simulation using a head-mounted display, and a low-immersive VR simulation using a desktop display. Analysis revealed no significant differences in the perceived sense of presence and in post-test knowledge, regardless of the level of immersion. Analysis of electrodermal activity (EDA) peaks, which indicate cognitive effort, revealed significantly more EDA peaks throughout the learning process with high-immersive VR. Similarly, the results of blink rate metrics, which decrease during cognitive effort, showed significantly fewer blinks for high-immersive VR. Hence, this study suggests that low-immersive VR, which is more accessible in terms of cost and implementation, might demand less cognitive effort and be at least as effective as high-immersive VR in terms of immediate knowledge retention.

Introduction

Virtual reality (VR) provides an authentic and immersive learning experience through simulated reality in computer-generated environments, and is therefore regarded as a productive platform for learning and training (Yu, 2021). VR supports interactive experiences of an alternate reality in which participants are avatars who can move, sense, touch, and act upon simulated computer graphics, supporting the perception that these objects exist. These unique immersive characteristics underlie theoretical VR affordances and are an excellent basis for learning through a constructivist perspective; situated and embodied learning; and experiential learning approaches (Fromm et al., 2021; Matovu et al., 2022). Therefore, VR has been partially adopted in the educational and pedagogical fields. A recent meta-analysis on the effect of VR technology use in education showed a clear benefit of learning with VR for improving learning achievements, interest in learning, and confidence (Yu, 2021). Due to the increased attention accorded VR as a promising educational technology in K-12 and higher education, more research is needed into the various VR immersive affordances that might impact learning.

VR environments can be classified as high-immersive or low-immersive. Slater and Wilbur (1997) emphasized that immersion is a description of the technology's ability to stimulate users' senses via graphics and multiple sensory modalities. High-immersive VR involves high-cost peripheral devices, i.e., a head-mounted display in which a high graphical fidelity screen is mounted in front of one's eyes with separate lenses for each eye and sound is delivered through earphones. By blocking out many visual elements of the real-world environment and inducing sensory stimuli that correspond with the virtual environment, high-immersive VR enables the user to immerse in the virtual environment. In contrast, low-immersive VR is often called desktop VR and takes the form of a window into a virtual world displayed on a computer monitor, where interaction is via a mouse, keyboard, or joystick.

Immersion can induce a sense of presence, i.e., the subjective feeling of being inside and part of a simulated virtual world (Witmer & Singer, 1998). While one can assume that high-immersive VR will induce a stronger sense of presence and better learning outcomes than low-immersive VR, research in this area is inconclusive. Recent studies suggest that although high-immersive VR incorporates more presence, it is also associated with lower levels of immediate knowledge retention, which indicates lower extents of learning (Makransky et al., 2019). In contrast, other studies demonstrated that high-immersive VR is superior to low-immersive VR in knowledge transfer (Han et al., 2022). To this end, this study aims to evaluate how different levels of immersion, low-immersive VR using a desktop display versus high-immersive VR using a head-mounted display, might impact the learning process and learning gains. Since extraneous cognitive processing is associated with learning via immersive virtual environments (Mayer et al., 2022), the current study utilizes a multimodal approach involving measures for capturing learners' cognitive effort, using electrodermal activity (EDA), sensors, and eye-tracking.

Research question

How does the level of immersion, low-immersive VR versus high-immersive VR, impact students' learning processes and outcomes as measured by a presence questionnaire and knowledge test and cognitive effort as measured by EDA and eye-tracking metrics?

Methods

Participants

In total, 52 freshmen nursing students at a university volunteered to participate in the study. Due to technical issues involving data collection (e.g., calibration errors), the data of four participants were excluded, resulting in a final sample size of 47 participants. Due to the nature of the nursing field, globally comprised of a large majority of women, most participants were female (n=40), and the mean age was 24±4.2 years. The study was conducted following the approval of the university's ethics committee (#0001776-3).

Research design and procedure

This study is part of a more extensive study (Dubovi, 2022). This was a quasi-experimental study with two compared conditions: high-immersive VR using an HTC Vive headset, and low-immersive VR using a desktop computer screen. Participants' demographics and pre-post knowledge tests were assessed via paper-and-pencil questionnaires. Following calibrations required to verify that eye-tracking and EDA signals were recorded properly, students were assigned to one of the study's conditions and the learning session with a VR-based simulation was initiated. Eye-tracking and EDA were recorded and real-time analyzed during the entire VR learning experience. Data collection was supported by the iMotions 9.2 Biometric Research Platform. The VR simulation incorporated the architecture of a 3D hospital (Dubovi et al., 2017). Playing the role of a nurse-avatar, participants were asked to learn about medication administration procedures.

Data collection instruments

Content knowledge test

The Medication Administration Test (MAT) assessed nursing students' understanding and practical applications of medication administration guidelines. The test was validated in a previous study (Dubovi, 2022; Dubovi et al., 2017). The test consists of 9 multiple-choice items. Analysis of the MAT using Cronbach's alpha yielded a good internal consistency score of .74.

Presence questionnaire.

The Presence Questionnaire (PQ) was developed by Witmer and Singer (1998) to measure the degree to which a direct interaction with a VR environment gives participants the feeling that the simulation sensations are real. The instrument includes three subscales: (1) Involved/Comparison; (2) Natural; and (3) Interface Quality. The PQ was completed immediately after learning with the VR simulation. The overall internal consistency in the current study was α=.80, similar to previous reports.

Cognitive effort

To evaluate the cognitive effort involved in learning with VR, we used automated continuous eye-tracking and EDA measurements. *Eye tracking*: Smart Eye Aurora hardware was used to collect real-time gaze data at 60 Hz frequency. The extracted metrics were students' blink rates per minute. Researchers have observed that blinking decreases during cognitive and memory processing, suggesting an inverse relationship between task difficulty and blinking; that is, increased difficulty lowers the blinking rate (Martins & Carvalho, 2015). *EDA*: A Shimmer 3 wristband was used to calculate the skin conductance level (known also as tonic level) and a fast-changing component often referred to as the phasic response or the skin conductance response (SCR). A peak detection algorithm and artifact rejection filter were utilized to identify the EDA metrics of EDA peaks per minute (Benedek & Kaernbach, 2010). The mechanism for this is tied to EDA the sympathetic nervous system, which in response to situations that comprise cognitive phenomena immediately activates sweat glands.

Results

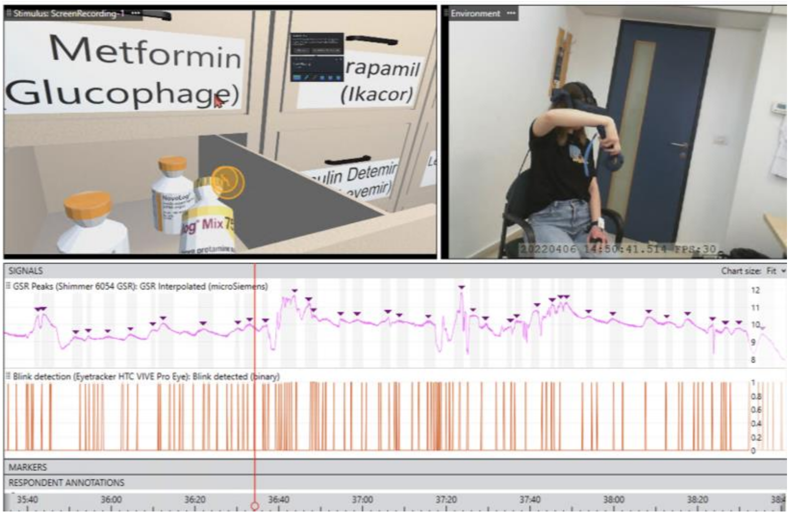
The post-test MAT content knowledge scores were significantly higher than the pre-test scores for both the high-immersive VR (93±11 vs.79±13, paired t=-4.675, $p<0.001$) and the low-immersive VR (92±11 vs.76±14, paired t=-4.927, $p<0.001$). There were no statistically significant differences in students' prior knowledge on the MAT between the two research conditions (unpaired t = -0.701, p = 0.487) as well as for the post-test MAT knowledge level (unpaired t = -0.245, p = 0.808).

Sense of presence within the VR environment is an important parameter of the learning experience. The results showed that the three PQ subscales were comparable between the high-immersive and low-immersive groups: Involved/Comparison (5.2±0.5 vs 5.2±0.6, unpaired t=0.413, p=0.359; respectively); Natural (4.5±1.2 vs. 4.8±1.0, unpaired t=0.902, p=0.243; respectively); and Interface Quality (6.0±1.0 vs. 5.8± 0.9, unpaired t=-0.483, p=0.515; respectively). Subsequently, there was no significant difference in overall PQ between the research groups (5.3±0.6 vs 5.3±0.6, unpaired t=0.048, p=0.860; respectively).

Students' cognitive effort while learning with VR was captured by EDA and eye-tracking metrics of blink rate. When comparing learning with high-immersive VR to low-immersive VR, LMM analysis for repeated measures showed a significant interaction between the type of VR simulation, EDA simulation phase, and peaks per minute (F (5, 39.433) = 5.139, p<0.01). Post-hoc analysis showed that students who learned with the high-immersive VR expressed significantly more EDA peaks per minute for the intro phase (p < 0.05) and for the application of the procedure phase (p < 0.001), than students in the low-immersive VR group (Table 1).

In addition, significant changes in blinks per minute were detected by an LMM for repeated measures analysis across the different VR simulation phases when comparing high-immersive to low-immersive VR (F (5, 44) = 7.817, p<0.001). Post-hoc analysis demonstrated that while learning with the high-immersive VR, students expressed significantly fewer blinks during the follow-up tutorial about the procedure compared to low-immersive VR (Table 1).

Figure 1
Real-time measurement of EDA peaks and blinks rate while learning with the high-immersive VR



Discussion

The main goal of this study was to examine whether the degree of VR immersion can impact learning process and learning outcomes. Our findings show that in terms of immediate knowledge achievements, learning with low-immersive VR was comparable to high-immersive VR. This finding is consistent with previous research (Mayer et al., 2022). Interestingly, our results also indicate that the level of perceived sense of presence was comparable between the study groups. A possible reason for this outcome has been suggested by Steuer (1992), who claimed that presence depends not merely on immersion level but also on its interactivity. It is therefore possible that since the VR simulation in both study conditions was highly interactive and enabled navigation and modification of the virtual hospital environment, it resulted in a high and equivalent sense of presence regardless of the high or low immersion levels of the learning environment. The major contribution of this study is grounded in the incorporation of automated measurements of EDA and eye-tracking to examine cognitive effort within VR environments and adds to the existing literature regarding the differences between high- and low-immersive VR. Our results suggest that learning with high-immersive VR might demand higher cognitive resources, which should be studied further in order to develop instructional approaches to reduce cognitive load and maximize learning. From a practical perspective, we show the educational value of low-immersive VR, demonstrated by our study to be as effective as high-immersive VR. This has notable financial and accessibility implications, especially for schools and students who have no access to costly computer-based VR technologies but can still provide effective low-cost learning opportunities.

Table 1
Changes in the number of EDA peaks and blinks per minute according to the VR simulation sequence phases and research groups

VR simulation sequence phases	GSR per minute Mean (±SD)		Blinks per minute Mean (±SD)	
	Low-Immersive VR	High-Immersive VR	Low-Immersive VR	High-Immersive VR
Intro phase	3.4 (±3.2)	5.3 (±2.3)	18.2 (±1.8)	17.9 (±2.1)
Patient assessment	4.1 (±2.6)	5.2 (±3.1)	17.8 (±1.8)	12.8 (±2.2)
Tutorial about the procedure	2.8 (±2.5)	3.8 (±2.3)	18.6 (±1.9)	14.8 (±2.2)
Application of the procedure	3.4 (±2.9)	7.11 (±3.4)	14.8 (±1.5)	12.4 (±1.7)
Follow-up tutorial about the procedure	3.5 (±2.6)	4.4 (±2.7)	17.8 (±1.9)	11.3 (±2.3)
Sum-up video of the procedure	3.4 (±2.8)	3.8 (±3.0)	19.6 (±2.3)	16.9 (±2.7)

The significant differences between the research groups are highlighted in grey

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Exploring the Link Between Cognitively Relevant Actions and Geometric Reasoning: A Pilot Study

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Abstract: The potential of grounded cognition and action-based learning is garnering increasing attention. This pilot study investigates the effect of performing cognitively relevant actions and the role of simulated action through gesturing on geometric reasoning. The results suggested that directing students to perform cognitively relevant actions led to a lower likelihood of correct intuition and insight formulation but a higher likelihood of correct proof formulation. Meanwhile, prompting students to use gestures was associated with a higher likelihood of correct intuition, insight, and proof formulation. However, the effects were not statistically distinguishable from zero. Nevertheless, the results hinted at a promising direction for further research into the moderating effect of simulated action. This investigation offers insight into embodied learning design and contributes to the discussion of the pedagogical potential of body movements to improve students' geometric reasoning.

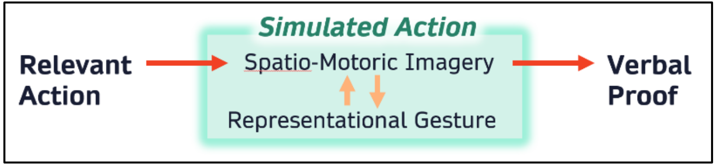
Theoretical framework and literature review

The theories of embodied cognition see human cognition not as an abstract mental activity but as caused or constituted by our body's perception and action (Shapiro, 2011). Among the varying perspectives under the banner of embodied cognition, *grounded cognition* places simulation's role in cognition at the center. The core tenet of grounded cognition is that cognition is a result of "simulation, bodily states, and situated action" (Barsalou, 2008, p. 617). The simulation that underlies cognition comprises mental and body-based action representations, which are in a reciprocal relationship. For example, when spatio-motoric imagery activates relevant neural areas for motor control and visual perception beyond a certain threshold, it gives rise to *representational gesture*s, spontaneously produced co-speech gestures that depict the semantic content of speech (Alibali et al., 2001; Hostetter & Alibali, 2008). At the same time, representational gestures ground complex ideas by introducing spatio-motoric action information to the speaker's mental representations and helping the speaker manage spatio-motoric information (Kita et al., 2017). We call these reciprocal processes between spatio-motoric imagery and representational gestures *simulated action*.

In recent years, action-based embodied learning has gained attention, where students' sensorimotor experience becomes a perceptual ground for referencing through various modalities, including gesture and speech (Abrahamson & Sánchez-García, 2016). In mathematics, actions that ground abstract concepts were proposed to influence students' geometric reasoning (Williams-Pierce et al., 2017). Performing *cognitively relevant actions* – actions designed to provide concept-specific body-based representations (hereafter, *relevant actions*) – was theorized to help produce correct verbal proof by feeding relevant spatio-motoric information to students' simulated action (i.e., activating spatio-motoric imagery and producing representational gestures) (Nathan & Walkington, 2017; Walkington et al., 2022). In other words, simulated action is believed to mediate the effect of performing relevant actions on verbal proof production (Figure 1).

Figure 1

Performing Relevant Action, Simulated Action, and Verbal Proof Production



Three circumstances motivate our study. First, the research on the effect of relevant action on geometric reasoning is nascent, and there are only a few relevant studies. Second, the few empirical findings have been ambivalent: Some found statistically distinguishable non-zero effects, while others did not. Third, to our best knowledge, no empirical study has examined the role of simulated action despite its critical importance as an intermediary between performing relevant action and geometric reasoning. This study aims to estimate the effect of relevant action on geometric reasoning and gather experimental evidence to understand the role of simulated action. Two research questions guided this study: ‘Does performing relevant actions promote geometric reasoning? If so, by how much?’ (*RQ1*) and ‘Does simulated action mediate relevant action’s effect on geometric reasoning?’ (*RQ2*). In addition, we asked an exploratory research question ‘Does simulated action moderate relevant action’s effect on geometric reasoning?’(RQ3) Here, we report the results from a pilot study.

Method

Sample

The sample consists of 32 adult undergraduate students recruited from a large university in the Midwestern United States. All 32 participants were English-speaking students, but 10 spoke different languages at home (31.25%). There were 11 males (65.62%) and 21 females (34.38%), and no other gender self-identification was provided. Regarding mathematics course experience, 13 students (40.63%) had only taken mathematics courses below the level of college calculus, and 19 students (59.37%) had taken courses equivalent to or more advanced than college calculus.

Design features and protocols

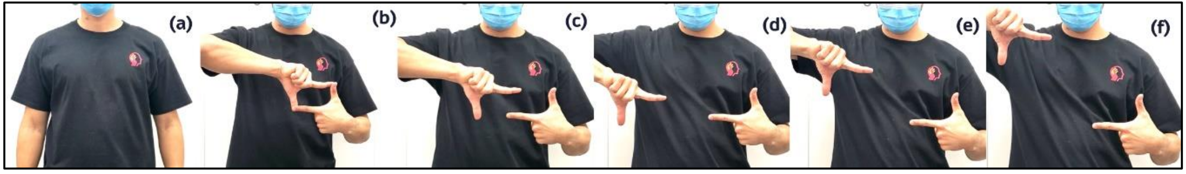
We designed a repeated-measure, 2-by-2 factorial, group-randomized experiment in which we directed students to perform relevant actions or prompted them to use representative gestures (Table 1). The main task was to prove or disprove a given geometric conjecture. Each student completed five conjectures. We selected conjectures from secondary mathematics textbooks that explore the general properties of geometric shapes. The verbiage was modified so that all the conjectures are either always true or false (e.g., “If you triple each side of any quadrilateral, then the area is always 9 times greater” (The *quadrilateral conjecture*)). The order of conjecture presentation was counterbalanced by using a Latin square to create four conjecture orders.

Table 1
Protocol Variation by Experiment Condition for Each Conjecture

	Directed		Not Directed	
	Prompted	Not Prompted	Prompted	Not Prompted
1	Directed to perform relevant actions	Directed to perform relevant actions	N/A	N/A
2	Read a conjecture	Read a conjecture	Read a conjecture	Read a conjecture
3	Prompted to use gestures with verbal proof	N/A	Prompted to use gestures with verbal proof	N/A
4	Proved the conjecture	Proved the conjecture	Proved the conjecture	Proved the conjecture

In the *Directed* conditions, we asked students to perform relevant actions by watching video clips of an actor and following the movements. Each relevant action was designed to help visualize the key geometric objects and their transformation relevant to the veracity of a given conjecture. For example, the relevant actions for the quadrilateral conjecture enact the idea of expanding a quadrilateral so that its sides are three times longer (Figure 2). In the *Prompted* conditions, we asked them to use hand gestures to support their verbal proofs and help the listener’s understanding. Such a request was to boost their simulated action process more than usual by making them more conscious about their spatio-motoric imagery and representational gestures.

Figure 2
Relevant Actions for the Quadrilateral Conjecture (In Six Frames, from (a) to (f))



Students were paired and randomized into different conditions as a group. The paired students came into an isolated lab space simultaneously and performed verbal proof tasks. We chose to pair students to elicit more representational gestures even in the absence of prompting. Since the outcome was measured at the conjecture level within a student, we introduced a few constraints to prevent spillover between students. First, the two students took turns in proving conjectures. Second, they proved different sets of five conjectures that mirror each other in topic and wording but differ in shapes or properties. Third, when a student was asked to watch video clips, the other student turned around, not to see the video. The video did not have audio. Fourth, when a student was actively proving, the other student was asked not to react in any fashion.

Analysis and predictions

160 video clips of individual proofs were generated from the video and audio recordings of participants' engagement in the task (16 groups x 2 participants x 5 conjectures). Each proof was the unit of analysis. We excluded one case of non-compliance, where the participant was prompted to use gestures but did not, leaving the total observations 159. As outcome measures of geometric reasoning, one of the authors transcribed and coded for *intuition* (The immediate assessment of the conjecture's truth value is correct), *insight* (The explanation is only composed of the key mathematical ideas that are relevant to prove the conjecture correctly) and *proof* (The explanation is general, logical, and operational (Harel & Sowder, 2007)) as binary variables. The three codes captured different levels of rigor in proof. Producing *representational gestures* was also coded as a binary variable among the students in the Not Prompted conditions. We used two-level hierarchical linear models (HLM) to estimate the treatment effect and account for the nested nature of the data (proof outcomes nested within students). We did not consider the random effect of group membership since the between-group variation was negligible.

Regarding RQ1, we predicted we would find a positive effect of directing relevant actions on intuition, insight, and proof (*H1*). For RQ2, we expected a positive effect of gesture prompting on intuition, insight, and proof (*H2a*), a positive effect of directing relevant action on representational gesture production (*H2b*), a positive association of representational gesture production with intuition, insight, and proof among the students who were in the Not Prompted conditions (*H2c*). For the exploratory question RQ3, we tested the interaction effect between directing relevant action and gesture prompting on geometric reasoning measures without an a priori hypothesis.

Results

The relevant statistics are in Table 2. For H1, the results were mixed. Compared to the Not Directed conditions, the odds ratios in the Directed conditions were 6.15% lower for intuition (d_{cox}=-.04), 1.50% lower for insight (d_{cox}=-.01), and 9.01% higher for proof (d_{cox}=.05). Consistent with H2a, the odds ratios in the Prompted conditions were 5.65% higher for intuition (d_{cox}=.03), 13.78% higher for insight (d_{cox}=.03), 4.39% higher for proof (d_{cox}=.03). However, directing to perform relevant actions was associated with a 5.69% lower odds ratio of producing representational gestures (d_{cox}=-.04), which was inconsistent with H2b. In contrast, Consistent with H2c, using representational gestures was associated with an 8.37% higher odds ratio for intuition (d_{cox}=.05), 16.38% higher for insight (d_{cox}=.09), 9.42% higher for proof (d_{cox}=.06). As for the exploratory question, the directions of the interaction effects between directing relevant actions and gesture prompting were mixed, while the magnitudes were relatively large. The effect of directing relevant actions in the Prompted condition as odds ratios was 82.42% lower for intuition (d_{cox}=-1.05), 73.18% lower for insight (d_{cox}=-.80), while 66.87% higher for proof (d_{cox}=.31) than the Not Prompted conditions. All the differences were not statistically significant at a 95% confidence level.

Table 2
Results (OR = Odds Ratio; Diff. = Difference in OR; Int. = Intuition; Ins. = Insight; Prf. = Proof)

	RQ1: Rel. action			RQ2: Simulated action (Mediation)							RQ3: Simulated action (Moderation)		
	H1			H2a			H2b	H2c					
	Int.	Ins.	Prf.	Int.	Ins.	Prf.		Int.	Ins.	Prf.	Int.	Ins.	Prf.
OR	0.94	0.98	1.09	1.06	1.14	1.04	0.94	1.08	1.16	1.09	0.18	0.27	1.67
Diff. (%)	-6.15	-1.50	9.01	5.63	13.78	4.39	-5.69	8.37	16.38	9.42	-82.42	-73.18	66.87
Std. error	0.10	0.08	0.06	0.10	0.08	0.06	0.13	0.14	0.12	0.07	1.17	0.81	0.98
d_{cox}	-0.04	-0.01	0.05	0.03	0.08	0.03	-0.04	0.05	0.09	0.06	-1.05	-0.80	0.31
p-value	0.51	0.86	0.15	0.58	0.12	0.48	0.65	0.57	0.20	0.23	0.14	0.10	0.60

Discussion and conclusion

We reported the results from a pilot study where we examined the effect of cognitively relevant actions on geometric reasoning by comparing the students who were directed to perform relevant actions against those who did not. Also, we examined the role of simulated action by prompting half the students to use gestures while formulating proofs and comparing them to those who were asked to use gestures. Our estimation showed that performing relevant actions led to lower likelihoods of correct intuition and insight formulation but a higher likelihood of correct proof formulation; gesture prompting led to higher likelihoods of correct intuition, insight, and proof formulation; performing relevant actions led to a lower likelihood of representational gesture production; and using representational gestures was linked to a higher likelihood of correct intuition, insight, and proof formulation.

The results lent little support to the positive effect of performing relevant actions (RQ1) or the mediating role of simulated action (RQ2). Only the hypotheses about the positive effect of gesture prompting (H2a) and the positive association between representational gesture and geometric reasoning (H2) were consistent with the results. Furthermore, the effect size estimates were minimal and not statistically distinguishable from zero at a 95 % confidence level. As a result, we could not make meaningful inferences about either the effect of performing relevant actions or the mediating role of simulated action from the present pilot study.

However, some noteworthy findings hinted at a promising direction for future research. The exploratory analysis of the interaction between performing relevant actions and being prompted to gesture (RQ3) showed a relatively large interaction effect on geometric reasoning compared to other effects of interest. For example, prompting to gesture was linked to an 82.42% lower effect of performing relevant action on intuition and a 73.18% lower effect on insight. In addition, notwithstanding the p-values over the .05 threshold, the corresponding p-values are among the lowest (.14 and .10, respectively). Considering the small sample we collected for the pilot study, we take the large effect sizes and the relatively low p-values as encouraging signs for a further, larger-scale investigation into the moderating effect of simulated action.

Besides the small sample size, the pilot study presented above has a few additional limitations for interpreting the results: Coding was done only by one author; the conjectures were not standardized; and the cognitive relevant actions used for the intervention were not validated.

Nevertheless, this investigation contributes to a broader discussion of the pedagogical potential of body movements in the mathematics classroom. Especially the findings of a larger-scale study will inform the development of action-based embodied learning design in geometry and other areas of mathematics. Experimental evidence for the effectiveness of performing cognitively relevant actions will help mathematics teachers and curriculum developers consider including cognitively relevant actions to improve students' geometric reasoning. On the other hand, the potential moderating role of simulated action between cognitively relevant action and geometric reasoning hints at the value of attending to students' simulated action by guiding their gestures per the directed relevant actions.

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Supporting Near-Peer Women Mentors in Out-of-School Time STEM Programming

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Abstract: This study examined the experiences of near-peer women mentors in an out-of-school time (OST) STEM program for middle school girls of color. 11 mentors reported and reflected upon their overall experiences in interviews. Key findings include that, for example, training is an essential part of mentors' work; they wish to have more training on pedagogy and more opportunities to bond with other mentors. This study extends the literature on STEM mentoring in OST environments, deepens the understanding of mentors' experience in STEM programming, and provides important implications for mentor training and OST STEM program design, such as providing opportunities for reflective practices to understand mentor needs, supporting mentors' non-STEM skill development, involving mentors in working towards the program goal, and fostering community building among women mentors.

Introduction

Studies indicate that women mentoring girls' learning and career development is a promising means of promoting girls in science, technology, engineering, and mathematics (STEM) (e.g., Stoeger et al., 2016). Intentionally recruiting women as mentors and role models creates an inviting out-of-school time (OST) environment for girls to participate, build confidence, and develop interest in STEM. This study shines the spotlight on supporting women mentors in near-peer women-girls mentorship in OST STEM space. Near-peer women mentors, who are normally college or high school students, are also traditionally underrepresented in STEM. Getting a better understanding of how near-peer women mentors perceive their mentoring experience informs the design of an effective mentoring program that benefits both women mentors and girls. Here, we seek answers to these questions, "How do near-peer women mentors perceive their experiences in an OST STEM program for girls?", and "How might we support them?"

Literature review

Peer or near-peer mentorship

The definition of mentoring has grown since the 1980s, and there is no one widely accepted definition because of its complexity. Mentors perform three primary functions: (1) providing vocational or skill support that directly enhances their career; (2) offering psychosocial support via counseling, friendship, confirmation, and encouragement; and (3) functioning as role models by demonstrating appropriate behaviors (Kram, 1985).

Peer or near-peer mentors have been perceived as more relatable than mentors with hierarchical status (e.g., Vandal et al., 2018). In education, such mentorship has been linked to student success in many aspects, such as socialization (Allen et al., 1999), and engagement in STEM (Wilson et al., 2012). The engagement of peer or near-peer mentors has also been frequently reported as a potential structural solution (e.g., Zaniewski & Reinholz, 2016) to solve the issue of mentor scarcity and mentee retention, which is critical for women in STEM.

Near-peer women-girls mentorship in STEM

Identity is particularly important for those who are traditionally underrepresented in STEM. Women, for example, experience significant discouragement or isolation in a climate with few role models and mentors, a dearth of female peers, and perceived bias against women in STEM (Seymour & Hewitt, 1994). Strengthening girls' STEM identities, near-peer women-girls mentorship helps them develop a sense of belonging (Inzlicht & Good, 2006) by connecting with same-gendered role models who are close in age, knowledge, and experience (Stout et al., 2013). Women mentors help girls alleviate negative stereotypes and build confidence in STEM because women appreciate those who understand their experiences and unique challenges (Bernstein, et al., 2010) and are able to see that others "like them" can be successful in their field.

Impact of mentoring on mentors and contribution to the literature

As is shown in the increasing but still lacking literature (e.g., Petersen et al., 2020), near-peer mentoring in STEM has been proven to be beneficial for mentors, through such means as solidifying mentors' prior STEM knowledge and skills (e.g., Garcia et al, 2021), enhancing leadership skills (Gunn, Lee, & Steed, 2017), and developing professional networking (Lim et al., 2017). Additionally, heavy reliance on survey-based data collection methods also raises validity concerns (Allen et al., 2007). In this study, we mainly conducted 1-1 interviews to obtain a deep understanding of mentors' experiences.

Methods

Research context and participants

The Digital Youth Divas (DYD) is an on-going project for middle school girls of color in a mid-sized racially and socioeconomically diverse community. Since its inception in 2013, the DYD has been implemented in various configurations, including weekly workshops, summer camps, and showcases. It has trained around 40 near-peer women mentors who have taught approximately 500 girls. Each session involves hands-on learning experiences designed to make connections between STEM and girls' own interests, such as art, fashion, or music.

In this study context, 13 mentors facilitated 16-week workshops for a total of 47 10-12-year-old girls. The girls were racially diverse: approximately 30% identified as African American, 26.42% Latino or Hispanic, and 11.32% Caribbean Islander. Among 11 mentors who agreed to take part in this study, all identified as women, the average age was 18, 7 were high school students, and four were undergraduate students (see Table 1).

Table 1
Background Information of 11 Mentor Participants

Participant ID	Gender (W=Women; M=men)	Age	Education level
P1	W	22	Undergraduate
P2	W	20	Undergraduate
P3	W	19	Undergraduate
P4	W	21	Undergraduate
P5	W	17	High School
P6	W	17	High School
P7	W	16	High School
P8	W	18	High School
P9	W	17	High School
P10	W	16	High School
P11	W	15	High School

Data collection and analysis

Due to the COVID-19 pandemic, we conducted the interviews via Zoom, and each lasted 60 minutes. We asked questions such as "What are some things that you wanted more of in this position?" "Do you feel you've gained any skills in this position?" Interviews were audio-recorded, and extensive notes were taken. 96-page transcripts in Word were analyzed using a thematic approach. I read through all transcripts and notes and looked for patterns to find overarching themes. A four-question self-assessment was also distributed via Qualtrics asking about their work performance, engagement, work preparation, and acknowledgement received at work. I manually calculated the percentages of the 11 valid responses for each item. In this paper, we present preliminary results that describe how near-peer women mentors perceived their experiences in a same-gendered STEM learning environment and design implications that help create a supportive environment for women mentors.

Preliminary results

We provide preliminary results from this work by briefly describing mentors' responsibilities, experiences they enjoyed, challenges they faced, and personal growth.

Mentors' responsibilities

Mentors mentioned three major aspects of their work; training, facilitating, and making connections with girls. All participants saw training as an essential task for a mentor. Unlike undergraduate mentors who perceived their job as "teaching STEM knowledge or skills" or "helping with projects," high school mentors focused more on making personal connections with the girls.

Enjoyable experiences

Both interview and survey data indicated that mentors actively participated and enjoyed a comfortable and supportive same-gendered working atmosphere. High school mentors often looked up to the undergraduate mentors for guidance and help. P6 said, "I really liked how there was just like a big community of girls and women who wanted to do STEM and liked [that] they can all relate to each other."

Challenges

Mentors brought up two areas as the greatest source of challenges, training and communication. First, despite the fact that all mentors felt that training was beneficial, 73% of the mentors (n=8) pointed out some training logistics for improvement (e.g., "there was not much training after the program started"); and over half of the mentors said that the training content should be deeper and broader, covering pedagogy and communication, for example. P4 would love to learn more about "making conversations with girls and creating an inclusive learning environment".

Second, 55% of the mentors hoped to get more informed about the program overall. P1 brought up, "we weren't clearly communicated about everything that was going on [in the program]." Furthermore, around half of the mentors claimed that they desired more bonding time with other mentors. P7 said that "[having] dinner together really created a group identity", and they felt more motivated at work. High school mentors were interested in more bonding time with undergraduate mentors to seek resources and advice on college and career.

Personal growth

More than half of the mentors (n>5) claimed they experienced personal growth in STEM knowledge, career, communication skills, and confidence. All mentors claimed that they gained STEM knowledge and skills during programming, such as 3D printing, coding, etc. They also explicitly claimed that working as a mentor helped with their professional development (e.g., leadership skills). P9 said it "helped me learn how to navigate a workplace setting". More than half of the mentors (55%) further indicated that their social and communication skills improved. P5 said, "I've always struggled to be more open. I feel like this job made me step up a little bit [by] giving me more responsibilities. This job made me more confident."

Reflections and implications

This study supports and extends the literature with high school and undergraduate women mentors anecdotally expressing their personal development and challenges. Tasks mentors described reflected Kram and Isabella's (1985) description of peer mentor functions, including knowledge and information sharing, emotional support, and friendship. Reflecting on mentors' perceived experiences, we proposed these design principles.

(a) Provide opportunities for reflective practices to understand mentor needs: Reflective practices (e.g., biweekly survey) help program designers develop more effective interventions and help mentors recognize the value of their work and boost their confidence and motivation.

(b) Support development of mentors' non-STEM skills: Effective mentor training that equip mentors with important skills is one of various factors that determine the success of mentoring interventions (Stoeger et al., 2019). Mentors in this study felt that training on pedagogy and communication were important but lacking.

(c) Involve mentors in working towards the program goal: Providing a clear picture of the program, ensures that everyone on the team works closely towards a communal goal in a supportive and motivating work environment. Ambiguity about the program results in a weak connection (Garcia et al., 2021) among everyone in the program, which prevented mentors from fully participating in and growing with the program.

(d) Foster community-building among women mentors: Women mentors in this study enjoyed working with and bonding with other women mentors outside of the work occasion. Interestingly, high school mentors considered undergraduate mentors as "role models" and were willing to seek advice for their future academic and career development. The bond can be created, fostered, and strengthened in a safe and supportive community.

As a limitation of this study, we acknowledge that we present findings from a small data set using mainly one qualitative method, one-on-on interview. With a vivid picture of women mentors' experience even at this small scale, we are inspired and motivated to explore more deeply how girls and parents perceive such mentorship and how women mentors grow in their future STEM learning and career pathways.

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How Aligned Curriculum Design of Thinking Moves and Thinking Routines Influences Students’ Movie Analysis and Perception of Learning

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Abstract: The Visible Thinking approach (VT) is designed to develop thinking skills. However, the effective implementation of VT in teaching can be hindered by misalignments in coordinating course objectives, thinking routines (TRs), and thinking moves (TMs), leading to a lack of attention to students' thinking performance. To address this issue, this study developed a college-level EFL Movie English course that incorporated four selected TMs, course-specific goals, and matching TRs, along with a designed TMs assessment rubric. We examined the impact of this curriculum on students' movie analysis performance and their perception of thinking and learning, using self-evaluation, analysis writing, and self-reflection from participants. The results indicated improvements in four TMs, with considering different viewpoints and perspectives showing the greatest improvement. Furthermore, students' reflections demonstrated a positive influence on their thinking and learning. The study highlights the importance of course alignments for a VT approach to effectively function as a thinking curriculum.

Importance of teaching thinking

Current education trends emphasize the importance of teaching thinking, but studies suggest that discrete or decontextualized teaching of thinking is ineffective for developing integrated thinking skills (Resnick, 1987; Beyer, 2008). Thinking education, according to Resnick (1987), is believed to be more effective when embedded into a social setting and the success lies in long-term engagement and social interactions in a sociocultural environment where thinking is valued and supported (Resnick, 1987). Teaching of thinking should be guided and embedded in curriculum and situated in a sociocultural environment where thinking is made visible and thinking dispositions can be enculturated through long-term engagement in thinking (Tishman, Jay, & Perkins, 1993).

Visible Thinking Approach

Visible Thinking approach (VT), developed by Visible Thinking Project of Harvard Graduate School of Education, has caught much attention in recent years and was and proved to yield positive influence in deeper learning and cultivation of thinking dispositions (Ritchhart & Church, 2020). VT has three main cores: *thinking routines (TRs), thinking moves (TMs), and thinking dispositions*. *TRs* are a set of procedures that expert teachers of thinking employ as tools for activating students’ thinking, guiding students to take thinking actions (TMs), making students’ thinking visible, creating cultures of thinking, and eventually cultivating students’ *thinking dispositions*. Through repeated use of TRs, teachers can have on-going assessment of students’ thinking and learning to give needed support, and students gradually internalize use of TRs and eventually develop thinking dispositions (Ritchhart, Church & Morrison, 2011; Ritchhart, 2015).

Applications of visible thinking and thinking curriculum misalignments

VT has been applied and researched in diverse subject matters, such as social studies (Lim, 2017), math teaching methodology (Gholam, 2018), critical writing in economics (Lin, Zeng & Lim, 2018), clinical reasoning (Delany & Golding, 2014), and language learning. As to language learning, VT was proved enhance discussion or interaction in ESL or EFL (Balboa & Briesmaster, 2018; Dajani, 2016; Khalid & Yang, 2021) and college-level EFL academic writing (Hooper, 2015). However, despite that VT is an effective approach to teaching of thinking, there is a common set of misalignments present in previous research. We call them thinking curriculum misalignments. Thinking curriculum misalignments means failure to align course objectives, TRs, TMs, and learning assessment. These misalignments have caused some problems. First, misalignments between TRs, TMs and course objectives lead to ambiguity of how TRs assist students’ thinking and learning and help reach course objectives. For example, some research only used TRs to promote language interaction without addressing connection to TMs (Balboa & Briesmaster, 2018), and some claimed to promote said thinking but the failed to aligned its use of TRs (Hooper, 2015). Some falsely called TRs as “visual” thinking routines without addressing course objectives (Gholam, 2018). Another problem is that misalignments between use of TRs and learning assessment makes it hard to explain how assessment reveals students’ change of thinking. For example, some research used periodical exams or standardized tests as assessment but failed to explain influence of use of TRs (Lin, Zeng, & Lim, 2018); some claimed students' improvement of thinking without providing direct evidence (Gholam, 2018); yet another used writing assessment as direct evidence but failed to align its use of TRs and TMs (Hooper, 2015). Thus, there is an urgent need for alignments of course objectives, TRs, TMs, and learning assessment. We wish to solve the above problems by proposing an aligned thinking curriculum design and see how the aligned curriculum affects learners' thinking and learning outcome. We ask: 1) In what way does aligned design of TRs & TMs-incorporated curriculum and teaching intervention affect students' performance of movie analysis? 2) In what way does aligned design of TRs & TMs-incorporated curriculum and teaching intervention affect students' perception of thinking and learning?

Research methods

We employed a case study method (Creswell & Poth, 2013) because case study can respond to the complexity of a real-world context via observation and collection of multiple sources of evidence. Also, in response to the uniqueness of our aligned thinking curriculum and our research focus on how the aligned curriculum affects students' thinking and learning, we adopted purposive selection approach (Creswell & Poth, 2013) and selected a 3-credit EFL elective in a Taiwanese university, titled *English Movies & Social Issues* to enact our curriculum.

Case description: Aligned TRs & TMs-incorporated curriculum and teaching intervention

Our design of the aligned TRs & TMs-incorporated curriculum was enacted in the *English Movies & Social Issues* course for a semester (eighteen weeks), and the VT approach was the underlying principle of all course activities and interaction. This course was an EFL course designed for intermediate level non-English majored students. There were 20 students in this class, all of whom were Taiwanese. One of the researchers was also the instructor in this case. Throughout the semester, four movies were analyzed. We adapted the design principle suggested by Ron Ritchhart (2015) and proposed our aligned curriculum design by 1) selecting four TMs (building explanations and interpretations, making connections, considering different viewpoints and perspectives, and reasoning with evidence) that correspond to course nature and common thinking weakness observed by the researchers; 2) translating TMs into course-specific goals statements; 3) selecting TRs that match the goals statements; and 4) designing assessment rubric that uses four TMs as criteria and divided each into three levels with aligned description of performance. Take TM considering different viewpoints and perspectives for example. It was translated as course objectives and forthcoming rubric as: challenge the perspective of the movie, look at things from the perspectives of different people or things, and step inside the movie character's position and his/her perspective. To reach these objectives, TRs *Circle of viewpoints* and *Step inside* were then used repeatedly in different movies to guide students' thinking and movie analysis. Then TM considering different viewpoints and perspective taking were used to assess students' performance and provide feedback.

Data collection and analysis

We collected the following data to respond to our research questions: a pre- and post-test of thinking self-evaluation, movie analysis writing, and students' self-reflection. First, twenty pre and post-test of thinking self-evaluations were collected in Week 2 (pre-test) & Week 16 (post-test). Students evaluated their degree of agreement to each statement on a 5-point Likert scale. The results were analyzed with descriptive statistics and t-test. Secondly, eighteen movie analysis writing was collected in Week 2 & Week 17 (Writing 1 and Writing 2) and required students to analyze social issues in the movie "Hidden Figures." They were graded with the TM grading rubric, which was piloted in another similar course and showed high reliability (Cronbach's α value is 0.886). The results were analyzed with descriptive statistics and t-test to capture students' change of performance. To further capture the qualitative nature of students' learning process, eighteen students' self-reflections about their learning experience were collected in Week 18 and analyzed by open-coding approach.

Results

How TRs & TMs-incorporated curriculum affects students' movie analysis

As shown in Table 1, analysis results of pre and post-test of thinking self-evaluation showed that p-values have all reached significant statistical difference between pre- and post-tests for all four TMs. And the TM considering different viewpoints and perspectives has the biggest effect size (-0.96), followed by the TM building explanations and interpretations (-0.83).

Table 1
Analysis result of pre and post-test of thinking self-evaluation (n=20)

thinking moves	pretest average	posttest average	average difference	t	df	p	Cohen's d
building explanations and interpretations	3.65	4.213	0.563	-3.71	19	0.001*	-0.83
making connections	3.717	4.067	0.35	-2.101	19	0.049*	-0.47
considering different viewpoints & perspectives	3.633	4.167	0.534	-4.292	19	< .001*	-0.96
reasoning with evidence	3.5083	4.117	0.534	-2.43	19	0.025*	-0.543

Secondly, as shown in Table 2, analysis results of movie analysis showed that p-values have all reached significant statistical difference between average score of Writing 1 and Writing 2 for all four TMs. The TM considering different viewpoints and perspectives has the biggest effect size (-1.062), followed by making connections (-0.709).

Table 2
Analysis Results of movie analysis writing (n=18)

thinking moves	**Writing 1 average**	**Writing 2 average**	**average difference**	**t**	**df**	**p**	**Cohen's d**
building explanations & interpretations	2.556	2.833	0.277	-2.557	17	0.02*	-0.603
making connections	2	2.556	0.556	-3.007	17	0.008*	-0.709
considering different viewpoints & perspectives	1.5	2.278	0.778	-4.507	17	< .001*	-1.062
reasoning with evidence	2.444	2.667	0.223	-2.204	17	0.042*	-0.519

To sum up, the above two analysis results showed that while students' use of TMs have improved consistently, the most obvious improvement was shown in considering different viewpoints and perspectives.

How TRs & TMs-incorporated curriculum affects students' perception of thinking and learning

Students' self-reflection demonstrated two themes: perception of thinking improvement and learning process. The first theme corresponds with the targeted TMs very well that students' reflection about improvement of thinking could easily fall into four topics titled as four TMs. The second theme about learning process was divided into two topics: expression confidence and gain from group discussion. We then calculated the number of students whose reflections fall into each theme and topic and presented the result in Table 3.

Table 3
Coding results of students' self-reflection (n=18)

Theme	**Topics**	**No. of students**
Perception of thinking improvement	building explanations & interpretations	13
	making connections	17
	considering different viewpoints & perspectives	15
	reasoning with evidence	10
Learning process	expression confidence	10
	gain from group collaboration and discussion	12

As shown in Table 3, 15 students (83%) mentioned their improvement in considering different viewpoints and 17 students (94%) felt improvement in making connections. We can see that aside from the positive research results of movie analysis writing, students also perceived overall improvement of their thinking. The second theme helped the researchers capture students' learning process. Ten students (56%) felt more confident and more expressive in group discussions and gained a sense of achievement. Twelve students (67%) reported gain from group collaboration and discussion and reflected that the constant group sharing and collaboration by following thinking routines gave them an open space to listen to different opinions and thus inspired them to trigger more thoughts of their own. Meanwhile, they felt interaction and feedback they give each other genuinely and supportively boosted their confidence of expression and provided them new perspectives.

Discussion and implications

In response to problems brought by thinking curriculum misalignments, we proposed an aligned TRs and TMs-incorporated curriculum and analyze its impact on students thinking and learning. Our positive research results lead to three important implications. First, our alignments make it possible to explain how use of TRs corresponds to course objectives and our TM grading rubric makes students' action of thinking and learning outcome assessable and traceable to course objectives. Second, our alignments provided practitioners an applicable example of how generic principle of teaching of thinking can be transformed into domain-specific design principle. Third, the present design of a thinking curriculum solved the problem of decontextualized teaching of thinking and situated teaching of thinking in a meaningful social context. The alignments send a clear message to students about the importance of deepened thinking and building knowledge in the community of learning. This echoed with previous literature that learning happens when thinking is made visible and situated in a community of practice (Collins, Brown, & Holum, 1991). We acknowledge our limitation of addressing only four TMs. Further research may be conducted to assess other TMs. It'd be also valuable to adopt our thinking curriculum alignment in other courses to generate a more solid design principle.

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“As a Woman, I Learned to Be Hard”: Exploring a Network of Dualisms in the Geoscience Education Department

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Abstract: This paper explores how geoscience education contributes to a ‘linked networked of dualisms’ (Plumwood, 1991) that reinforce binary distinctions between feminine/masculine, nature/culture and emotion/reason. We examine how those demarcations get enacted at the level of the ‘skin’ (Ahmed & Stacy, 2001) and are *felt* as ‘atmospheric practices’ (Bill & Somensen, 2021). The linkage between those dualisms became apparent following interviews with ‘Jessica’ a graduate student in the geoscience department retelling her experiences with sexual harassment and microaggressions in a culture where she had to ‘learn how to be hard’ as part of a ‘work hard, play hard’ culture. We explore the various ramifications of ‘hardness’ in relation to the gendered and material practices that perform Jessica’s ways of being as a student in the geoscience department. One conclusion is that ‘over-representation of the rationalist Man’ (Wynter, 2003) in this setting happens *affectively*, at the level of the skin.

Introduction

This paper is situated within the vast literature that examines issues of under representation, microaggressions and social inequities faced by racially and gender diverse students in science education and STEM majors (e.g., Vakil, & Ayers, 2019). One of the ways that science education maintains those inequities is by reproducing existing hegemonic structures in society (Strong et al., 2016). This paper explores how geoscience education, (broadly a STEM related field) contributes to a ‘linked networked of dualisms’ (Plumwood, 1991) that reinforces binary distinctions between feminine/masculine, nature/culture and emotion/reason. We examine how those demarcations get enacted and are sensed at the level of the ‘skin’ (Ahmed & Stacy, 2001) as ‘atmospheric practices’ (Bill & Somensen, 2021) and are not simply conceptually/discursively rehearsed. The emotional and corporeal aspects that make up students’ lived experiences in STEM are often overlooked and without such understanding, “the struggle against (racial and gendered) inequity will always be incomplete” (Bonilla Silva, 2019, p. 2). This paper explores how practices within geoscience leave their impressions on the ‘skin’ of ‘Jessica’ a graduate student in the geoscience department retelling her experiences with sexual harassment and micro-aggressions in what she describes as a “work hard, play hard culture”.

Ecofeminism and affect

Geoscience education focuses on fostering an understanding of the Earth and its history. In generating such knowledges, the geosciences rely heavily on practices, that involve extraction of non-renewable resources and the displacement of communities to produce goods and luxuries for industrialized countries (Marin Spiotta et al., 2020). Hence, Monarezz et al. (2021) see racism and colonialism to be necessarily intertwined with the history of geoscience (and other related fields, e.g., paleontology). With a recognition of patriarchal edifices within projects of colonialism (Wilson, 2005), St John et al. (2016) discuss pervasiveness of sexual harassment in the geoscience department. In considering this context, ecofeminists offer important insights that highlight “important connections between how one treats women, people of color, and the underclass on one hand and how one treats the nonhuman natural environment on the other” (Warren, 1997, p. xi). Shiva (1993) finds that it’s especially important “to examine the connections between the violence of unjust, non-sustainable economic systems and the growing frequency and brutality of violence against women” (p. xiv). Braidotti et al. (1994) similarly argue: “that we must recognize that women and nature are simultaneously subjugated, and that this subjugation takes historically and culturally specific forms” (p. 75). For instance, Western philosophies have taught us “that our bodies and emotions are untrustworthy sources of knowledge” (Kheel, 2009, p. 2). As such, emotions have often been feminized as subjugated ways of knowing, setting them squarely against reason and judgment (see Boler, 2004). The invisibility of bodies and knowledges is not only tied to a dismissal of emotions but to their hierarchies (what emotions are deemed acceptable and not in Western societies) and how such hierarchies have served to further de-legitimize historically marginalized peoples, with implications for contemporary schooling practices (Zembylas, 2022).

Our paper draws on ecofeminist scholars and feminist-affect scholars in suggesting that “rationalism is the key to the connected oppressions of women and nature in the West” (Plumwood, 1991, p. 3) and to highlight how those connected dualities are themselves enacted affectively and corporeally. Ahmed and Stacy (2001) propose a 'thinking through the skin' as a thinking not on "the body as the lost object of thought but on the modes of being-with and being-for, where one touches and is touched by others" (p. 1). To consider the interface between bodies and their worlds is to analyze how 'bodies' *surface* in social relationships "without necessarily fetishizing the body" (p. 3). Hence, emotion/reason duality is not simply relegated to a conceptual separation that is reproduced discursively, but such a demarcation is sensed/produced at the interface of the skin. Cultural geographers have attended to the spatiality and affects of the lived body in social settings by turning to "atmospheric practices and atmospheres as practiced" (Bill & Somensen, 2021, p. 305). An atmospheric practice is the *attunement* to people, objects and places through the affects of the lived body; it's the feeling you get when you enter a room. The notion of affective atmosphere insists that our intimate feelings do not belong to us but are an effect of how bodies encounter other bodies. Yet, Ahmed reminds us, how we become attuned and attune others to our bodies come from 'past encounters'. In that sense, "the work of equality is a deeply corporeal work" (Ahmed, 2014, p. 101) accounting for the effects and affects of a skin that does not simply contain us but that exposes us to others (Ahmed, 2004).

Åhäll (2018) seeks to reclaim affect as a feminist knowledge, offering a critique to the separation between affect and emotion which tends to reinforce "a binary, gendered logic between a mobile, impersonal and masculinized affect and a contained, feminized, personal emotion" (p. 40). For her, "there is no feminism without affect" (p. 38). This means that how we feel about the world, already tells us how the world works, which helps to generate feminist questions (where feminism is understood beyond just 'women's stuff'). Such feminist questions can support more nuanced insights about how humans encounter each other in educational spaces.

Sensing geoscience education is an attunement to how bodies touch and are touched (materially, emotionally/affectively). Vea (2020) argues that "practicing affect" is a way of knowing and feeling in situated learning practices. Similarly, in our analysis we focus on how *practices* are in themselves 'felt' phenomena that intertwine bodies with their social and material environments (Bill & Somensen, 2021). We outline those practices through the experiences of 'Jessica' a graduate student in the geoscience department re-telling her experiences with sexual harassment in her undergraduate degree and how she had to learn to develop a 'hard (skin)' in this environment. As such, we advance that geoscience education is implicated in "the social and cultural production of the skin" (p. 4) (and relatedly categorizations of the human, see McKittrick, 2015; Adams & Weinstein, 2020), affecting how women (and possibly other gendered and racialized groups) might experience their belonging to the field.

Methodology and context

Data for this study comes from a larger project that examines race and gender-based issues in STEM education at the postsecondary level. Data collected for this research include an exploratory survey of students' experiences of gender and race-based discrimination in STEM fields in a major Canadian city and follow up interviews with consenting participants to gain an in-depth understanding of their experiences. The present research takes a case study approach (Stake, 1995) looking at the experiences of 'Jessica', a graduate student in the geoscience department. A case study affords a possibility to study the particularities and complexities surrounding students' experiences (Stake, 1995). At the time of the interview, Jessica identified as a white heterosexual woman. Two interviews were conducted with Jessica. The first interview was for one hour and the second follow up interview was for 45 minutes. In the first interview, Jessica shared personal experiences with sexual harassment and microaggressions, that were mostly pronounced during her undergraduate degree. In the follow up interview, we asked Jessica to further elaborate on previous answers based on emerging themes. The authors also invited Jessica to provide her feedback on data analysis and dissemination and to check specificities of experiences shared in the first interview. For our analysis, we focused on specific practices of how bodies come into contact with other bodies, as a result of attuning to the affective intensity and hardness of recounted moments that were felt on the surfaces of Sarah's skin (first author, cisgender woman) encountering the stories of 'Jessica' in the moment of the interview. Rather than asking what those practices mean, our analysis looks at what those practices 'do' in materializing surfaces and boundaries (Ahmed, 2007), giving the geoscience department its distinct atmospheric 'feel'.

Discussion of findings

Jessica described geoscience education as a 'work hard, play hard' culture, which could be viewed as an "atmospheric practice" (Bill & Simonsen, 2021) surrounding how students are attuned and attune themselves and others to their education in this field. We trace the 'work hard play hard' atmosphere to four material and bodily practices: drinking, forcing, blocking and carrying, as evident in stories shared by Jessica. We intentionally use those verbs to highlight *the affective forces* that work on the skin and are worked by the skin to contour the body as ‘given’ either (emotional) woman/ (rationalist) man, nature/culture, and that serve to re-intensify the entanglements between those dualities (Plumwood, 1991).

Drinking

In elaborating on the ‘hardness’ aspect of the geoscience education culture, Jessica mentioned how it rests on heavy drinking and partying. She recounted an experience where, following field work (where students go to the field to apply learned techniques), an instructor stopped the bus next to a liquor store and bought a case of beer for everyone to celebrate their hard work in the field, asking them not to tell anyone. The pervasive and secretive drinking culture perpetuated by some of the teaching faculty, and where drinking is seen as a way to forge relationships for future employability, draw boundaries for who can (and what it takes to) participate in this culture. Heavy drinking is considered “the mark of man” (Dempster, 2009), reproducing an atmosphere of masculinity, attuning bodies to objects (alcohol), to each other and to their relationship to a practice that defines the field.

Forcing

Jessica shared her experiences with another male student who would call her in the middle of the night, kiss her without her consent, touch her inappropriately, and force a hug after showing up uninvited to her apartment. She discusses the occurrences of those events in relation to various out-of-school networking events that are essential to students’ success in their degree (e.g., forging relationships and bonding in those social events facilitate group work inside the classroom, as Jessica later explained). Relatedly, Jessica discussed the sanitized version of her courses in geoscience that overlooked how geographers trespassed lands and forcefully displaced communities through their extractive practices, portraying them instead as “rugged explorers, working with rocks who made ‘great’ contributions to science”. In its various bodily enactments, practices of forcing and trespassing justify and entangle the instrumental treatments of women and nature.

Blocking

Jessica described instances where a male classmate would repeatedly and intentionally block her when she is talking to her friends, standing in between them, shaking their hands, as if she didn’t exist. In confiding to her female supervisor who supported her during those difficult times, she advised her to “to put an armor on” to be able to deal with those things. As such, Jessica learned to develop a ‘hard skin’, not showing her vulnerabilities nor her emotions, yet still somehow mocked at. Those various instances of being blocked (by her male colleague) and her attempts at blocking her emotions through putting a hard skin, show how the geoscience department simultaneously de-humanizes women while re-entangling the emotional with the feminine.

Carrying

In field school, Jessica, along with 3 other women in the program, felt pressured to work extra hard, so they could prove themselves. She mentioned having to “carry more to keep up with the rest of the guys”. Later in the day, she would hear her peers chatting in the middle of the night about who she had a crush on. She said, in this culture: “it would be safer to be in a relationship, it’s sort of a visible boundary to let people know that [as a woman you are] off limits”. Retelling her emotional state during those times, she mentioned having to “carry a black cloud over her head”. Carrying speaks to the material (physical) and atmospheric aspects of inhabiting a ‘female body’ and further contributes to the exclusionary boundaries of the geoscience department.

Conclusion and significance

The “work hard, play hard” affective atmosphere and its constitutive bodily and material practices in the geoscience department contribute to a ‘rationalist conception of the human’ that operate to justify instrumental treatment of humans and non-humans (White, 2013). One conclusion is that the ‘over-representation of the rationalist Man’ (Wynter, 2003) in this setting happens *affectively*, at the level of the skin. Challenging atmospheric practices of STEM education (in this case a work hard, play hard culture) may be an entry point to “decolonizing the very institutions that have shaped our ontologies of what it means to be human” (Adams & Weinstein, 2020, p. 248). This study further meets previous research that looks at how ‘emotions’ are a target in their own right for processes of identification (Vea, 2020). While the present analysis draws on experiences of one student who identifies as a white woman in a STEM-related field, our analysis acknowledges the need for an intersectional lens that takes into better account the nuanced sensations that delimit how different groups (with both visible and less visible identity traits) might experience their belonging to STEM fields.

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International Society of the Learning Sciences

Mind the (Is/ought) Gap: A Call for an Applied Ethics of Design-Based Research

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Abstract: Design-based research typically aims to mediate certain actions that learning scientists perceive as worthy or good, meaning that it is an inherently ethical activity. However, the ethical considerations that motivate learning scientists are oftentimes left implicit. In this paper we call for an applied ethics of DBR, which would make the ethical reasoning that is fundamental to our work a more systematic part of our scholarship. We begin by explaining why moral responsibility for learners' actions can be viewed as shared between learners and the learning scientists who designed their learning environment. We then posit that coherentism, which combines top-down and bottom-up methods of moral justification, is the most apt approach to an applied ethics of DBR. Finally, we conclude by highlighting one way in which an ethics of DBR might transcend the learning sciences community to advance ethical theory more broadly.

Introduction: The ethics of DBR

What motivates learning scientists to engage in design-based research (DBR), and how can they be sure that their efforts are worthwhile? We posit that ethical considerations are fundamental to DBR, even though they are oftentimes left implicit in learning sciences literature. Sandoval's (2014) notion of conjecture mapping, for instance, details how DBR is intended to mediate a shift from *what is* towards *what ought to be*, meaning that it is an inherently ethical process because it requires researchers hold the view that some actions and outcomes are in some way *better* than others. And yet, there is no rubric in his proposed logic model dedicated to articulating or justifying the moral reasoning undergirding researchers' DBR work (Cf. Cohen, Ben-Zvi & Hod, 2023).

In what follows, we address three issues that are key to developing the ethics of DBR. In the first section we argue that learning scientists bear some moral responsibility for students' actions, even though it is students themselves who are meant to become better people or do better deeds as a result of DBR. In the second section we call for the development of an applied ethics of DBR akin to what can be found in other specialized fields such as medicine, law, business, or war. We also posit in this section that the unique features of DBR lend themselves to a *coherentist* method of moral justification, which combines top-down and bottom-up approaches to moral reasoning. And finally, in the third section we outline a unique type of empirical ethics that we envision for the learning sciences community and explain why we believe that learning scientists are well-positioned to make a meaningful contribution to ethical discourse more broadly. Our overarching goal is to encourage learning scientists to be more explicit about their ethical commitments, and to provide some rudimentary conceptual tools that might ultimately pave the path towards a systematic and rigorous ethical literature to complement and extend the rich DBR discourse that has already taken hold in our community.

From an ethics of design to an ethics of DBR

Underlying any ethical discourse is the assumption that people strive (or ought to strive) to do good deeds and avoid doing bad ones. Once this has been established, ethical reasoning touches on questions such as what makes one deed better than another, how might an agent distinguish between good and bad deeds, or what course of action an agent ought to choose when two deeds (or more) are available. Ethical discourse also assumes a measure of agency comprising freedom and intentionality because for agents' actions to be good or bad, they must be aware of what they are doing and be capable of doing something else instead. Assisting those in need is typically viewed as good, and stealing as bad, only if they reflect choices made by an agent. Simply digesting one's food after eating it is an action that usually involves neither free will nor intentions, and hence is ethically neutral.

One corollary to all of this is that ethical discourse typically focuses on the relationship between agents and *their own* actions, meaning that bringing it to bear on DBR might be challenging. DBR does not form a direct link between scholars' agency and their own actions, but rather is oriented towards the actions of others: it is centered on a process whereby researchers design and investigate a learning environment in which they hope that learners – *not* researchers themselves – will act in certain ways. To put things differently, we might argue that DBR either affords students enough agency or it doesn't. If it does, and students still have enough intentionality and free will for their actions to be considered good or bad, then we might argue that designing the learning environment is morally neutral. On the other hand, if the learning environment denies agency by forcing learners to act in certain ways, then students' actions would be rendered neutral because they had no choice in the matter. This analysis would lead us to articulate the ethics of DBR in zero-sum terms: either scholars' actions are ethically charged and learners' actions are neutral, or vice versa, but not both.

An alternative view that accounts for a complementary contribution of learners and researchers to learners' action builds on the notion of mediation, which has always been central to the learning sciences. Verbeek (2009) identified perception and action as two primary forms of mediation. Some tools, such as glasses or thermometers, amplify and reduce certain aspects of reality in ways that shape how we perceive it, while other tools, such as speedbumps or disposable cups, are imbued with scripts (a term he borrowed from Latour, 1992) that "suggest specific actions and discourage others" (Verbeek, 2009, p. 230; see also Norman, 2013). Given the ubiquity of technology and the fact that almost all human activity is mediated by one technology or another, Verbeek argues that it would be futile to discuss ethics in isolation from technology. His conclusion is that agency must be viewed as distributed between individuals and the technologies that mediate their perception of reality, their potential actions on it, and by extension also their sense of self and others. For instance, all ethical questions surrounding pregnancy and unborn fetuses are shaped by the technologies that allow us to see inside people's bodies and act upon them, such as ultrasound and other sophisticated tests, procedures, and medications. These technologies cannot determine *on their own* whether, or under what circumstances, abortions are ethical; but neither can any ethical discussion of abortion disregard the technologies that are available. Verbeek therefore concludes that "design is inherently a moral activity. By designing artifacts that will inevitably play a mediating role in people's actions and experience, thus helping to shape (moral) decisions and practices, designers 'materialize morality'; they are 'doing ethics by other means'" (p. 235).

In a similar vein, we maintain that learners' actions are inevitably mediated by their learning environment, which can include curricular materials, task structures, participant structures, and more (Sandoval, 2014). All these elements are designed to amplify and reduce how learners perceive certain elements of the curriculum and of reality and are imbued with scripts that call on learners to engage in some actions and avoid others. Adopting Verbeek's approach therefore suggests that the morality of learners' actions is distributed between learners, their learning environments, and their designers. By extension, we would argue that by engaging in DBR, learning scientists must assume some of the moral responsibility for students' actions (but not all of it!), and must explain – to themselves and others – why they view some educational actions and outcomes as better than others. But where do scholars' views of good, bad, right, and wrong come from, and how can they justify them? We address this question in the next section.

The case for coherentism in DBR

By calling for a more robust discourse surrounding the ethical dimensions of DBR we are expressing the hope that learning scientists will eventually develop a body of *applied ethics* akin to those found in medicine, business, war, law, and other fields. In contrast to general moral theories about what is good and right (and how to justify claims about what is good and right), applied ethics are concerned with more practical questions that arise in specific settings – often professional ones. They are intended to guide professionals and practitioners in their work by addressing the unique circumstances that they regularly encounter (Beauchamp, 2005).

We have already suggested that when scholars answer questions about the knowledge and skills students *ought* to acquire or how their identities or communities *should* develop amid learning, they should systematically justify the claim that these are *good* outcomes. Especially given that learning scientists design learning environments with the explicit aim of altering the current state of affairs, they must be equipped to convince themselves and others that they are doing the right thing. But how are they to know what is right? Beauchamp (2005) distinguished between *top-down* and *bottom-up* methods of justification in applied ethics. *Top-down* models are those that seek to bring general convictions about what is good to bear on a specific field such as DBR. For instance, learning scientists who are morally committed to safeguarding the future of the planet by minimizing human reliance of fossil fuels may design a learning environment with the goal of strengthening learners' understanding of global warming (Herman, 2015). They would view such a learning environment as *good* because it is aligned with their broader ethical convictions, namely their belief that they are morally responsible to do more to mitigate global warming. In contrast, bottom-up models extrapolate general ethical imperatives from individual cases that are viewed as authoritative. A good example in the learning sciences is the centrality of expertise, which learning scientists often viewed as an ideal type worth emulating. The *Reading Like a Historian* project is a case in point; it constitutes a DBR effort to teach students to adopt some cognitive tools used by expert historians, whose expertise is the primary justification for their tools' *goodness* (Reisman, 2012).

On its own, each of these methods of justification is fundamentally flawed (Beauchamp, 2005). The bottom-up method is a classic case of the is/ought problem, originally articulated by Hume (1739), who warned against moral reasoning that infers from the empirical (*what is*) to the ethical (*what ought to be*) without providing ample evidence. In other words, the fact that expert historians ask certain questions when they read historical texts does not in itself justify the claim that this is what they – or anyone else – *ought* to do. In a similar vein, the top-down method is always insufficient on its own because translating general moral principles into real-world contexts requires specification, meaning that it must account for "feasibility, efficiency, cultural pluralism, political procedures, uncertainty about risk, non-compliance by disaffected parties, moral dilemmas, and the like" (Beauchamp, 2005, pp. 12-13). For example, climate change is a politically charged topic that may arouse resistance or be unsettling (Herman, 2015; Walsh & Tsurusaki, 2017). Therefore, learning scientists ought to take learners' expected responses and emotions into account alongside their commitment to mitigating climate change because simply teaching about climate change will not necessarily result in the desired outcome. Hence, the commitment to the future of the planet cannot on its own justify the design of a specific learning environment intended to teach about climate science.

Coherentism is an approach that integrates the top-down and bottom-up models by applying moral theory and principles to increasingly more specific cases, and simultaneously developing the said theory based on the experience and insight gained by applying it. Gutierrez and Jurow's (2016) approach to Social Design Experiments demonstrates how a coherentist approach can be implemented by learning scientists who are engaged with the ethical dimensions of DBR. In their own words, Gutierrez and Jurow's (2016, p. 565) approach is intended to advance "[1] the social agenda of ameliorating and redressing historical injustices, *and* [2] the development of theories focused on the organization of equitable learning opportunities." The first goal embodies a top-down approach and the second embodies a bottom-up one, whereas the combination between the two embodies coherentism. Due to the iterative nature of DBR, a coherentist approach is especially apt for our research community. Within coherentism, broad moral theories (e.g., "ameliorating and redressing historical injustices") and specific examples of how they are applied (e.g., how to design for "equitable learning opportunities") are *always* taken to be dynamic and subject to change in light of one another. Indeed, according to Beauchamp (2005, p. 11), when adopting the coherentist approach

> we have no reason in applied ethics to anticipate that the process of achieving moral coherence will either come to an end or be perfected. A moral framework adequate for applied ethics is more a process than a finished product; and moral problems […] should be considered projects in need of continual adjustment by reflective equilibrium.

A vision of empirical ethics in DBR

In this final section we outline how we think an applied ethics of DBR can transcend the confines of the learning sciences community and have a broader impact on ethical theory. To accomplish this, we briefly shift our gaze to bioethics, a field that has witnessed the emergence of a new genre of research known as *empirical bioethics*. This sub-field "seeks to ask and answer questions of bioethical interest in a way that draws on the strengths of both philosophical and empirical analysis" (Davies, Ives, & Dunn, 2015, p. 1). Dating to the beginning of the century, the empirical turn in bioethics emerged as an alternative to traditional forms of applied ethics dominated by theologians and philosophers, which many physicians considered "too abstract, too general, too speculative, and too dogmatic" to inform their day-to-day work (Borry, Schotsmans, & Dietrickx, 2005, p. 64). According to McMillan (2017, p. 31), "good empirical ethics[...] should fuse robust ethical argument with the groundedness and sensitivity to context that result from a well-constructed empirical investigation."

We maintain that due to the unique nature of DBR, learning scientists are well-poised to contribute to efforts to advance a more empirically grounded applied ethics that can transcend the is/ought gap by adopting a coherentist approach that employs innovative empirical methods. For example, one promising innovation in DBR along these lines is Participatory Design Research, an approach that has called on learning scientists to develop an ethical discourse that is dually grounded in ideology and rigorous empirical research. In their discussion of Participatory Design Research, Bang and Vossoughi (2016, p. 174) argued that current research paradigms often "maintain, either explicitly or implicitly, normative hierarchically powered decision-making structures." These hierarchies notably include implicit ethical judgements and moral reasoning about what is right and good, which means that they foreground scholars' views in ways that can suppress the views of students, teachers, and other partners in DBR projects. As an alternative, Bang and Vossoughi (2016) propose a participatory approach to DBR that would require learning scientists to undermine these power structures by widening their views of what constitutes empirical research to include "historical, relational, and axiological perspectives and the ways these are embodied and experienced." (p. 174) In line with this emerging research paradigm, it has become increasingly more common for learning scientists engaged in DBR to be forthcoming about their own lived histories in order to empirically frame their research partnerships in terms of subject-subject relations. Foregrounding our positionalities as researchers in a systematic way and analyzing their consequentiality as a key element of our methodology offers a compelling example of the unique contribution that our community stands to make to a broader ethical discourse because it holds promise as a way of theorizing how we draw on empirical research to make the leap from *what is* to what we believe *ought to be*, and how our scholarship can help get us there.

Conclusion

We are convinced that all learning scientists who design and integrate innovative learning environments do so because they want to make a valuable contribution to learners and to society. But up until now, our community's engagement with the ethical considerations driving their work has been somewhat sparse and anecdotal. The purpose of this paper was to lay some foundations for a more robust and systematic ethical discourse that might become a core element of DBR. We started out by showing how the ethics of design employ the notion of mediation to support the claim that agency and moral responsibility for learners' actions is distributed between learners and researchers. We then went on to outline a crucial correlation between the iterative design of DBR and the coherentist approach to moral justification in applied ethics, which combines top-down and bottom-up methods of moral reasoning. Finally, we identified participatory design research as one methodological innovation that an empirical ethics of DBR stands to contribute to other fields. By foregrounding researchers' positionalities, the participatory approach to DBR can help elucidate the theoretical leap from what is to what ought to be, a puzzle that has eluded ethicists for centuries.

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The Relationship Between Appropriation and Guided Participation During Teacher Professional Learning

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Abstract: In a community of practice, such as those designed to support teachers' professional development, learning is fostered through participation in the joint enterprise of the community as teachers appropriate practice and engage in guided participation of practice. Because sociocultural activity is not sequential or isolated, this study explores the interaction between guided participation and appropriation in one environment designed to support teacher learning: side-by-side coaching. In side-by-side coaching, a teacher and coach partner to co-enact a focal pedagogical practice with the teacher's students during instruction. In our analysis, we explore the relationship between appropriation and guided participation during side-by-side coaching, finding two kinds of teacher learning opportunities at their intersection. Both theoretically and analytically, our findings indicate that appropriation is inherent to the process of teacher learning, rather than an outcome or end point.

Introduction

In a community of practice, such as those designed to support teachers' professional development, learning is fostered through participation in the joint enterprise of the community (Wenger, 1998). Participation is construed broadly in this theoretical approach, from working alongside a more knowledgeable other to interacting with the community's tools and artifacts. Rogoff (1995) further developed this theory of learning into an analytic lens, proposing that participation in communities occurs – and can be analyzed – in three interdependent planes: the apprenticeship plane, the guided participation plane, and the participatory appropriation plane. In the apprenticeship plane, participation in activity is shaped by sociohistorical, cultural, and institutional contexts. In the guided participation plane, individuals participate in shared activity, communicating and coordinating efforts, refining and participating in activity. While in the appropriation plane, individuals take up, transform, and enact practices, making them part of their repertoire. Rogoff argues that in any system of sociocultural activity all planes are relevant and mutually constituted.

These approaches to learning in sociocultural activity have been widely taken up in research on teacher professional learning, across teaching disciplines, school levels, and learning designs (e.g., Grossman et al., 2001; Horn, 2005; Loucks-Horsely et al., 2009). Much attention has foregrounded the guided participation plane, focusing on interactions between and among teachers and teacher educators, how such interactions are designed, sequenced, and co-constructed (e.g., Gibbons et al., 2021; Horn, 2010). Other forms of research focus on the effects of professional development (PD) and examine appropriation as it occurs after PD, when teachers return to their classrooms to implement what they have learned (c.f., Longhurst et al., 2022). This work foregrounds one plane over others to examine its mechanisms and implications, an approach Rogoff (1995) argued was appropriate provided all planes were acknowledged.

Ultimately, sociocultural activity is not sequential or isolated, (Rogoff, 1995). Instead, learning involves moving between multiple planes. In this study, we investigated how guided participation and appropriation co-occur and support one another during teacher professional learning (e.g., Ghousseini et al., 2015). Broadly, we seek to understand the learning opportunities emerging at the juncture of appropriation and guided participation.

This study explores guided participation and appropriation in one environment designed to support teacher learning: side-by-side coaching. In side-by-side coaching, a teacher and coach co-enact a focal pedagogical practice with the teacher's students during instruction. Either adult might lead interactions with students, and the pair engage in professional discourse about the enacted practice as it occurs, making decisions or addressing emergent problems of practice. In our analysis, rather than foregrounding one plane, we explore the relationship between two by asking: What is the relationship between appropriation and guided participation during side-by-side coaching? How did these structures interact to support teacher learning opportunities?

Methods

Study design, participants, and data

This study was embedded in a teacher-initiated research-practice partnership between teachers at a public, urban elementary school in California and the mathematics teacher educators at a local university, including the first author who served as the coach. The three participating teachers spanned different grade levels (Grades 1, 2, and 4) and stages of their careers (2-17 years teaching experience). All three shared the goal of learning to support students to learn collaboratively through problem solving and discourse. The coaching period of this study lasted four weeks for each teacher. Each week, the teacher and coach engaged in side-by-side coaching during two mathematics lessons, for a total of 7-8 lessons of side-by-side coaching per teacher and 21 side-by-side coaching lessons across the three teachers. Within these lessons, we focused on conferring interactions, where the teacher and coach interacted with small groups of collaborating students (Munson, 2019); it was these conferring interactions that teachers were learning to facilitate and was, therefore, the initial unit of analysis.

Analysis

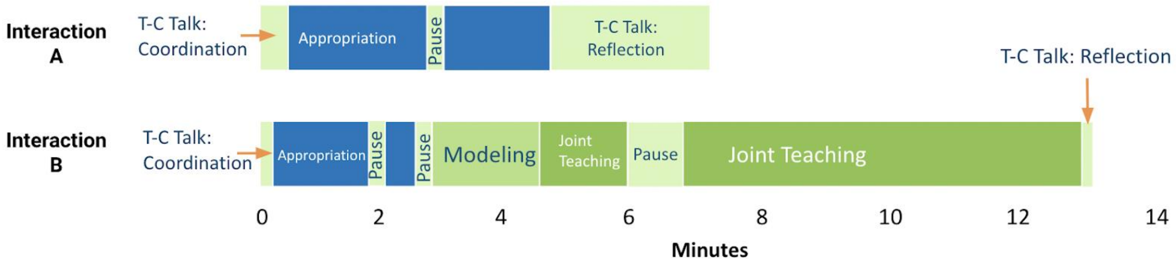
In the first phase of analysis, we coded each conferring interaction (n=50) for the type of participation drawing on Rogoff's conceptions of guided participation and appropriation. We operationalized guided participation and appropriation by who was leading instruction (teacher, coach, or both), the instructional activity, and whether students were part of the interaction. *Appropriation* of conferring was conceptualized as occurring during a conferring interaction when coaching was taking place and the teacher was leading the instruction. We operationalized *guided participation* around the central principle that guided participation involved both the teacher and coach participating in conferring (the focal pedagogical practice) or professional sensemaking through coaching. We isolated instances of appropriation and guided participation across all 50 conferring interactions and identified five types of guided participation that occurred within conferring interactions: (1) joint teaching, (2) modeling, (3) coordination, (4) pauses, and (5) reflection. In the second phase of analysis, we looked for patterns in how instances of appropriation were sequenced with and related to instances of guided participation within conferring interactions. We created maps of each conferring interaction to show the sequence and duration of participation in each form of activity. We then looked for patterns in how these instances were sequenced across all 50 conferring interactions.

Findings

We found that in side-by-side coaching, teachers moved between appropriation of practice and five forms of guided participation. Appropriation was common during coaching, occurring in 23 of 50 conferring interactions. Across these 23 conferring interactions, there were 35 instances of appropriation, indicating that appropriation and guided participation were sometimes interspersed. The mean duration of each instance of appropriation was approximately 2.5 minutes, with conferring interactions lasting approximately 11 minutes on average.

Appropriation interacted with guided participation in two primary ways. First, appropriation was often interspersed with pauses, a form of guided participation in which the coach and teacher stepped back from interacting with students to discuss student thinking and make instructional decisions about what to do next (c.f., Interaction A in Figure 1). These brief interactions allowed the teacher to resume appropriation with new ideas or directions. Second, appropriation often occurred at the beginning of conferring interactions, then gave way to other forms of guided participation, most frequently joint teaching with the coach or the coach modeling instruction (c.f., Interaction B in Figure 1). In these instances, appropriation allowed the teacher to identify areas where guided participation could further support their learning.

Figure 1
Examples of Two Structures of Conferring Interactions Including Appropriation and Guided Participation



First, conferring interactions in which appropriation was interwoven with pauses (n=5) allowed the teacher to take full responsibility for enacting the focal practice while occasionally accessing the coach for support making decisions and interpreting student thinking (c.f., Interaction A in Figure 1). In those interactions, guided participation occurred through coordination prior to engaging with students, where the teacher and coach discussed how the interaction might proceed; reflection following the interaction; and pauses during the conferring interaction, where the teacher and coach stepped back from the conversation with students to engage in discussion before re-engaging with students.

For example, Interaction A shown in Figure 1 illustrates a conferring interaction that began with coordinating the roles of the teacher and coach, followed by several minutes of appropriation by the teacher. During this conferring interaction, the students were playing a game about telling time on analog clocks, and the teacher, Hope, wanted to check that students were using the correct hands on the clock to tell time. After sharing this plan with the coach during coordination, Hope listened in as a group of students began working. As the students got going, Hope asked them to explain how they were able to determine the time, and how they knew which hand was the hour hand. The students offered that the "long hand is the hour hand" while the other hand "kept moving around." Hope seemed to notice some confusion the students had in distinguishing the hour, minute, and second hands. The coach paused the interaction at that point, saying to Hope, "Maybe tell them you want them to focus on this clock," referring to the clock on the activity sheet, rather than the clock on the classroom wall. Hope immediately took up this suggestion, resuming her appropriation of the conferring practice. Through this engagement with the clock drawn on the activity sheet, the students were able to work with Hope to differentiate the hour and minute hands, and correctly determine the time being represented. After the interaction with students ended, the coach and teacher reflected on the interaction for several minutes before moving on to the next phase of the lesson. As part of the reflection, they discussed the challenge of the clock on the wall, which had a moving second hand, as compared to the clocks students were using, which just had hour and minute hands. They wondered together about multiple representations of clocks that students might see, and the mathematics involved in telling time. In this interaction and others like it, the pause created the opportunity for the teacher to access a targeted pedagogical move that she could immediately implement to further the interaction with students while continuing to appropriate the practice with students.

Second, in conferring interactions where appropriation was followed by joint teaching or modeling (c.f., Interaction B in Figure 1), the teacher was able to locate the frontier of their comfort with independent enactment and shift into guided participation though joint teaching with or modeling by the coach (n=16). In joint teaching, the coach and teacher actively co-led instruction, while in modeling, the teacher actively observed the coach leading the conferring interaction with students. All of these conferring interactions also included moments in which the coach and teacher paused instruction to make sense of student thinking and make decisions about instructional next steps. Appropriation, in interactions with this structure, served as an entry point to guided participation in the enactment of the focal practice.

For example, Interaction B in Figure 1 shows a conferring interaction that began with coordination, where the teacher, Hope, told the coach she wanted to check in with a student and her partner who had been struggling. Hope began by eliciting the pair's thinking about whether 9 = 10 - 1 was true or false, and one of the students said she was starting with the nine. The coach interrupted for a brief pause, asking Hope what she noticed about the child's thinking. Hope posited that the child was thinking about the problem left to right, and then resumed the interaction with the students. The pair then claimed that the equation was false because 9 + 9 = 18. Both students appeared to have introduced addition to the equation. The coach turned to Hope for another pause at this point, saying "It seems like the equation is really tripping us up. The symbols, right?" The coach asked to step in with the students, and at that point the interaction shifted into modeling as a form of guided participation. The coach asked the students a series of questions about the meaning of the equal sign. Once the coach had re-established an understanding of what the equal sign represented, Hope rejoined the conversation, shifting from modeling to joint teaching as both the teacher and coach continued to press on the students' interpretation of the equation. Using an equation mat to model the equation, eventually the students were able to make sense of the equal sign and distinguish the meaning of 9 = 10 - 1 from 9 + 9 = 18. As Hope and the coach left this group, Hope reflected on the interaction and wondered if other groups might need the same support with the equation mat. In this interaction, Hope led the interaction with students, appropriating conferring, until it became unclear how to fully uncover what the pair were confused about. Following a pause, the coach stepped in and modeled a set of probing questions, creating the opportunity for Hope to rejoin the conversation and engage in joint teaching. This final, extended engagement in guided participation with students through joint teaching helped the students distinguish comparing from joining and also gave Hope insight into the potential needs in the rest of the class.

Discussion

Drawing on a community of practice approach to teacher learning, practice-based and practice-embedded teacher learning designs have primarily focused on developing a repertoire of pedagogical tools to support guided participation in the practices under investigation. However, Rogoff's (1995) framework argues for considering the interdependence between guided participation and appropriation in joint activity. Applying this analytic lens to side-by-side coaching, we find that, indeed, appropriation interacted with guided participation to support opportunities for teachers to learn to enact practice. At the juncture of appropriation and guided participation, teachers had the agency to draw on a more knowledgeable other to fuel appropriation or explore emergent problems of practice in joint activity. That is, appropriation and guided participation were mutually supportive. Appropriation supported identifying the emergent problems of practice that could be grappled with during pauses, joint teaching, and modeling. Guided participation in the form of pauses supported further appropriation by addressing teachers' emergent questions such that they could re-enter teaching leading the interaction. Both theoretically and analytically, our findings indicate that appropriation is inherent to the process of teacher learning, rather than an outcome or end point.

While this study examined side-by-side coaching, we believe that there are additional settings in which appropriation and guided participation might co-occur, including student teaching (e.g., Valencia et al., 2009), lesson study (e.g., Fernandez & Yoshida, 2012), and other forms of practice-embedded professional learning (Gibbons et al., 2021). This raises the question of whether other designs which include movement between appropriation and guided participation may create the two kinds of learning opportunities identified here: opportunities to seek sensemaking or decision-making support and opportunities to identify an emergent problem of practices and seek joint participation on enactment. We call on the field to consider both how teacher professional learning may be designed to create such opportunities to learn and to further investigate whether other learning opportunities emerge at the nexus of appropriation and guided participation in varied learning contexts.

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Activating Resources for Incorporating Culturally Relevant Teaching in STEM Curricula

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Abstract: Studies reveal that significant instructional challenges persist when teachers integrate culturally relevant teaching (CRT) in science classrooms, often due to insufficient structural support and available resources. Additionally, teaching of STEM requires teachers to have access beyond material resources, such as lesson plans that they acquire in professional development. We present a case study of one experienced science teacher implementing an innovative STEM curriculum that integrates bioinformatics, data literacy, and mobile learning. We use a resource activation framework to examine constraints occurring when implementing the curriculum that was specifically designed for CRT. We analyzed the teacher's daily reflection posts, classroom observation notes, and a post-implementation interview. We found that symbolic resources (i.e., perceived institutional social values that are ascribed to different forms of instruction) impacted the teacher’s instructional choices. Our findings suggest that successful implementation of STEM curricula is dependent on teacher’s activation of different forms of resources often simultaneously.

Introduction

Studies on equitable science teaching in urban schools stress the need to design inquiry-based curricula that involve culturally relevant teaching (CRT) (Brown, 2017). Traditionally underrepresented groups, such as people of color, enter and are retained in STEM fields at lesser degrees (NSF, 2018). CRT can lessen the educational debt experienced by students who have been historically underrepresented in STEM disciplines (Ladson-Billings, 2006). CRT is a pedagogy of empowerment (Ladson-Billings, 1995), linking learning and culture in ways that aim to improve academic success, foster critical consciousness, and support cultural competence in the classroom, which give students opportunities to relate themselves to science in and out of school. Common barriers for enacting CRT in STEM include lack of structure and resources for preparing teachers, such as professional development (PD) training opportunities, model teachers who can positively demonstrate CRT instruction, and curricula of CRT that align with the standards (Barron et al., 2021). These limitations are amplified when teaching with innovative STEM curricula which focused on emerging disciplines, such as bioinformatics, computational thinking, machine learning, and data science**.** This is because in-depth conversations of CRT have not quite yet emerged (Brown, 2017).

Literature on implementing STEM curricula indicates that their successful implementation in classrooms depends on external resources beyond individual experiences and resources that teachers can acquire in PD (Brand, 2020). These resources, among others, can take the form of cultural resources, such as teachers’ pedagogical skills, or symbolic resources, such as the importance that STEM ideas have in the standard curriculum (Rivera Maulucci, 2010). Yet how teachers understand and activate essential resources to successfully implement innovative STEM curricula is still not well understood (Wang et al., 2020). Moreover, research on STEM education typically focuses on two forms of resources that are material, such as teaching supplies or curricula, and cultural resources, such as students’ prior knowledge (Brand, 2020). The demands of teaching dictate that teachers should utilize multiple resources simultaneously, and supporting teachers requires a more robust understanding of the complex nature of the resources that teachers draw upon (Rich, 2021). Rivera Maulucci (2010) proposed a resource activation framework that aims to systematically explore the ways that teachers utilize diverse resources concurrently. For STEM curricula to be incorporated with CRT, we used a resource activation lens to analyze an in-service teacher’s experience in adapting and teaching a bioinformatics problem-based learning unit in which students collect, analyze, and visualize air quality data collected through mobile apps and sensors. This study is guided by the following questions: (1) What resources did the expert science teacher activate to implement the bioinformatics curriculum? and (2) how did the interrelationships between the resources impact the activation?

Theoretical framework

This work is guided by the resource activation framework (Rivera Maulucci, 2010). According to Rivera Maulucci (2010), “activation” refers to an intentional use and adaptation of knowledge and commitments to improve pedagogical strategies and support teaching practices. In her resource activation framework, resources for teaching science can be categorized as material, cultural, social, and symbolic resources. Available *material resources* include learning supplies, such as textbooks, data collection devices, computers, and consumable equipment. Material resources can result from the context in which teachers work. Activating material resources could look like a teacher finding a short news clip that reports inaccurate data representation which could easily mislead the audience, and using it to facilitate students' discussion about the application and ethical use of data in the real world. *Cultural resources* are "knowledge, skills, education, and experiences within particular contexts" (Maulucci, 2010, p. 824). In an educational setting, cultural resources include the understanding of students and the teaching context; teachers' knowledge and conceptual understanding of data literacy (e.g., context, variability, aggregate, visualization, and inference); teachers' pedagogical and instructional strategies to foster critical data literacy and/or school's preferred instructional approach (e.g., problem-based learning, inquiry-driven learning, mobile learning, culturally relevant pedagogy); students' knowledge, experience, language, and academic abilities; and the culture of the school. *Symbolic resources* refer to value or prestige a community ascribes to an activity or goal. In an educational setting, symbolic resources refer to the perceived status or importance of teaching and learning. Symbolic resources highlight the institutional social value that is ascribed to different forms of instruction. For example, in our study, whether and how data literacy in STEM domains is prioritized, and recognition of teachers' efforts to integrate data literacy into their existing curricula. A teacher's symbolic resources might be activated when a principal recognizes the teacher for their efforts to bring cutting-edge knowledge into her science classroom or when the teacher is afforded some autonomy to design lessons using new pedagogy.

Methodology

Context

This study is part of a larger NSF-funded project that aims at constructing an innovative STEM curriculum in the context of bioinformatics that integrates culturally relevant pedagogy into the high school science classroom (Yoon et al., 2022). The curriculum is grounded in real-world problem solving that engages students with the community issue of asthma and air quality to explore data literacy as it pertains to biology. This issue was chosen because it is a problem that is highly relevant in the city, especially among students of color (Bryant-Stephens et al., 2012). A three-week summer PD workshop was designed to help teachers teach this curriculum. We ran the PD for 75 hours in July 2019. During the PD, six teachers learned the bioinformatics content and were introduced to pedagogical concepts such as student-centered, community-centered, and culturally relevant approaches. Teachers were asked to reflect on their learning after morning and afternoon sessions in a Google Classroom site that was created for sharing and storing of PD resources.

Participants

We used a case study method which requires researchers to purposefully select information-rich cases, as they will allow researchers an in-depth understanding of relevant and critical issues under investigation (Yin, 2017). To gain such insight, we chose to investigate Tracy, one of the teachers who participated in the PD, who implemented the curriculum in her environmental science class at a public high school in the Northeast U.S. She had been nominated as an expert teacher by the director of science in the school district. She identified herself as African American and was in her 5th year of teaching, with previous experience teaching biology, environmental science, and AP environmental science, all at the high school level. On the pre-PD survey, she indicated her passion toward teaching science. She responded, "I love Biology, I love to get students just as excited as I am in the subject(s)," and "I hope that I complete the PD with more knowledge, with something I can take back to my student in the classroom. Something that is real life, relatable to my students, and hands-on." These comments highlight her strong interest in providing authentic and meaningful learning experiences to her class.

Data source and analysis

We collected three data sources: daily reflection posts, classroom observation notes, and a post-implementation interview. The daily reflection posts were gathered to learn about how her perception of CRT changed as a result of PD participation. These posts were based on prompts given by the PD instructors, were submitted to Google Classroom throughout the PD. The prompts included, "1) What do you think about this content in terms of how you already teach? 2) What issues or challenges do you foresee in teaching this content to your students?" A total of 15 reflections were collected. The observation notes included descriptions of the classroom conditions, the teacher's instructional practices, and the activities and interactions among students taking place. Tracy's class was observed 9 times out of the 14 classes devoted to this project, which totaled 16 hours of instruction. Observation ranged in length from 33 minutes to 55 minutes with an average length of 46 minutes. The semi-structured post-implementation interview, which lasted 67 minutes, was conducted to probe the teacher's specific practices, beliefs, and understanding of implementing the new curricula, as well as the teacher's experience of preparing the class and participating in the project. Authors deductively coded data to identify instances that demonstrated the teacher activating resources in four categories of material, cultural, social, and symbolic resources. For example, the teacher's interview response, "[The principal] is very supportive over new [curriculum ideas] and if it supports the students' learning, then he will try his best to support it," was coded as symbolic because the teacher had symbolic support from the principal to pursue a more innovative approach to science teaching. Any discrepancies that occurred were negotiated until consensus on the codes was reached.

Findings

Shift in symbolic resources to navigate cultural and material resources

During the PD, Tracy did not appear to have enough symbolic resources for her to navigate cultural resources and turn them into material resources. In the PD, the teacher was asked to post a reflection after each morning and afternoon session. One of her posts captured how she initially felt about CRT in her instructional practices.

> It is a topic that I don't cover unless students bring it up. I stick strictly to the curriculum. However, I think I'm sensitive to the student racial/social needs just because I'm an African American woman who also grew up in [City] ... but I shouldn't use that as an excuse. I will try to educate myself on implementing social and environmental awareness into my curriculum; especially in AP [Environmental Science]. The only issue I foresee is educating myself and trying not to impose my personal feelings on the issues discussed.

In this post, Tracy explained that CRT was not part of her core instructional approach prior to the PD, but expressed an interest in incorporating it more. She also mentioned in her post-implementation interview, "we have to [be] making sure that what we're teaching, it's aligned to the standards, and that we just don't have the standard and [are] teaching whatever we want." She pointed out the lack of recognition from the school district for bringing CRT to science class while taking standards into account. These examples illustrate that there were not enough symbolic resources for her to navigate culturally relevant approaches (cultural resource) and incorporate them into activities in science class (material resource).

To overcome symbolic resource constraints, through the PD, Tracy was able to connect her shared identity to teaching goals which extended access to symbolic resources. For example, in the second half of her reflection post above, Tracy expressed an affirming attitude toward incorporating CRT in her science class. Her perceived importance of CRT indicates that her view of science teaching has shifted (symbolic resource) and that she admitted to using her positional identity as a source of strength in pursuing her interest in incorporating CRT in her implementation. In other words, symbolically, her positionality and PD experiences amplified her perceived value of CRT in science, as well as its perceived importance by others at the school.

Activating symbolic resources to make space for racial and cultural connections

During the school-year implementation, activating symbolic resources were salient in Tracy's class implementation and it drove the energies and focus to engage in choosing authentic and real-world examples. In other words, Tracy adapted the curricula acquired from PD in ways that reflected her students' interests and context. Tracy used symbolic resources in several ways to activate cultural and material resources simultaneously.

She actively sought to incorporate personally relevant and real-world examples to students, such as lead levels in children's blood in the city. For example, in the observation note on the lesson introducing data visualization, the researcher detailed that Tracy used a picture of [City] that included information about the incidence of children with high blood lead levels. Then, the class discussed what could be the cause of high lead levels in children's blood and looked at the correlation between environmental variables and health. In her interview, she explained the reason for this adjustment and said, "I felt like that was really good for the kids because they're from [City]. They can see the area that they live in. They can analyze that." Tracy clearly intended to bring CRT for science into the classroom to help students engage with and learn science. In another example, she discussed an oil refinery fire and explosion incident in [City] which happened six months prior to the lesson. As she used this example, many of the students actually remembered the incident and started to talk about it. Tracy extended the conversation by asking, "What do you think that did to the air quality for people who lived in that area? How did that affect them? And what type of people live in that area?" In her interview, she articulated a clear goal for students to be able to personally connect with the community issues and solve them in science as she tried to "bring in that real-world information and trying to take something that doesn't seem realistic and making it realistic because they already know that it happened. Maybe so many kids even actually live near [near the incident].” These examples reveal that Tracy connected science to issues that concerned students’ communities (cultural resource) and used examples that students were familiar with (material resource) as she considered them valuable to science instruction (symbolic resource).

Discussion

This study advances the current literature on STEM implementation by providing empirical evidence of how a teacher activated different types of resources in order to successfully implement new curricula. These findings indicate that the teacher relied on diverse resources in addition to the material resources that she acquired in the PD (Maulucci, 2010). While other studies have shown that CRT is not limited to curricular practices perceived as important for teacher enactment (Barron et al., 2021), this study’s outcome extends this conversation in terms of how symbolic resources are activated by teachers to implement CRT. In this paper, the teacher’s view of social and community issues and the decision chosen to navigate her belief motivated her to identify and activate multiple resources for CRT. Still, a focus on symbolic resources may begin to excavate some of the initial structural barriers that might derail implementation of STEM education. We argue that developing teachers’ resource activation is an important instructional practice for teaching STEM curricula that incorporate CRT. Finally, it is important to note that teacher PD should provide more opportunities for teachers to identify available resources and ways to activate different types of resources in various situations.

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Get Loud on TikTok: Climate Action & Critical Data Practices

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Abstract: Climate education that focuses on scientific facts at a global scale is often distant from youth's everyday experiences. To better frame climate education, in this work, we analyze youth-created, short-form videos on the social media site TikTok to understand how youth experience and discuss climate change and climate action. Data analysis reveals multiple discussion themes, namely advocacy, sustainability practices, knowledge sharing, and reaction. Youth demonstrate a variety of practices with data, including using personal data, combining data sources, situating data in personal and local contexts, and positioning their experiences as valid data points. We discuss implications for framing climate education and data practices to incorporate how youth interact with data in everyday contexts.

Introduction

Climate change-induced impacts threaten the livelihoods of communities around the world. Against this backdrop, learning standards have emphasized the role of education in promoting climate action (NGSS, 2013). Such learning stems from understanding of everyday decision-making and takes place beyond the classrooms. To inform the framing of climate education, researchers have analyzed youth-created written and multimedia artifacts in learning contexts (Littrell et al., 2020; Zummo et al., 2021). Social media presents another source to study how youth learn through creating and interacting with content (Greenhow & Lewin, 2016; Literat & Kligler-Vilenchik, 2019). In this study, we analyze youth-created, short-form videos on the social media site TikTok to examine how youth frame understanding of climate change and climate action. TikTok presents a generative research site, with 2 billion monthly active users globally and a significant number of users aged 13 to 24 years old (Iqbal, 2023).

In developing understanding of climate change, youth navigate multiple data sources, such as news, scientific research, and policy reports; experiences with local climate patterns; and personal sustainability practices. Social media platforms amplify the exposure to these different data streams. As content creators on social media platforms, youth have the opportunity to combine various data sources through multimedia channels such as image, audio, and video footage (Askari et al., 2018). These affordances can invite youth to engage in *critical data practices*—ways in which youth "access, engage with, and are positioned by and position data in relation to their lives and communities" (Calabrese Barton et al., 2021; p. 1). In this work, we explore how social media afford opportunities for youth to discuss content and engage in critical data practices. We ask:

- RQ1: What discussion themes emerge on TikTok in relation to climate change and climate action?
- RQ2: What data practices do youth engage in when discussing these themes?

Social media for self-expression and learning

Social media platforms provide sites for self-expression and learning (Mills et al., 2018). Self-expression invites youth to draw from personal funds of knowledge, defined as practices and experiences with family, community, peer, and popular culture (Moje et al., 2004). Greenhow and Lewin (2016) reported on how young people aged 16 to 25 used Facebook to discuss environmental science issues. They found that youth employed article links, photos, and text to illustrate multiple topics of personal interests. Through the process, youth might learn to draw from everyday lives to articulate scientific understanding (Mills et al., 2018). Beyond sharing knowledge, youth use social media to express emotions (Wielk & Standlee, 2021). In climate education contexts, social media can be key sites to display strong emotions, such as fear, anger, and frustration, to appeal to broad audiences (Wielk & Standlee, 2021). Youth may also emphasize hopefulness to build agency for climate movements (Soler-i-Martí et al., 2022). Emotional expressions can be conducive for learning, particularly within social action contexts (Vea, 2020) such as climate change and climate action discussion.

Data practices

In addition to self-expression, exploring content on social media sites like TikTok allows us to examine the data practices that youth engage in. Education researchers have highlighted the importance of accounting for both "big" data (e.g., large-scale, aggregated statistics from institutional datasets) and "small" data (e.g., personal experiences), as one way of interpreting, critiquing, and participating in data literacy (Calabrese Barton et al., 2021; Irgens et al., 2020; Lee et al., 2022). Such views of data as consisting of both "big" and "small" data are grounded in frameworks of racial data literacy (Philip et al., 2016) and data feminism (D'Ignazio & Klein, 2020). Both frameworks highlight the importance of personal experiences within social, political, and historical contexts, as one way to examine and redefine power behind data sampling, analysis, and communication.

Scholars have proposed ways to combine "big" and "small" data in youth's lived experiences (Irgens et al., 2020). For example, Calabrese Barton et al. (2021) examined the critical data practices in which youth remixed, repositioned, and recontextualized data to make sense of the COVID-19 pandemic. Remixing entails combining data sources to present a more rounded view of one's experiences. Recontextualizing refers to critiquing data within personal and community practices. Finally, repositioning occurs when youth view themselves as agents and not just parts of the aggregate statistics. Youth use small, personal narratives to counter the perspectives from large-scale data as part of youth activism. These practices are meaningful in climate education. First, they help to situate data in grounded contexts and allow youth to critique broader socioecological impacts of human actions (Littrell et al., 2020; McGowan & Bell, 2022). Second, they position youth to notice who is missing in data patterns. Such critiques build towards reimagining data work (D'Ignazio & Klein, 2020).

Methodology

Data sources

The data sample consisted of 410 videos in English from TikTok, a social media site for creating and sharing short-form videos. To sample videos related to climate change and climate action, we first searched for videos tagged with "#climateaction" on the site and identified additional, thematically related tags that frequently appeared with this tag, including #climatechange, #sustainability, #ecotok, and #environmentalactivism. We added the first 100 results under each of those hashtags to our data sample (i.e., top 100 videos when searching for "#sustainability"). The results were curated by TikTok to show videos that used the hashtags and had large counts of views, shares, and comments. After removing duplicates (11 videos) and videos unrelated to climate change or climate action (79 videos), the final sample consisted of 410 videos from 248 creators. The videos were published between June 2020 and August 2022. On average, the videos were 35.8 seconds in length ($SD = 31.3$ seconds). Before data collection, we obtained confirmation from the university's Institutional Review Board that the research did not involve human subjects because the videos were public. We did not store locally any personally identifiable data such as profile pictures, video, and audio.

Analytical approaches

The coding scheme consisted of two dimensions: (1) discussion themes, and (2) data practices. We developed the discussion themes codes inductively by watching a sample of 20% of the videos and noting the key topics. Advocacy-themed videos invited others to take action or acknowledged the work of climate activists, many of whom are from BIPOC (Black, Indigenous, and People of Colors) communities. Sustainability videos demonstrated eco-friendly and sustainability practices. Knowledge sharing videos disseminated news and institutional reports. Finally, Reaction videos expressed emotions in response to climate policies and practices.

For data practices, we turned to critical data practices for remixing, recontextualizing, and repositioning (Calabrese Barton et al., 2021). Remixing combined data sources and data types. Meanwhile, recontextualizing situated data within personal and local contexts (e.g., city, state, country), and repositioning used personal and community perspectives to critique and counter other data sources and data narratives. Additionally, to understand whether youth drew from personal experiences in their videos, we added a code for "personal data".

We analyzed the videos for presence (coded as 1) or non-presence (0) of codes. The authors first coded 20% of the data separately, discussed coding discrepancies, and coded another 20% of the corpus separately to reach substantial inter-rater agreement (Cohen's κ values: .93, .97, .92, .91 for the discussion themes, and .73 for remixing, .71 for recontextualizing, .61 for repositioning). We resolved disagreements through three rounds of discussions. The first author coded the remaining data. We explored the discussion themes, and ran Chi-squared tests to examine how young people leveraged different data practices to discuss different themes.

Figure 1

Screenshots Showing Advocacy (panel A), Sustainability (B), News (C), and Reaction (D)

A. Advocacy

B. Sustainability

C. News/ Knowledge

D. Reaction

Findings

Youth discussed a variety of themes in their videos, including advocacy (31%), eco-friendly and sustainability practices (31%), sharing knowledge (21%), and reaction (17%). Panel A (Figure 1) shows a screenshot from an advocacy-themed video that acknowledges environmental activists from Latin America. As an example of sustainability practices, Panel B (Figure 1) shows footage of a newly planted garden of native milkweeds. For knowledge sharing, youth employed multiple approaches, such as dancing or lip-synching while displaying climate-related information on screen (panel C). Finally, reaction videos displayed a range of emotions—worries at the lack of action (panel D), hope, determination to act, and reminder for self-care to combat climate anxiety.

Data practices

The videos also showcased data practices—drawing from personal experiences (34% of videos), remixing data from various sources (29%), recontextualizing in personal and local contexts (44%), and repositioning "small", personal narratives as data points to supplement or counter institutional data (5%). Personal data came from experiences with climate-induced hazards at local levels and first-hand accounts of how such hazards disproportionately affected different groups (e.g., people with disability, lower income groups, island nations). In painting a comprehensive picture for their audiences, youth remixed data sources, such as news, scientific reports, and sustainability practices. For example, in discussing the latest climate report that predicts an increase in the average global temperature by more than 1.5 degrees in the next five years, a creator combined screenshots of the report with popular culture (a screen from the cartoon The Simpsons) and sustainability practices (e.g., renewable energy, efficiency standards). In these cases, youth demonstrate critical data practices. They determine which information might be more relevant to their audience and visualize different data types in relatable lights.

In curating from diverse data sources, youth recontextualized data and climate science discourse in their lives and communities. For example, in supporting divestment from fossil fuels, a video creator discussed ways for her viewers to examine their universities' investments. The creator pointed out that "At first glance, you might not see any fossil fuel investments explicitly" because investments could be bundled in mutual funds. She then provided a data tool she used (Fossil Free Funds) to look up the portfolio of different funds. Here, the creator critiqued the completeness of a data source and illustrated a data tool within a personally relevant context.

Furthermore, youth demonstrated instances of repositioning data—using the experiences of themselves and their communities as counter data points and not just parts of large-scale, anonymized statistics. In one video, a creator sat in front of the camera and used his experience to challenge the accessibility of outdoors recreations to different communities: "Saying just "get out into nature" can be very disconnected […] Nature's been commodified and something that is rarer and rarer and people only with wealth and whiteness can access." This example illustrates a case of positioning one's experiences in community to counter a dominant narrative.

Youth used data practices to support different discussion themes. Chi-squared tests suggested significant relation between themes and remixing, $\chi^2(3, N = 410) = 12.63$, $p = .01$, recontextualizing, $\chi^2(3, N = 410) = 33.55$, $p < .001$, and utilizing personal data, $\chi^2(3, N = 410) = 99.26$, $p < .001$. There was no significant association between themes and repositioning, $\chi^2(3, N = 410) = 4.03$, $p = .26$. Post hoc analyses with Bonferroni corrections suggested pairwise differences between themes, meaning that videos of different themes employed data practices differently. For example, videos that featured sustainable practices relied more on personal data and recontextualizing than other themes (personal data: 68%, other themes: 12%-16%; pairwise p range <.001 - .02; recontextualizing: 64%, compared to 25%-41% in others; pairwise p range <.001 - .03). An explanation of this finding is that youth demonstrated sustainable practices in familiar contexts (e.g., home, garden, transportation), transforming the abstract idea of individual responsibility into concrete experiences.

Discussion & conclusion

Our work explores how youth participate in discussion surrounding climate change on social media. A limitation is that the analysis was conducted with videos in English, and we invite future work to consider videos in other languages to examine the broader, global discourse. While we did not find cases of misinformation in our data corpus, extending the analyses to capture such instances in the comments on the videos can be a future direction.

Our work adds to understanding of how social media can reveal insights into youth's self-expression of important civic topics, specifically the multiple data practices that youth engage in. In curating data for an audience on the platform, youth situate data in relatable contexts, remix various data types, and position their experiences as valid data points. These practices may present opportunities to interweave data sources and validate perspectives from small data. Researchers have argued that small data provide the contextual grounding for understanding large-scale data patterns (Calabrese Barton et al., 2021). Attending to youth's social media practices offers a way to better understand such data practices. Importantly, the current research has implications for the design of learning environments to make climate education relatable to youth. We do not argue that all educators should adopt TikTok in instruction, as there are real concerns of jeopardizing students' privacy. Rather, findings illustrate how we may reenact the platform's affordances in learning design, for example, to encourage youth to create data narratives and articulate the links between climate action and personal contexts. Educators can also draw from the discussion themes and various data practices, to scaffold climate education conversations.

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Designing Bugs or Doing Another Project: Effects on Secondary Students' Self-Beliefs in Computer Science

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Abstract: Debugging—finding and fixing bugs in code—is a heterogeneous process that shapes novice learners' self-beliefs and motivation in computing. Our Debugging by Design intervention (DbD) provocatively puts students in control over bugs by having them collaborate on designing creative buggy projects during an electronic textiles unit in an introductory computing course. We implemented DbD virtually in eight classrooms with two teachers in public schools with historically marginalized populations, using a quasi-experimental design. Data from this study included post-activity results from a validated survey instrument (N=144). For all students, project completion correlated with increased computer science creative expression and e-textiles coding self-efficacy. In the comparison classes, project completion correlated with reduced programming anxiety, problem-solving competency beliefs, and programming self-concept. In DbD classes, project completion is uniquely correlated with increased fascination with design and programming growth mindset. In the discussion, we consider the relative benefits of DbD versus other open-ended projects.

Introduction and background

Debugging—finding and fixing bugs in code—is an essential computational practice, a heterogeneous and open-ended process that shapes how novice learners perceive themselves in relation to computing which impacts their motivation to persist (DeLiema et al., 2022). While debugging is often difficult to learn and to teach (McCauley et al., 2008), encountering bugs can generate fear and anxiety, leading to disengagement and the avoidance of computer science (CS) (Kinnunen & Simon, 2010). Typical debugging teaching practices and curricula emphasize top-down instructionist designs that focus on small, isolated problems and linear strategies for finding well-defined bugs (see McCauley et al., 2008). Contrastingly, in our approach of Debugging by Design (DbD) students create, exchange, and solve buggy open-ended, personally relevant projects. We build on a longstanding tradition of constructionism, emphasizing learner agency by designing applications for others (Harel & Papert, 1990). DbD aims to put students in control over bugs, framing failure as a productive, social experience rather than a negative, discouraging one. Exploratory work on DbD found that students engaged in practices that characterize growth mindsets such as choosing challenges that led to more learning, praising effort, approaching learning as constant improvement, and developing comfort with failure (Morales-Navarro et al., 2021). Weeks after completing DbD, students expressed greater comfort and improved skills in debugging (Fields et al., 2021).

When encountering bugs in computing, students engage with a wide set of values and processes, including self-beliefs that are shaped by experiencing failure and that impact how they react to future failures. Self-beliefs are an array of different self-terms—for instance, self-concept and self-efficacy—that share an emphasis on the beliefs individuals hold about their own abilities and attributes (Valentine et al., 2004), in this case about computing. Measuring student beliefs is important because pernicious belief systems, together with structural inequities, play a role in limiting the participation of historically marginalized groups in computing (Margolis et al., 2017). At the same time, addressing students' beliefs about their own abilities in computing can have an impact in their participation and help shift in their views of CS ability from something that is innate to something that is developed with experience and practice. Since DbD aims to empower students in debugging—by designing creative, multimodal buggy projects for others to solve—we measured student self-beliefs about computing in a quasi-experimental design study within a broader e-textiles unit, asking: Did participation in the DbD/comparison (Music) activity impact students' project completion? Did completing either class project relate to students' CS self-beliefs and was this influenced by whether students were in the DbD or the comparison (Music) activities?

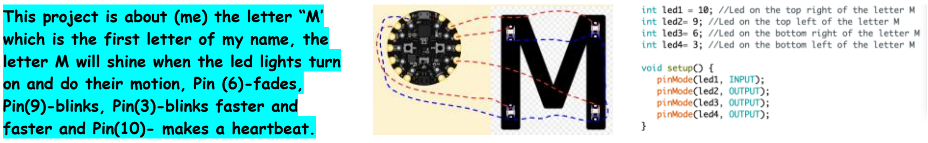
Debugging by Design

DbD took place within the e-textiles unit of *Exploring Computer Science* (ECS), an inquiry-based CS curriculum committed to broadening participation in computing by addressing the structural inequities and beliefs systems that limit participation from historically marginalized groups (Margolis et al., 2017). During the 10-12 weeks e-textiles unit students create four projects. In these open-ended physical computing activities that integrate coding, circuitry, and crafting, facing failure and unanticipated challenges are expected and inherent in the learning process with problems distributed across modalities (Kafai et al., 2019).

In designing DbD, we extended constructionist approaches by shifting the focus from designing functional artifacts (Harel & Papert, 1990) to designing non-functional, or buggy, projects for others (see Fields et al., 2021). The DbD activity was designed to take place during eight 50-minute-long lessons. Due to the Covid-19 pandemic, together with one experienced e-textiles teacher (not in this study), we created a version of the curriculum that could be taught online with students at home. At the beginning of the activity, students discussed with each other different errors and problems they had encountered when creating e-textile projects. Then student groups decided on the bugs they wanted to include in their designs. They were required to have at least 5 bugs in their code but limited to 1 bug in their circuit diagram. After receiving teacher approval on designs, they wrote a project statement, made a circuit and aesthetic diagram of a buggy project and prepared buggy code for the project (see Figure 1). Teachers then helped students exchange project plans with each other; students built and solved each other's buggy designs. In this study we also designed a *comparison activity* where in place of DbD, students created a new project with programmed music. This provided opportunities to go deeper into programming (by coding tones and rhythms, using arrays, for loops, and conditionals) and the inevitable debugging that happens in creating e-textiles projects without the explicit focus on designing bugs for others, unique to DbD. In this study we were curious to find out the potential benefits of the different activities.

Figure 1

A student DbD design: project description, circuitry and aesthetic design, and buggy code excerpt.



This project is about (me) the letter "M' which is the first letter of my name, the letter M will shine when the led lights turn on and do their motion, Pin (6)-fades, Pin(9)-blinks, Pin(3)-blinks faster and faster and Pin(10)- makes a heartbeat.

```
int led1 = 10; //Led on the top right of the letter M
int led2= 9; //Led on the top left of the letter M
int led3= 6; //Led on the bottom right of the letter M
int led4= 3; //Led on the bottom left of the letter M

void setup() {
   pinMode(led1, INPUT);
   pinMode(led2, OUTPUT);
   pinMode(led3, OUTPUT);
   pinMode(led4, OUTPUT);
}
```

Methods

Context and participants

Two experienced teachers at different schools, with high percentages of historically marginalized secondary student populations (58-95% free and reduced lunch; 85-99% non-white), taught eight ECS classes with e-textiles. In Spring 2021 these two schools, in two large West Coast districts, offered online instruction due to the COVID-19 pandemic. Using a quasi-experimental design, five classes participated in the DbD activity (158 students; 90 took the post-survey with 37% identifying as female, 91% speaking a language other than English at home, 58% with no prior CS experience) while three classes (93 students; 54 took the post-survey with 22% identifying as female, 83% speaking a language other than English at home, 46% with no prior CS experience) focused on the comparison (Music) activity. Teachers randomly and pragmatically (e.g., fitting their block schedule) chose classes to implement the activities. Because of the timing of the study at the end of the virtual school year in the second year of the pandemic, there was a high degree of attrition in student participation in the schools. Our IRB allowed for collecting anonymous surveys while identifying the teacher and class period. We did not request information on ethnicity because we believed (and the IRB board agreed) that collecting ethnicity alongside gender by classroom would inevitably make students identifiable. Due to the nature of the implementation of the study, i.e., during a pandemic with virtual schooling, simply comparing DbD against the comparison activity was insufficient as some students started the projects but did not finish them. As such, to investigate the relationship between project completion in both DbD and comparison activities and student CS self-beliefs, we included a survey question about project completion—how far they got in the DbD or music projects— designed to allow us to compare survey responses and how much students participated in the DbD or comparison (Music) activities.

Data collection and analysis

To assess the impact of DbD and comparison activities, 144 students completed a survey at the end of their respective activities. The survey contained a previously validated instrument for nine CS self-beliefs constructs (see Table 1; for details about the instrument see Morales-Navarro, in press) using confirmatory factor analysis (with factor loadings average of .742 and range between .491 to .875; reliabilities between .713 and .889). For the present study, each construct also demonstrated good reliability (all Cronbach's alphas ranged between .729 and .918). For each construct, responses were recorded using a four-point Likert scale to encourage greater reflection and avoid neutral or indifferent responses (1=strongly disagree; 4=strongly agree). To determine project completion in both activities, the survey asked, “Please select the option that best describes how far you got in completing the following project”; responses ranged from “Didn’t do it” (1) to “Finished” (5). Teachers created assignments that required students to complete our online survey in their school’s learning management systems with time to complete the survey during class and as homework within a certain time. To assess the impact of DbD, two sets of analyses were conducted. First, an analysis of variance (ANOVA) was conducted to examine differences between DbD and comparison activities on project completion. Second, within DbD and comparison activities, correlation analysis examined the potential bidirectional relationship project completion had with the nine CS Beliefs (see Table 1).

Findings

Notably, ANOVA results found no significant difference between DbD (M = 1.537, SD 2.56) and comparison (M = 2.56, SD = 1.550) activities in terms of project completion, F (1, 142) = 0.000, p = 1, partial η2 = 0.

For students doing either DbD or comparison activities, correlation results show that the extent to which they completed the project was related to significant increases in CS creative expression and e-textiles coding self-efficacy (see Table 1**)**. This reinforces findings from previous studies (Kafai et al., 2019) that showed gains in creativity and e-textiles coding self-efficacy during the e-textiles unit without DbD or the extra music project activities. That said, it is worth noting that highly engaged students or those with previous CS backgrounds may have been more likely to complete the projects in both activities. Similarly, access to Wi-Fi and other learning resources during virtual pandemic school very likely influenced project completion.

Table 1

Correlation between project completion and constructs across DbD (N = 90) and comparison (N = 54).

Construct	DbD	Comparison	Construct	DbD	Comparison
CS Beliefs			CS Mindset		
Problem solving competency beliefs	.191	.364**	Programming fixed mindset	-.032	-.178
Fascination in design	.257*	.229	Programming growth mindset	.313**	.230+
Value of CS	.201	.266	CS Outcomes		
CS creative expression	.284**	.363**	Programming anxiety	.042	-.330*
E-Textiles coding self-efficacy	.321**	.335*	Programming self-concept	.190	.297*

+p < .10, *p < .05, **p < .01, ***p<.001

Among those doing the DbD activity, the extent to which they completed their projects (designing intentionally buggy artifacts and solving their peers’ buggy projects) correlated with significant increases in fascination in design and programming growth mindsets. This highlights how designing and solving bugs may influence students’ beliefs about design and the potential of creating personally meaningful failure or buggy artifacts in empowering learners to design bugs and engage with their designs in novel ways (Fields et al., 2021). The correlation of project completion with programming growth mindset in the DbD condition supports earlier findings that suggest that agency-driven debugging approaches may be particularly well suited to promote growth mindset (Morales-Navarro et al., 2021). It is also worth considering that while the survey was conducted right after students completed the activity, earlier work found a marked difference in students' perception of DbD immediately after completing it and several weeks after, with most students expressing distress and frustration about bugs right after the activity but comfort and competence with bugs weeks after the activity (Fields et al., 2021). For the comparison activity students, project completion correlated with lower programming anxiety, higher problem-solving competency beliefs, and programming self-concept. This is not surprising as the project pushed students into new programming domains (i.e., music, arrays, etc.), suggesting that this helped students gain confidence in their coding abilities.

Discussion

Our study takes a holistic approach to studying constructionist, CS education interventions by looking at the relationship between secondary students’ computing self-beliefs and completing one of two creative physical computing projects in a quasi-experimental design. One highlight from our results is that students’ perspectives on themselves with computing relate to how far they got in making the projects. This finding, across both DbD and comparison groups, foregrounds that making personally relevant e-textiles projects, whether a normal open-ended project or a specifically buggy project, may be beneficial for students' development of self-beliefs in CS. This suggests that progressing toward completion in projects is important for students to fully benefit from constructionist learning activities. As Harel and Papert (1990) argue, creating projects contributes to the affective side of cognition as learners shape their relationships with the concepts they encounter through personal appropriation of knowledge. Even amid a global pandemic at the end of a year of virtual classes, in public schools with high percentages of marginalized students (by class and ethnicity), significant results demonstrate the potential gains from engaging students in making these creative, challenging projects. With Debugging by Design (DbD), project completion was uniquely correlated with programming growth mindset, demonstrating a potentially distinct benefit of DbD that complements open-ended, constructionist-driven projects more generally. These findings are important because programming growth mindset is particularly important for retention, perseverance, and endurance amongst marginalized populations in CS (Kinnunen & Simon, 2010; Margolis et al., 2017). Therefore, educators and researchers should further consider the role that integrating DbD projects may have in supporting students when making projects.

Our research provides many potential directions for future study. Research should explore the specific roles of different aspects of DbD—both designing bugs for peers and solving bugs by peers—in fostering growth mindsets. Our earlier case study research in one classroom documented that students exhibited growth mindset practices largely while designing bugs (Morales-Navarro et al., 2021), yet this current study demonstrates the importance of doing the entire scope of the DbD project, from designing to solving peers' buggy projects. At the same time, replicating this study in in-person classroom settings and conducting case studies of students' design processes could be beneficial to better understand the differences between DbD and comparison activities in relation to self-beliefs without so many other factors in play (e.g., a pandemic, virtual education). Further, while we attend to self-beliefs in this study, future research should also investigate what contributions DbD or comparison activities make to learners' conceptual understanding, for instance developing breadth of knowledge about types of bugs or strategies for identifying and solving bugs. Finally, we have explored DbD in one specific context—designing e-textiles in an introductory computing course; many other applications are possible.

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Building Belonging for Multiply Marginalized Neurodivergent Students in STEM Higher Education

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Abstract: Neurodivergent students often struggle with a sense of belonging, given barriers to self-advocacy, mental health, and social skills. This is even more challenging for multiply marginalized students, such women and people of color who are underrepresented in STEM programs. Exacerbating these problems is the dearth of effective professional development for helping STEM instructors better teach neurodivergent students. To prototype inclusive, effective training, we collected survey data from undergraduate STEM students about their experiences as neurodivergent students and what needs and recommendations they had for instructor practice. This short paper presents preliminary survey results and a theoretical curriculum approach for instructor professional development for neurodiversity in STEM.

Introduction

Any class, at any grade level, may include students with typical neurodevelopment (neurotypical), as well as students with attention deficit/hyperactivity disorder, autistic students, and many others whose ways of thinking and processing differ from the expected norm (Neurodivergent) (Kapp, 2020). Many neurodivergent students have abilities and traits that are highly valued in college, including strong interest in subjects like Computer Science or Engineering (Wei et al., 2013), creativity, or systematic thinking (Baron-Cohen et al., 2009). Unfortunately, approximately 30% of neurodivergent students who enter STEM programs drop or transfer out before graduation (Wei et al., 2014). Neurodivergent students can struggle in learning environments designed for their neurotypical peers (Fabiano et al., 2018), and often face mental health and relationship challenges that impact their sense of belonging (White et al., 2011). From a social model of disability, disability is a product of environmental barriers and practices that could—and should—change to better all, like the inclusion of ramps for those with mobility differences (Shakespear, 2006). Teaching practices and learning environments can change to make learning easier for all students, but especially those with neurodivergent traits. Creating ecosystems of belonging calls for preparing instructors to make inclusive classrooms (O'Keefe, 2013; Thurston et al., 2017); thus, the need for neurodiversity professional development.

Professional development for inclusive classrooms

College instructors are not typically trained on neurodivergent needs, but studies show that professional development can be an effective approach to improving instructor interactions with neurodivergent students (Thurston et al., 2017). Likewise, good relationships between instructors and students can make a difference for students' sense of belonging, an important part of long-term motivation to remain in college (Morrow & Ackerman, 2012; Vaccaro et al., 2015). For neurodivergent students, their instructors' behavior and practices have two significant impacts. First, instructors play an important role in students' self-advocacy. Prior experiences with instructors who reject accommodations because they believe them to be unfair or unreasonable can teach students not to trust their instructors with accommodations (Sarrett, 2018). This is a long-term problem, since most instructors require that students disclose their accommodations early in the semester or not at all. Trained instructors, meanwhile, are less likely to discourage students from using their accommodations (Wynants & Dennis, 2017). Second, despite an instructor's best intentions, their teaching practices can be more inclusive only if they are knowledgeable of neurodivergent needs. Instructors without neurodiversity training may believe, for example, that they are helping neurodivergent students by providing a few long-term, extremely flexible deadlines, when this can make anxiety and time management more difficult for students with memory issues (Ericson, 2017). With a critical level of knowledge, however, instructors who are aware of reading anxiety among students with dyslexia or ADHD may use more frequent, smaller deadlines to help students stay on track and lower anxiety. Likewise, instructors may avoid giving students notes or presentations from classes to preserve accountability and make sure students are paying attention during class. But for neurodivergent students (i.e., students with auditory processing differences, distraction from sensory difficulties like flickering lights, or attention disorders) the task of trying to take notes may instead impede learning (Maydosz & Raver, 2010). Providing notes or a simple outline to all students could improve learning for all and prevent students from failing.

Intersectionality in STEM

The intersection between neurodiversity and other types of diversity compounds these challenges for neurodivergent students and their instructors. *Intersectionality* is a theoretical lens for understanding how things like race, gender, disability, and power within a social structure collectively impact individual students (Collins & Bilge, 2020). The experiences of neurodivergent students who are diverse in other ways (i.e., multiply marginalized) are inherently different from those who represent the majority group in their program (Mallipeddi & VanDaalen, 2021). Thus, context is relevant to the effectiveness of training. In this case, we are interested in science, technology, engineering, and mathematics programs (STEM) in the United States, where women, queer, and Black, Latinx, and indigenous students face high rates of discrimination and a low sense of belonging as underrepresented members of their field (Mooney & Becker, 2020). There is a lack of empirical research exploring the ways in which fear of discrimination or other intersectional factors will impact neurodivergent students. Historically, interventions and research conducted without the input of those with disabilities tend to be ineffective and even harmful (Kapp, 2020). To prevent this, professional development design must begin with inclusive research design. In this case, that means including the historically underrepresented knowledge and expertise of multiply marginalized neurodivergent students from STEM programs.

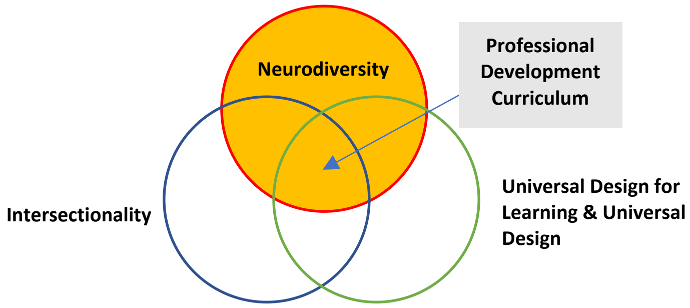
Surveying neurodivergent students

Our process of designing neurodiversity professional development began with an examination of the literature. However, it was not clear from published research findings what needs neurodivergent students of all genders or races require instructors to know about or know how to address. Consequently, in the spring of 2022, we created and distributed a survey among undergraduate and graduate STEM students in an international university in the northeastern United States. Survey prompts asked whether students identified as neurodivergent, regardless of a medical diagnosis, as a lack of diagnosis was likely to bias the sample towards white males (Begeer et al., 2009; Zuckerman et al., 2021). Students were also asked for demographic data, whether they had experienced common neurodivergent challenges, and asked to provide information about how instructors could improve. Students (n=54) were grouped based on whether they had identified as belonging to groups that would be multiply marginalized in STEM (e.g., white, female, and neurodivergent, rather than white, male, and neurodivergent). Preliminary mixed-methods analyses (e.g., chi-squared tests of independence and open coding procedures on qualitative responses) suggest significant differences in responses between multiply or singly marginalized students. In particular, a substantial proportion of multiply marginalized neurodivergent students reported that *peer and instructor lack of awareness about neurodiversity* was a significant problem as compared to their singly marginalized peers. Qualitative responses echoed the problem, for example, “I feel guilt whenever I’ve tried to explain myself to my instructors. I’m always behind deadline and missing assignments.” Comparatively, few singly marginalized students reported this problem (neurodivergent and white or Asian male with no additional disabilities). Qualitative responses further indicated that multiply marginalized students’ perception of instructor awareness impacted other factors, such as *time management* and *class format challenges*. They attributed this to perceptions of instructors’ willingness to provide requested support, such as notes or recordings, extra time to complete assignments, or honoring accommodations. Most of the multiply marginalized students requested that instructors better understand their accommodations requests and have a better general understanding of how their conditions impacted their daily lives. Although students were not explicitly asked about discrimination on a basis of race or gender, multiply marginalized students more frequently indicated that a fear of discrimination limited their willingness to self-advocate, while some majority/singly marginalized students expressed that they had openly discussed their neurodiversity with instructors or found their own solutions to problems. Both groups had suggestions that could be relatively simple to implement, such as structured breaks, more clarity in online lesson formats or assignment guidelines, and the provision of notes or slides to review confusing lessons.

Prototyping professional development for STEM instructors

Based on the nature of the problem, literature related to the stated issues, and preliminary findings, we have determined a need for professional development rooted in neurodiversity literature, Intersectionality, and effective pedagogical approaches to respond to student needs. Each of these topics is significantly larger than what is strictly necessary or practical to incorporate into a professional development course. Instead, prior literature and student responses suggest the potential for focusing on several discrete areas within each, drilling down from knowledge to solutions. First, this approach begins with generally applicable neurodiversity awareness (e.g., how to define it, how different models of disability help us to understand how it impacts students and the barriers they encounter, and common neurodivergent struggles in classrooms), a critical foundation that multiply marginalized students identified as central to their sense of belonging in their program. Not all instructors are aware neurodiversity even exists, let alone the impact it has on seemingly able-bodied students. Second, we can build on this foundation to teach instructors to anticipate overlap with issues of race, gender, discrimination, and other contextual factors that impact multiply marginalized students. This is essential, despite the variety of universities that now offer diversity training of some kind, because other training does not typically address the impacts on self-advocacy of students' perceptions, fears, and experiences with racial or gender discrimination. Third and finally, this foundational knowledge forms the basis for applying pedagogical approaches like Universal Design, Universal Design for Learning, and Universal Design for Instruction. Each of these approaches provide frameworks for examining and transforming learning environments, teaching practices, and instructional tools to make them more inclusive for neurodiverse classrooms. We chose these frameworks because of the demonstrated success in both making classrooms and instructional practices more neurodiversity-inclusive and because they have been used effectively in STEM fields (e.g., Thurston et al., 2017). Additionally, at their core is the goal of improving instruction for all students. This is essential for neurodiversity inclusivity, since all students are different, even if they share some needs. Small changes can make a big difference to students' ability to engage meaningfully with class, like how reducing noise in a classroom and providing better lighting improves all student learning, but can make the difference between frustration and flourishing for neurodivergent students (Kinnealey et al., 2012). Many of the students' recommendations or requests were possible to fulfil with the application of a Universal Design-related framework. As one student explained, "Recorded lectures and/or video lectures help me cope with my zone out periods because they allow me to rewind to a spot where I was still focused and watch again," an option that could be utilized by instructors without official accommodations requests to support students with auditory processing, attention, and mental health problems. Through this three-part approach, all overlapping with a foundation of neurodiversity knowledge and awareness, we can build a curriculum for inclusivity in STEM (see Figure 1).

Figure 1
Key areas of focus for curriculum in neurodiversity professional development



Conclusion

These preliminary findings indicate that instructors must learn more about neurodiversity to positively impact students, but that neurodiversity must be viewed from an Intersectional lens. Additionally, instructors must be armed with effective pedagogical approaches to improve students' learning in neurodiverse classes. We recommend that curriculum for professional development for neurodiversity be founded the overlap between these three factors, building on existing literature as well as diverse student opinions. Once instructors understand these concepts and how they overlap, they can be equipped with effective frameworks and practices for transforming classroom practice to improve learning environments and student-teacher relationships, such as Universal Design for Learning. We recognize that additional topics, or alternative pedagogical approaches, could improve learning for neurodivergent students; this is but one solution. Likewise, we acknowledge that students will, at times, request changes that are not to their benefit (e.g., the complete removal of deadlines). But, we advocate the use of collaborative approaches that can temper student expertise of their experiences with the expertise of existing research on neurodivergent learning and student behavior. What is important is that student voices be included in the first place, to ensure that the foundation of instructor practice rests in genuine understanding of diverse and intersectional student experiences above all else.

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The Influence of Open-Ended Exploration in STEM-Focused Minecraft Environments on Post-Intervention Knowledge Assessments

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Abstract: Video games continue to be heavily researched mediums for knowledge acquisition and transfer. However, there is not a lot of research looking at how adolescent learners actively explore open-ended game environments and comprehend the conceptual STEM knowledge embedded in-game. Additionally, using a popular game, Minecraft, has potential to attract the attention and interest of young learners through a means that poses low barriers for engaging STEM content. Existing familiarity with game mechanics in Minecraft allows learners to focus on content without having to learn new controls. This research looks at how interest in STEM and Minecraft is related to the amount learners explore their environment, as well as their performance on knowledge questions posed at the end of a one-week summer camp experience. Findings suggest that existing interest has little effect on exploration habits, but exploration habits do influence the amount of conceptual knowledge learners recall in interviews.

Introduction & background

Novelty of information or situations is considered a key ingredient for inducing information-seeking behavior in learners (Baram-Tsabari, 2015), where the learner feels rewarded by exploring and closing an information gap (Hidi, 2016). Closure of information gaps result in positive affect and can lead to a self-boosting effect where more knowledge gaps are identified, explored, and closed (Murayama, 2022). The relevance of the material to the person also makes a difference, where learners who can relate content to the self are more likely to continue engagement and deepen understanding (Renninger & Hidi, 2021). Research on valuing of content by learners has shown marked increases in interest when utility-value interventions are used in classrooms, such as prompting learners to connect information to their personal experience (Harackiewicz, Smith & Priniski, 2016). Both personal relevance and novelty have been identified as interest triggers, or aspects of the environment that might motivate a learner to actively explore content for meaning (Renninger, Bachrach, Hidi, 2019). Flum and Kaplan (2006), raise the importance of exploration and information-seeking as an educational goal and argue intentional exploration induces information-seeking, leads to reflection, and forces reorganization of one's self-concept, leading to the development of self-sustaining, enduring interest. Open-ended video games, such as Minecraft, possess adaptable features that can be used to extricate how open exploration of an environment contributes to interest development and concept learning.

Minecraft is a popular open-ended sandbox game that provides players a great deal of autonomy to explore, build, and create (Baek et al., 2020). Minecraft has been used to some success in educational settings to improve creativity (Checa-Romero, 2018), increase interest in math (Bos et al., 2014), and understand how pre-existing interest in STEM might influence engagement with scientific measurement tools (Lane et al., 2022). Given the possibilities to utilize Minecraft for education and research, we examine how exploration of rich, customized worlds in Minecraft is influenced by interest in STEM and contributes to conceptual understanding of Earth Science and Astronomy content.

Participants

Participants in the study ($n = 12$) were middle school students participating in a one-week summer camp program organized in partnership with a university in the western United States. Of the participants, 12% were female, 4 identified as White/Caucasian, 2 identified as Hispanic, and 6 preferred not to answer. Participants attended the summer camp for 4 hours each day, for a consecutive 5 days (20 contact hours total).

Materials & procedure

Most of each day was spent playing on our Minecraft server, which hosts 15 customized maps of hypothetical version of Earth (i.e. What if Earth orbited a colder sun) and known exoplanets (i.e. Kepler 182-f). Maps were designed in consultation with an astrophysicist who approved of all astronomy and earth science content built into each map. Each map features non-playable characters (NPCs) the player can interact with and learn more about the environment. There are also quests the players are prompted to undertake that might include taking measurements of radiation, finding a specific item, or uncovering the reason behind a phenomenon occurring. Every participant was provided a laptop, mouse, and access to Minecraft: Java Edition (see Figure 1).

Figure 1
Setup for 1-week camp using Minecraft to introduce hypothetical Astronomy scenarios

Participants completed a STEM & Minecraft interest survey, validated by our lab, before the start of the program. The survey consisted of 25 Likert-type items related to STEM interest, 20 Likert-type items related to STEM-related Minecraft interest and 5 menu-based or open-ended demographic questions. Likert-type items were worded “On a scale from 1 (not at all interested) to 5 (extremely interested), how interested are you in the following activities:”. An example of a STEM interest question is “Learning about how different plastics, resins, and powders change during 3D printing”, and an example of a STEM-related Minecraft question is, “Creating systems to transport resources”. Participants were introduced to our server through exploration of rocket launch facility and lunar base. These worlds prompted players to take science measurements, type in-game observations, and explore the environment. Subsequent worlds were briefly introduced before players were given the freedom to explore and complete quests. Exploration of each world was followed by discussions unpacking the features of the world and causation of visible phenomena. Other activities, such as drawing and demonstrations with inflatables, augmented Minecraft play. On the final day of camp, each participant was interviewed one-on-one by a member of the research team. Interview questions focused on participant interest in STEM (i.e. “Do you ever search the internet for information about outer space or watch YouTube videos about space?”) and included a series of knowledge questions referencing course material. An example of a knowledge question is, “What can you tell me about the moon and how it affects us here on Earth?”, and transfer questions immediately follow, such as “What do you think would happen on Earth if the moon doubled in size?”.

Analysis

Aggregate scores for STEM interest and Minecraft interest were calculated from the pre-survey. If participants completed the survey in less than 4 minutes their survey data was discarded. An exploration metric was calculated for each participant based on how many squares of a 10x10 grid overlaid on each map they visited. Location data was collected every 3 seconds for each participant, and a numeric output representing their exploration was generated. For example, if a participant’s exploration crossed into a total of 25 grid spaces they would have an exploration metric of 25 for that particular world. Average exploration for each participant was calculated for all maps they were present for and explored. In total, 11 maps were included in the average, and the average constitutes a participant’s overall exploration metric.

Interviews were analyzed using a coding scheme based on the work of Renninger, Bachrach, & Hidi (2019) that details possible interest triggers in informal environments. The triggers were adapted to capture participant behaviors related to interest development, such as their tendency to seek out additional information (Renninger & Hidi, 2021), expressions of positive affect regarding STEM learning in Minecraft (Hidi & Renninger, 2006), as well as intent to reengage with content. The adapted scheme was developed from previous data and reliability was assessed (Yi, Gadbury, & Lane, 2021). The coding scheme consists of 7 possible codes (i.e. MCL = interest in learning STEM in Minecraft, IS = information-seeking behavior, AFF = liking or excitement). Two researchers on the project segmented interviews into “interest episodes” and then applied the codes. An interest episode is a response that reflects the triggers mentioned previously, such as stating that Math or Science is their favorite subject in school. Once segmented, each researcher independently coded all interviews and then compared codes. Researchers achieved 99% agreement. Disagreements were resolved in conference.

Knowledge questions from interviews were segmented by one researcher, and a scoring scheme was applied by two researchers to assess correctness of answers. Answers for each question were provided by an expert in Astronomy and broken down into three levels of reasoning. A participant received a “0” if they stated, “I don’t know” or the answer was off-topic, a “1” if their answer was on-topic but incorrect, a “2” if the answer provided evidence and was partially correct, and a “3” if the answer was entirely correct and/or included in-depth reasoning and inference as to why the phenomena occurred. Scoring was done by both researchers for 10 participants and a total of 89 responses. Researchers achieved 82% agreement on scores, and disagreements were resolved through discussion. Average scores were then calculated for each participant.

Because of a small sample size and predominantly non-normally distributed data, non-parametric analysis was used to examine the correlations between the variables.

Results

Spearman correlations revealed a significant relationship between only the exploration metric and the score on the knowledge questions from the interviews (see Table 1). Results showed a low overall mean exploration across all participants, considering that a score of 100 is possible. However, not every square of the overlaid grid contains information or content, and therefore are not relevant to learner goals. Additionally, standard deviation is low for exploration, which indicates similar exploration metrics across participants. All other correlations were non-significant, but moderate correlations were found between interest episodes from interviews and Minecraft interest from survey, STEM interest from survey and knowledge questions scores, as well as STEM and Minecraft survey interest. The negative relationship between MC Int and STEM Int is unusual, as the validation process of the surveys revealed positive correlations between the two constructs. Granted, this does not rule out the possibility that some participants sign up for the camp based solely on the opportunity to play Minecraft. Observations from staff noted that learners with high interest in Minecraft tend to disengage from the STEM content in favor of testing the limits of our customized server and engaging in games, such as hide and seek, within Minecraft.

Table 1

Spearman correlations for summer camp interest an knowledge

	Expl	KnQu	IntEps	STEM Int	MC Int
Expl	1				
KnQu	0.62*	1			
IntEps	0.17	0.17	1		
STEM Int	0.08	0.3	0.02	1	
MC Int	-0.03	-0.53	0.57	-0.3	1
mean	13.05	16.3	12	81.38	80.09
sd	1.66	2.31	2.45	11.65	12.36

Note: Expl = Exploration, KnQu = knowledge question score, IntEps = Interest episodes from interview, STEM Int = STEM interest score from survey, MC Int = Minecraft interest score from survey. * = $p < .05$

Discussion

Relatively higher exploration was associated with higher mean scores on knowledge questions in a 1-on-1 interview near the end of the camp experience. This significant result points towards the possibility that the more of a map a participant explores, the more NPCs they will meet, the more content they will expose themselves to, and in the end the more concepts they will comprehend and recall at test. Greater exploration indicates a propensity for breadth of understanding, whereas limited exploration might indicate a participant became more focused on a point of interest, promoting depth of understanding. Since the questions cover broad concepts across the worlds then it follows that a breadth approach tends to result in higher mean scores on a knowledge assessment.

Exploration had near zero correlations with STEM and Minecraft interest, which might indicate the environment being explored is novel enough to trigger situational interest or excitement for the content, regardless of initial interest in STEM or Minecraft prior to entering the experience. The survey more closely captures the enduring interest a learner has in STEM and their relationship with different STEM domains. Regardless of enduring STEM interest the learner enters the camp with, they will find something in each world worth exploring and pre-existing interest does not play a major role in exploration/exploitation decisions. The relationship between STEM interest episodes from interviews is also low and non-significant, which points towards a similar conclusion. One of the overall goals of the broader project is to attract learners of varying abilities so seeing learners of varying levels of interest explore in similar manners reflects positively on the goals of the project. However, while not significant, STEM interest does bear a positive correlation with performance on knowledge questions, raising the notion that kids with higher STEM interest also possess higher levels of general STEM knowledge, can apply that knowledge broadly, and can perform better than those with lower levels of interest and knowledge. On the other hand, Minecraft interest is negatively correlated with performance on knowledge questions to a moderate degree, which could be a result of learners focusing more on playing Minecraft in personally preferred ways instead of our intended goals. Perhaps, learners with high interest in a popular game tend to have preferred playstyles they easily fall into that often do not align with educational goals.

Limitations and future directions

Additional measures should be taken to determine differences between depth of understanding regarding concepts versus breadth of understanding. Concluding participants who explore less are not comprehending concepts as much as those exploring more the map devalues possible points of interest where they may want to develop a more in-depth knowledge, such as crop growth or animal habits on these worlds. Time spent in map locations where salient signals related to content are present is worth considering in future analyses of exploratory behavior. Also, continued research with larger sample sizes should be conducted to assess the generalizability of the results.

Closer examination of playstyles and engagement with educational content, in relation to Minecraft interest, should be undertaken to see if learners with increased familiarity tend to favor their own preferences over the intended goals of the intervention. This could be a cautionary take on customizing popular games for educational purposes. Additionally, a measure of situational interest would help unpack how much engagement with the Minecraft environment is influencing a learner's immediate interest, and thereby their inclination to explore and acquire knowledge. A lack of triggered situational interest might be related to disengagement with the game environments and task goals laid out at the beginning of the camp.

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The Digital Game-Based Language Learning Experience for Vocabulary Learning

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Abstract: Vocabulary plays a pivotal role in language learning, and it is widely accepted that an increase in vocabulary improves the learning experience of a second language. Literature shows that one of the impressive benefits of digital game-based language learning (DGBLL) is that it helps students' vocabulary development. This study examines learners' vocabulary learning experiences in a DGBLL context grounded in constructionist theory as they built their own games based on their understanding of different non-fiction texts. Network analysis of interviews found that *application, fun*, and *game-making* were the core components of the learners' experiences and that *translating information, enjoying non-fiction texts*, and *enjoyment* were most critical to the learners' involvement.

Introduction and background

The K-12 school population in the United States is witnessing a significant increase in enrollment of English language learners (ELLs), who comprise the fastest-growing sector (Enyinnah, 2014). However, teaching ELLs can pose a challenge due to differences in language and culture (Kelley et al., 2010). One solution to this issue is digital game-based language learning (DGBLL), which involves creating digital games to promote learning (Khalili, 2014). DGBLL has the potential to facilitate language acquisition and provide ELLs with the necessary language skills for success in their academic pursuits.

To explore the effectiveness of DGBLL, this study tasked students with creating their own video games based on non-fiction texts that they had no prior knowledge of. The study aimed to identify the aspects of DGBLL that aided students in learning new vocabulary while designing their games, while also evaluating their attitudes toward language learning and technology.

This study is based on constructivist theory, constructionist theory, motivation theory, and dual coding theory. Constructivist learning theory is grounded in the work of Piaget (1952), Vygotsky (1978), and Bruner (1996), who defined learning as the active construction of knowledge and meaning. Constructivist learning theory is different because it expands the constructivist perspective on learning (Papert, 1993) by placing more emphasis on the art of learning and on the significance of learning through making (Ackermann, 2001). Motivation theory focuses on the factors that engage learners in the learning process and help to explain their learning outcomes, either intrinsically or extrinsically (Deci & Ryan, 2013). Additionally, dual coding theory states that cognition refers to two different subsystems, a verbal system that is directly composed of language, and a nonverbal system that processes nonverbal objects and events. Hence, knowledge consists of the use of verbal and nonverbal systems (Sadoski, 2005).

In particular, the study employed Scratch (https://scratch.mit.edu/), a programming platform developed by the Massachusetts Institute of Technology Media Lab, which offers a development environment and a website where users can share projects, games, and ideas (Moreno-León & Robles, 2015).

Over eight weeks, young learners participated in an online game-based language learning workshop comprising eight 50-minute sessions. Following the program's conclusion, the researcher conducted interviews with the participants. The study sought to answer the following research questions: *(1) What were the leverage points in networks of relationships regarding aspects of learner experiences that can be used to design DGBLL experiences in the future? (2) How were learner experiences related to aspects of learning theory in which the program was grounded, and what does this indicate about how different aspects of constructionist theory are related to different aspects of dual coding theory and/or motivation theory?*

Methods

Thirteen elementary school-age (9-13 years old) learners participated in this study. Participants were second-generation Bangladeshi American ELL students, and all the students spoke Bengali at home. Parents reported that these students had beginner to intermediate-level proficiency in Bengali. The students were also struggling readers in English and had low English vocabulary knowledge. None of the participants had used Scratch before.

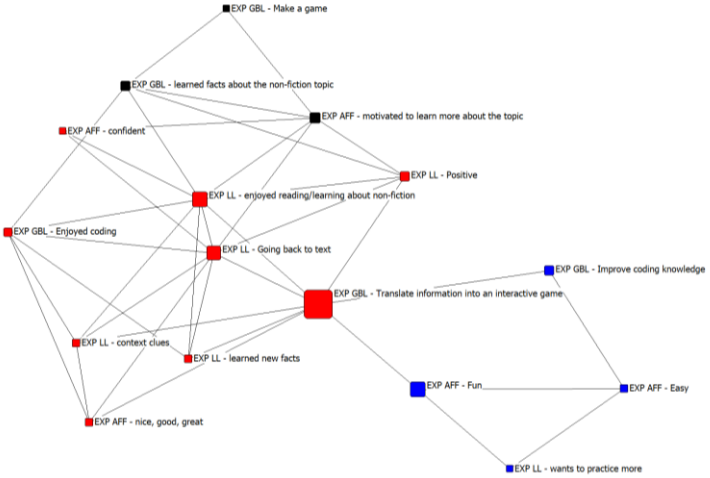
The curriculum for the program was developed by the lead researcher (the first author), and the fifty-minute sessions were conducted through interactive guided learning on Zoom. Each session involved students reading a non-fiction text, developing new vocabulary knowledge, and creating games using Scratch. The instructors facilitated the sessions by reading the non-fiction text aloud, explaining unfamiliar words, and demonstrating how to design a game. Moreover, students collaborated in Zoom breakout rooms and asynchronously used Google documents and Scratch between sessions. Although students worked together to generate ideas, they designed their digital games independently.

This is a convergent mixed methods case study, and measure for this study includes semi-structured interviews. All the interview data were coded in MAXQDA Analytics Pro qualitative analysis software based on the in-vivo coding for emergent codes, axial coding (Corbin & Strauss, 2015), and *a priori* categories based on the theories in which this study is grounded (Thornberg, 2012). To answer the research questions, the researcher conducted semantic network analysis using MAXQDA (Donaldson & Allen-Handy, 2020). For the first research question, clustered semantic network maps of learner experiences in terms of affect, game-based learning, and language learning were used to identify how various aspects of learners' experiences were related. After that, betweenness measures of centrality were used to identify leverage points (Freeman, 1977), which could be used to design more powerful DGBLL experiences in the future. For the second question, clustered semantic network maps of strengths and weaknesses of the design were used to identify the relationships between design strengths and weaknesses. Betweenness centrality measures were calculated, and these measures in the maps were used to identify leverage points in each theory which could provide insights to strengthen other theories.

Findings

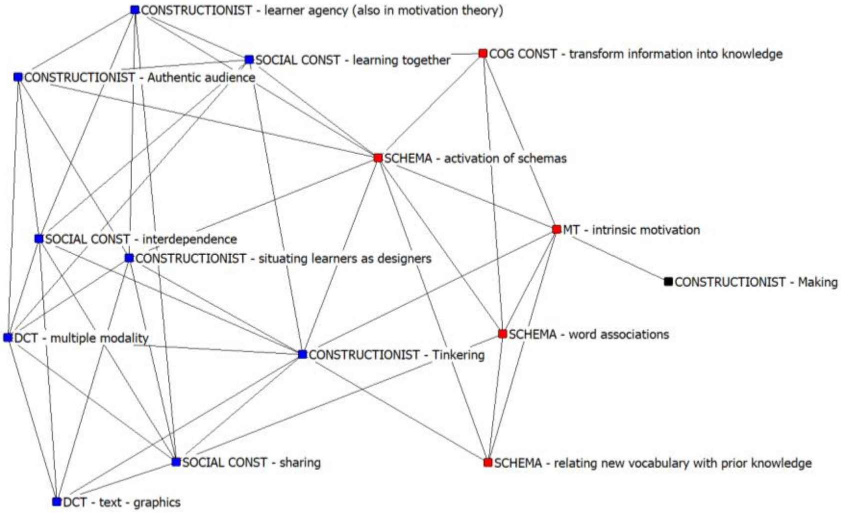
To answer research question one, a three-cluster semantic network map (Q= 0.23) was generated using the categories "game-based learning experience" (GBL), "language learning experience" (LL), and "affective experience" (AFF) using the Girvan-Newman algorithm (Girvan & Newman, 2002) (Figure 1). The network map was created using the correlation matrix at the $p<0.001$ confidence level. It was discovered that the most prominent leverage point was the game-based learning experience code of *translate information into an interactive game.* This leverage point indicates that the DGBLL experience may provide the unique affordance of contextualized language learning where the students use the language in a meaningful, goal-focused way (Reinhardt, 2018). Contextualization is known to be one of the most effective methods of second language vocabulary learning as it helps the learners to remember the vocabulary in semantically related groupings (Nation, 2001). Additionally, this DGBLL design provides students with space for sheltered use of language where they are able to progress through scaffolded steps (Reiser & Tabak, 2014). For example, thinking about all the leverage points closely, it includes the whole cycle of the workshop from start to finish. Therefore, if educators want to design a powerful DGBLL experience, they are well-advised to design their own workshops such that they are generative experiences that construct meaningful representations in the DGBLL context. Additionally, educators should include opportunities for reading, while also leveraging the positive affective experiences *(fun)*.

Figure 1
Learners' Experiences–GBL vs LL vs AFF (Leverage Points)



To answer research question two, a semantic network map was generated in the analysis software using the codes for the categories "constructionist theory," "dual-coding theory," and "motivation theory" (Figure 2). Using the Girvan-Newman algorithm (Girvan & Newman, 2002), the researcher identified a three-cluster semantic map (Q = 0.22) using the correlation matrix at the $p<0.001$ level. The ***construction-together*** cluster shows that several aspects of constructionist theory–including *focused tinkering, authentic audience*, and *situating learners as designers*–are connected to aspects of *interdependence* and *learning together* from social constructivist theory. This emphasizes how DGBLL allows for opportunities of collaboration (Reinhardt, 2018). Furthermore, the ***schema-construction*** cluster shows that the code of *activation of schemas* is connected to the codes of *relating new vocabulary with prior knowledge,* and *word associations.* This aligns with the schema theory of vocabulary learning which contends that connecting new words with prior knowledge and making word associations helps the learners to activate their schema which in turn, results in their vocabulary learning (Rasinski et al., 2017). Moreover, if we take the ***construction-together*** cluster and the ***schema-construction*** cluster, the first cluster includes all the nodes that points to the active, external learning by making artifacts whereas the second cluster includes all the nodes that points to the internal, cognitive process of knowledge construction. This aligns with the feature of constructionist theory where the learners make artifacts (in this case, digital games) and these artifacts mirror the embodied cognition of learners' minds (Papert & Harel, 1991). The **most interesting** finding is that this **externa**l (social constructivist) and **internal** (cognitive constructivist) process **simultaneously** helps the learner with knowledge construction (in this case, vocabulary learning). Even though the code of *making* is not a part of a cluster, it an important node in creating the dyad with the code of *intrinsic motivation.* Without this node, the semantic map becomes weak. This dyad suggests that the DGBLL context may have the potential for promoting intrinsic motivation.

Figure 2
Learning Theories



Implications and conclusion

Findings from this study of DGBLL for second language vocabulary learning show that DGBLL contexts may promote intrinsic motivation for the learners and provide them with the opportunity of contextualized language learning where vocabulary is learned through narrative in the gaming context (Pu & Zhong, 2018; Rahmi, 2018). Our findings provide evidence that DGBLL context has the potential to provide students with a learning experience which is based on the constructionist and social constructivist learning theories where students can be more *generative*, *collaborative* and share ideas with each other while promoting intrinsic motivation among the learners. Additionally, our findings emphasize the way that constructionist theory can be enhanced by the implication of social constructivist theory. While DGBLL has the option to only participate in constructivist theory and the code of *making*, implementing social constructivism and codes such as *tinkering, learner agency (also in motivation theory),* and *learning together* can enhance the positive learning experience in the design. Therefore, we suggest using these multiple learning theories in the learning experience designs may be beneficial for the development of learners' knowledge.

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Investigating 'Investigation and Design' in Introductory Science Courses for Transformative Professional Development

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Abstract: Teaching with Investigation and Design in Science (TIDeS) envisions that future teachers will learn science as undergraduates the way they are expected to teach science in the K–12 classroom: engaging all students in science investigation and engineering design in a discourse-filled, context-rich, inclusive learning process. The TIDeS project seeks to catalyze transformation of introductory undergraduate science courses by supporting faculty in the development and implementation of high-quality, rigorously tested curricular materials. To fully support faculty in the development and implementation of their new materials, we review analysis of baseline observational and interview data of 15 materials developers to better understand and address the needs of TIDeS instructors.

Introduction

Teaching with Investigation and Design in Science (TIDeS) is a National Science Foundation-funded project that envisions that future teachers will learn science as undergraduates as they are expected to teach science in their future classrooms. The majority of science courses that future teachers enroll in are introductory, general education courses, thus TIDeS focuses on these courses and the faculty who teach them. The project has four guiding principles: (1) Students will engage in scientific investigation and engineering design to deepen their understanding of core ideas; (2) Faculty and the curricular materials they use will cultivate an equitable learning environment where all students have equal access to learning and feel valued and supported in their learning; (3) Students will engage in addressing questions and solving problems that are relevant to their lives; and (4) Students will engage in authentic and meaningful scenarios that make use of real data and models and reflect the actual practice of science and engineering. The first goal of the project is to engage and support undergraduate faculty in developing, testing, and implementing high-quality instructional materials that put investigation and design at the center of introductory science courses. As of fall, 2022, three teams of instructors are in the process of creating new materials that will meet the guiding principles and goals of the project as encoded in a rubric, similar to the process described in Egger and colleagues (2019).

The second goal of the project is to assess the impact of the use of the materials and the development process. We are particularly interested in learning about how instructors' beliefs about teaching and their teaching practices change as they undergo a long-term, rigorous curriculum development and professional learning process structured around the guiding principles. To assess change, we started by collecting baseline data from instructors prior to any professional development or implementation of new materials in their classroom. Here, we present those baseline data and how we used those data to inform our professional development.

Methods

Participants

The materials developers (MDs) are 15 instructors who teach introductory undergraduate biology, Earth science, environmental science, and physics courses. Six teach at community colleges, two at bachelors-only institutions, four at masters-granting institutions, and three at doctoral/research institutions; the institutions are in 11 states across the country.

Data collection

We interviewed MDs using a seven-question, semi-structured interview protocol adapted from the Teacher Beliefs Interview (Luft and Roehrig, 2007). We asked: (1) How do you describe your role as a teacher; (2) How do you see your students; (3) Describe one of your most successful teaching experiences within this class and why you felt it was successful; (4) Describe one of your least successful teaching experiences and why you felt that way; (5) How do you decide how to approach a particular content area or topic in this class; (6) How do you know when learning is occurring or has occurred; and (7) What kind of support or professional development do you feel would benefit you most as a teacher in this class?

Responses to the first six questions were coded using the five categories of teacher beliefs identified in Luft and Reohrig (2007): *traditional*, where the focus is on information, transmission, structure, or sources; *instructive*, where the focus is on providing experiences, and is instructor-centered; *transitional*, where the focus is on instructor-student relationships and/or an affective response; *responsive*, where the focus is on collaboration, feedback, or knowledge and skills development; and *reform-based*, where the focus is on mediating student knowledge. Responses to question 7 were not coded as this related to support needed by the MD rather than a question to elicit teaching beliefs. In addition,, we coded interviews for TIDeS guiding principles to look for alignment prior to their involvement in TIDeS curriculum development.

We also observed 14 of 15 MDs teaching using an observation protocol adapted from the Classroom Observation Protocol for Undergraduate STEM (COPUS) (Smith et al., 2013) and the Science Discourse Instrument (SDI) (Fishman et al., 2017. Thirty-four observations were coded and categorized into COPUS profiles or instructional styles: instructor-centered, interactive-lecturer, or student-centered (Stains et al., 2018); and student and instructor behaviors were plotted over time. In addition, 27 15-minute segments of discourse were identified and transcribed from 12 of 15 MDs and coded using the SDI. All analysis were completed by two researchers. For coder reliability, researchers coded the same subset of observations and interviews separately, compared coding, and refined coding analysis upon consensus before continuing to code all observations and interviews. Both interview and observational protocols were tested for validity in a prior pilot study (Bhattacharya and colleagues, 2022).

Findings

Results from interview coding analysis showed MDs teaching beliefs as primarily *instructive* to *transitional.* COPUS results from the thirty-four observations indicate that the most common instructor practices were presenting (70 ± 26% of the total 2-min intervals of a given class) followed by guiding (55 ± 32%); while the most common student practices were receiving information (74 ± 25%) followed by students talking (41 ± 23%). COPUS analysis indicates that four of the observed MDs were profiled as instructor-centered, and four were interactive lecturers. Three were both instructor-centered and interactive lecturers; two use more student-centered practices. To examine the relationship between beliefs and practices, we compared results from interviews to COPUS profiles (Figure 1).

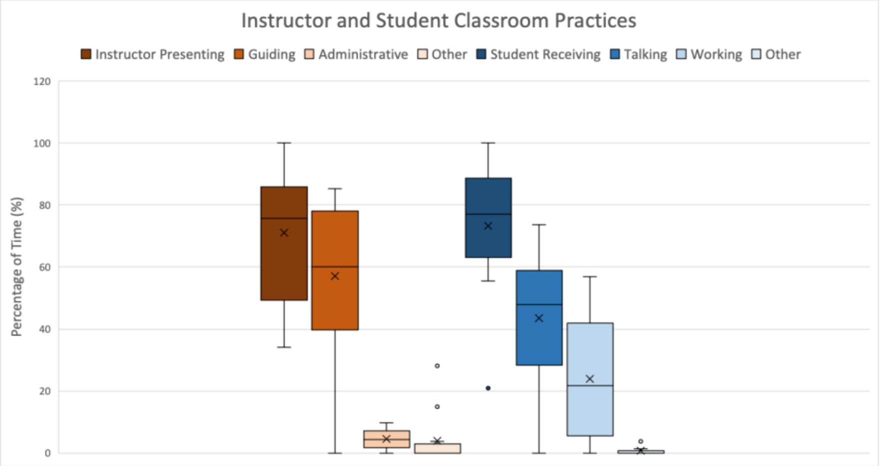
Table 1

Material developers' beliefs and instructional styles

	Interview					
	Trad	**Inst**	**Tran**	**Resp**	**Ref**	**COPUS Profile**
1		xxxxxx				Didactic (1); Interactive (2)
2		xxxx	xx			Interactive (1); Student-centered (2)
3		xxx	xxx			Didactic (1); Interactive (1)
4		/xx	xxx	/		Interactive (2)
5			/xx	/xxx		Didactic (2); Interactive (1)
6	*/xx*	*/x*	*/x*	*/*		*Didactic (1); Interactive (1)*
7		x	xxxx	/	/	Didactic (3)
8	*/x*	*//xxx*	*/*			*Interactive (1); Student-centered (1)*
9	*x*	*xxx*	*xx*			*Didactic (2)*
10		*x//*	*xx///*	*/*		*Didactic (1); Interactive (2); Student-centered (1)*
11		*xx*	*xxxx*			*Didactic (2)*
12	*xx*	*/xx*	*/x*			*n/a*
13		xxx	xxx			Interactive (1)
14	x	xxx	xx			Didactic (1); Interactive (2); Student-centered (1)
15		*/x*	*/xxxx*			*Didactic (1)*

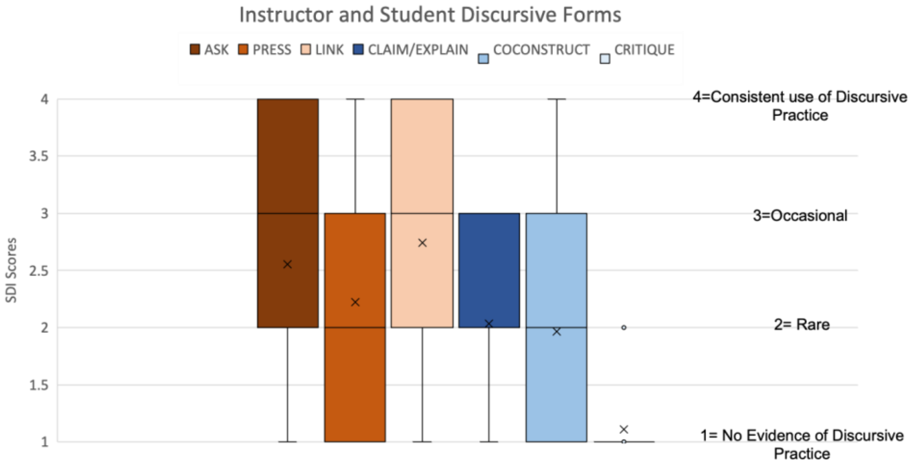
The SDI provides greater detail about the teaching practices of the MDs. Classroom science discourse focused on *building explanations* (across 63% of the 27 segments analyzed), *sharing observations* (41%), and *reviewing/recapping prior lessons* and *sharing background knowledge* (33% each) (Figure 1). There was no captured discourse with the purpose to 'design investigations'—a major component of the TIDeS project. We also noted very little think time was given to students during discourse.

Figure 1
Instructor and Student Practices in Classroom Observations (n=14 MDs)



We used the SDI discursive rubrics to assign scores of 1 to 4 for frequency of: (1) ASK: Do the instructors ask open ended questions intended to elicit diverse student responses; (2) PRESS: Do the instructors press students to support their contributions with evidence and/or reasoning; (3) LINK: Does the instructor connect students' ideas and positions in a way that helps build and develop the discussion; (4) CLAIMS: Do students offer explanations or claims/conjectures supported by evidence; (5) CO-CONSTRUCTION: Do students' contributions link to and build on each other to co-construct understanding; and (6) CRITIQUE: Are students offering critiques of the contributions of other students or the teacher? (Figure 2).

Figure 3
Instructor and Student Discursive Forms and Frequencies (n=12 MDs)



Instructors frequently use ASK and LINK discourse practices, but rarely PRESS students for more information. Students occasionally make CLAIMS, but rarely CO-CONSTRUCT their understanding and do not CRITIQUE their peers or the instructor in whole class discussions.

We did not expect to see alignment of teaching beliefs with the TIDeS guiding principles, and we found few instances. While all instructors are thinking about equity issues, they are not fully actualizing the guiding principle of *equitable learning.* There was no mention of students co-constructing their understanding through communication of ideas nor discussion of how the instructor invites students to express their prior knowledge or experiences in the classroom. Most lacking was the practice of *scientific investigation*, and *asking questions and solving problems* that are relevant to students, however all instructors understand the importance of relevance.

Discussion

Our results indicate that the observed practices of the instructors are not always aligned with their beliefs about teaching and learning science. For example, MDs expressed an awareness of and importance of equity issues in science learning whether or not they used equity-focused strategies in their teaching practices. While their beliefs represent a strong desire for creating equitable learning environments, MDs rarely provided students opportunities to participate in more student-centered activities in class. This misalignment of teaching beliefs and practices is further evidenced when comparing instructional styles to their teaching beliefs. Observational data showed that students are mostly listening or receiving information during class while MDs present this information, which resembles more traditional methods of teaching and learning that we strive to move away from in TIDeS. When examining science discourse in the classrooms, MDs tended to ask open-ended questions and link students' contributions, however, there were fewer instances of pressing students for their reasoning and linking in a way that allowed students to compare/contrast student contributions within the captured discussions. More guidance may be needed to support MDs in eliciting and working with their students' thinking in the moments of classroom activities/discussion. Students also rarely made or did not make claims supported by evidence, nor did they build upon or critique each other's contributions in a way that co-constructed their understanding. Therefore, students will need more scaffolded opportunities to participate fully in the classroom science discourse and activities.

Informed by this research, TIDeS researchers held a series of online webinars meant to provide supporting professional development for MDs. Presently, there have been eight 1-to-3-hour webinars covering a range of topics. All MDs were shown their aggregate data from baseline analysis during four of these professional development webinars. MDs also received a summary analysis of their baseline observational data for individual review and reflection. Other topics of webinars included scientific investigation and engineering design, equity in science learning, and using the language of the Next Generation Science Standards (NGSS). MDs were also given time to share progress and receive feedback within these webinar spaces. *Future directions* include continuing to share aggregate results from the implementation phases to participating MDs. Professional development workshops will continue to focus on classroom activities that engage students in scientific investigation and engineering design that reflect the actual practice of science, on strategies for facilitating productive science discourse, and equity strategies in science learning. The purpose of the webinars is, and will continue to be, to support MDs in enacting more of their beliefs in their teaching practices. Data analysis from implementation is on-going and will continue to inform the professional development of the TIDeS MDs and will be compared to baseline data to analyze change in teaching practices and beliefs across the course of the TIDeS project.

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Articulating a Sociocultural Framework for Identifying and Assessing Computational Thinking

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Abstract: The aim of this conceptual paper is to develop a socioculturally informed theoretical framework for identifying and assessing Computational Thinking (CT); with the purpose of providing guidance for educational practice as regards developing specific assessment tasks. Currently, understandings of CT diverge, rendering the identification of CT ambiguous and the foci for assessing CT unclear. Most existing empirical forms of CT-assessments draw on a cognitive approach to CT and emphasize programming skills and/or students' knowledge about computer science concepts. These forms do not clearly meet an *engagement condition* for CT-activities: that a CT-activity must require learners to engage with algorithmic processes. The framework developed here draws on James Greeno's sociocultural reconceptualization of cognitive phenomena at four different levels. For each level, it is articulated what engagement with algorithms consists in and what criteria for demonstrating engagement are. In addition, examples of assessment tasks at each level are provided.

Introduction

Following Wing (2006), Computational Thinking (CT) has increasingly gained the attention of policy makers, educators and researchers alike for its prime significance for citizens in the 21st century (e.g., Bocconi et al., 2022; Shute et al., 2017). As pointed out by Shute et al. (2017), there is, however, as yet no common, accepted definition of CT. This renders the identification of CT in practice ambiguous and the foci for assessing CT unclear.

This conceptual short paper aims to contribute to the articulation of a socioculturally informed (Greeno & TMSMTAPG, 1998; Wertsch, 1998) theoretical framework for identifying and assessing CT. The purpose is to provide guidance for educational practice as regards developing specific assessment tasks. The framework should encompass activities promoted by the different understandings of CT, given some reconceptualization of the activities to align them with a sociocultural approach. For this reconceptualization, I draw on Greeno's contrastive delineation of cognitive and sociocultural analyses of "cognitive phenomena" (Greeno, 2011)

Recent conceptualizations of CT-activities across the different understandings

In a recent article, Kafai et al. (2020) point out that, despite variances at the level of detail, the different understandings of CT broadly fall within three overall approaches: a cognitive, a situated, and a critical approach.

The first approach focuses on individual problem-solving understood as a sequential process of cognitive information-processing. Decomposition, pattern abstraction and modeling, design of an algorithmic solution, debugging, iteration and generalization are key CT elements emphasized by this approach (Shute et al., 2017).

The second approach originates in Resnick's (2014) constructionism, focusing on learners' creation of digital artefacts and participation in digital practices in collaboration with others. The approach emphasizes social and situated aspects of CT, but not in the sociocultural sense of negotiation of shared meaning (Wenger, 1998). Rather, the intellectual heritage from Resnick's constructionism is clear: the social and situated aspects are emphasized for their significance for the individual's construction of meaning. Personal expression, sense-making and creativity, and the individual's development of "computational fluency" (Kafai et al., 2020, p. 46) in digital practices are thus highlighted as key to CT within this approach.

The third approach focuses on learners' critical engagement with the political, moral, and ethical challenges connected with the design and use of IT. Central to this approach is the critique of algorithms underlying existing computational systems (e.g., social media, face-recognition software, or crime-prediction software) to reveal implicit biases and resulting inequities. In addition, the approach focuses on learners developing a nuanced and reflective understanding of computational systems in use, to allow construction of computer systems that are ethically, socially, and environmentally sensitive. The goals of reflection, critique and sensitive construction are integrated in an overall goal of "computational empowerment" (Dindler et al., 2020).

Dohn et al. (2022) identify what they term an *engagement condition* as a common trait across the different approaches. The engagement condition states that for a learning activity to be a CT-activity, the activity must require that learners engage with algorithmic processes. The approaches differ in their conceptualizations of "engagement with algorithms". For the cognitive approach, developing an algorithmic solution is key; for the situated approach, participation in digital practices; for the critical approach, critiquing underlying algorithms. Still, as shown below, the engagement condition allows integrating all three approaches within one framework.

Articulating a sociocultural framework for identifying and assessing CT

The engagement condition implies two questions that are central to articulating a framework for identifying and assessing CT: 1) What constitutes "engagement with algorithms"? 2) What counts as "demonstrating engagement"? The former is ontological, asking what "engagement with algorithms" *is*. The latter is epistemological, asking how we can *recognize* "engagement with algorithms" in student activity. Thus, the second question asks what the criteria are according to which an activity demonstrates "engagement with algorithms".

A recent review of existing empirical forms of CT-assessments shows a clear dominancy of the cognitive approach to CT (Tang et al., 2020). Furthermore, the authors point out that most assessments concentrate on programming skills and/or evaluate students' knowledge about computer science concepts such as selection, looping, algorithms, and sorting. They note that this is problematic since it is not explained "why assessing CT skills can be interchangeable with assessing programming or computational concepts." (p. 8). Given the engagement condition, the problem is that students may have knowledge *about* computer science concepts such as algorithms without *engaging* with the algorithms (question 1). Further, even within the cognitive approach to CT, it is not clear why being able to articulate such knowledge should be viewed as a criterion for "demonstrating engagement" (question 2). As regards programming skills, it may seem reasonable to say that programming activity "demonstrates engagement with algorithms" (question 2). However, even within the cognitive approach, it appears too restricted to view programming as the only way of "demonstrating engagement with algorithms" (question 2), let alone take it to constitute "engagement with algorithms" per se (question 1).

In contrast to the somewhat problematic assessment forms highlighted in the review by Tang et al. (2020), the aim of the present short paper is to contribute to a framework for identifying and assessing CT which can encompass all three approaches to CT. Furthermore, as the cognitive approach to CT has been dominant, the majority of assessment frameworks have been articulated based on a cognitivist understanding on learning. In consequence, it is under-explored how to approach assessment of students' shared negotiation of CT-subject-matter (e.g., how to follow and critique CT procedures). Therefore, my further aim is to provide a complementary perspective, based on a sociocultural understanding of learning. To clarify, this does not mean articulating the framework from the point of view of what Kafai et al. (2020) call the situated approach to CT: This so-called situated approach, as indicated, still focuses on the individual's sense-making, rather than on the social negotiation of meaning in a student group or classroom. In contrast, a sociocultural understanding of learning focuses on development of patterns of participation in a student group, development of shared repertoires of informational resources, and negotiation of interactional identities (Greeno & TMSMTAPG, 1998; Sfard, 1998; Wenger, 1998). I draw on Greeno's (2011) sociocultural reconceptualization of "cognitive phenomena" in articulating my alternative to dominant cognitivist assessment frameworks, in order to provide sociocultural answers to the ontological and epistemological questions above.

Greeno (2011) points out that cognitivist and sociocultural approaches agree on four levels of cognitive phenomena, but that they differ in their conceptualizations of these phenomena:

- *Level 1: Routine comprehension, conceptual understanding, problem-solving*. Conceptualized by cognitivist approaches as information-processing operations, schemata, acquiring components of procedures etc. Greeno embeds this in a sociocultural analysis focused on conversational contributions, patterns of reasoning in practice, and shared repertoire of schemata.
- *Level 2: Emergent understanding.* Conceptualized by cognitivist approaches as generative reasoning and flexibility in thinking. Sociocultural analyses at this level focus on negotiating different interpretations for mutual understanding, and positioning in interaction.
- *Level 3: Adopting tasks*. Conceptualized by cognitivist approaches as understanding task instructions and having task-level motivation. Within a sociocultural analysis, this level concerns practices that encourage problematizing and resolving, where students are positioned with competence.
- *Level 4: Conceptual growth, commitment to learning goals, sustained participation in learning practices.* Conceptualized by cognitivist approaches as conceptual change, motivational traits, and ways of knowing. Embedded in sociocultural analyses of changes in discourse practice, and positional, intellective identities regarding learning.

Applying Greeno's general analysis to the framework of CT-activities from Dohn et al. (2022) leads to the following levels of CT-activities, and accompanying answers at each level to the two engagement questions concerning ontological constitution and epistemological criteria:

- *Level 1 CT phenomena: Sequential, step-by-step rule-following.* Engagement with algorithms (ontological constitution) at this level is conceptualized socioculturally as rule-following reasoning in communicating with others, using analogue and/or digital means (question 1). Demonstrating engagement (epistemological criteria) at this level is understood socioculturally as done through i) conversational contributions, in particular use of specific terminology indicating step-by-step reasoning. In addition, engagement can be demonstrated by ii) using existing programs to solve tasks, provided the programs in question are acknowledged by students and teacher to be appropriate (question 2). This level mainly concerns CT phenomena emphasized by the cognitive approach to CT.

- *Level 2 CT phenomena: Creative construction and critical evaluation of algorithmic solutions*. Engagement with algorithms (ontological constitution) at this level is conceptualized socioculturally as a) creative construction together with others of shared algorithmic solutions (analogue and/or digital), involving substantial negotiation of the solutions' significance and b) critiquing the effects of algorithms in use. Demonstrating engagement (epistemological criteria) at this level is understood socioculturally as done through dialogic development of algorithmic solutions, explaining rationales and limitations, and imagining consequences. All three approaches to CT emphasize (different) CT phenomena at this level: Construction of algorithmic solutions by the cognitive approach; creative construction together with others by the situated approach; critiquing effects by the critical approach.

Table 1
Sociocultural framework for identifying and assessing Computational Thinking

Cognitive phenomenon	Sociocultural analysis focuses on	Ontological constitution of CT (engagement with algorithms)	Epistemological criteria for CT (demonstrating engagement)	Example of assessment task, to be performed with others
Level 1: Routine comprehension, conceptual understanding, problem-solving	Conversational contributions, patterns of reasoning in practice, shared repertoire of schemata	Sequential, step-by-step, rule-following reasoning in communicating with others, using analogue and/or digital means	Conversational contributions, use of specific terminology indicating step-by-step reasoning. And/or use of existing programs to solve task	Articulate flowchart/computer simulation of specific step-by-step procedure
Level 2: Emergent understanding	Negotiating interpretations, positioning in interaction	Creative constructing shared algorithmic solutions (analogue and/or digital), negotiating their significance, critiquing effects of algorithms in use	Dialogic development of algorithmic solution, explaining rationales and limitations, imagining consequences	Construct a flowchart (analogue) or program (digital) that models a named procedure. Explain the model and its limitations
Level 3: Adopting tasks	Practices that encourage problematizing, students positioned with competence	Initiating algorithmic task solution, initiating critique of algorithms in use	Agentic positioning regarding algorithmic solutions: Initiating construction. Querying validity and appropriateness	Open task that can be solved in several ways, including algorithmically
Level 4: Conceptual growth, sustained participation	Changes in discourse practice, positional identities	Sustained practice of agentic articulation of algorithmic perspective	Sustained discourse about algorithmic solutions: Repeated unenforced choice of initiating, constructing, and critiquing algorithmic solutions	Larger project with parts where each part can be solved in several ways, including algorithmically, and where the solution of one part constrains the others

- *Level 3 CT phenomena*: *Initiating algorithmic tasks and critical evaluations.* Engagement with algorithms (ontological constitution) at this level is conceptualized socioculturally as consisting in students' initiation, in dialogue with others, of algorithmic task solution and critique of algorithms in use. Demonstrating engagement (epistemological criteria) at this level is understood socioculturally as done through agentic positioning of oneself and others regarding algorithmic solutions. In particular, agentic positioning in the form of initiating shared construction of task solutions and/or of querying the validity and appropriateness of existing task solutions. All three approaches to CT emphasize *student initiation* at this level, albeit with somewhat different foci: Initiation of algorithmic task solutions by the cognitive approach; initiation of shared construction by the situated approach; initiation of queries regarding validity and appropriateness by the critical approach.

- *Level 4 CT phenomena: Sustained participation in algorithmic practices*. Engagement with algorithms (ontological constitution) at this level is conceptualized socioculturally as sustained practice of agentic articulation of algorithmic perspectives. Demonstrating engagement (epistemological criteria) at this level is understood socioculturally as done through sustained discourse about algorithmic solutions, in particular through repeated, unenforced choice of initiating, constructing, and critiquing – together with others – algorithmic solutions. All three approaches to CT emphasize *sustained participation* at this level, focusing on, respectively, sustained practice of initiating and constructing (cognitive and situated approaches) and critiquing (critical approach).

Table 1 summarizes the main points developed here for a sociocultural framework for identifying and assessing CT. The first column articulates Greeno's levels of cognitive phenomena. The second column contains Greeno's formulation of the general sociocultural focus for the level in question. The three remaining columns are specific to CT and constitute the novel contribution of the present short paper. Column 3 articulates what engagement with algorithms consists in for the CT phenomena at the given level (ontological constitution of CT at the given level). Column 4 presents the epistemological criteria for CT at the given level (i.e., what counts as demonstrating engagement with algorithms at the given level). Specific assessment tasks should allow students in negotiation with one another to demonstrate engagement with algorithms (i.e., live up to the epistemological criteria). The last column therefore provides examples of assessment tasks at each level for which this is the case.

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A Case Study of Practice-Based Science Enacted in General and Inclusive Elementary Science Classrooms: How do Teachers Provide Verbal Supports for Science and Engineering Practices?

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Abstract: Despite the importance of providing practice-based science to students in inclusive settings, little research investigates how teachers differentiate their support. This embedded, single case study examines how two elementary teachers enacted a four-week, practice-based science project in general and inclusive classrooms. Findings show that teachers necessarily customized practice-based science curricular materials to specific learning contexts, and highlight the potential unintended outcomes that may arise as students in different classes received different kinds of verbal support. This study provides insight into the ways that teachers can modify their enactment of activities to support students to engage in practice-based science, and the kinds of professional development experiences that elementary teachers may need to be able to support all students to engage in practice-based science.

Introduction and background

Science frameworks aim to engage students in the practices of scientists (e.g., American Society of Engineering Education (ASEE), 2020; K-12 Computer Science Framework, 2016; NGSS Lead States, 2013). For example, in the United States, the Next Generation Science Standards (NGSS) call for students to engage in science and engineering practices (SEPs), which include using mathematical and computational thinking to develop models and explanations of the natural world. Practice-based science puts forth a vision of students learning specific disciplinary content through the lens of cross cutting concepts (e.g., patterns, energy, scale) with students having agency over the kinds of questions and problems they answer and solve in classrooms. Expectations to facilitate these kinds of practice-based science experiences for students place high demands on teachers. For example, the NGSS promotes that teachers need to understand not only how to support students to engage in computational thinking practices but also how computational thinking practices relate to science content and practices (Weintrop et al., 2016). Elementary teachers, especially those who may not have disciplinary backgrounds in science, engineering, mathematics, or computer science, may need help to engage their students in these kinds of experiences. Moreover, research suggests that teachers hold high expectations in science for students with and without learning disabilities, but they may need support to provide high-quality science opportunities for all students (Taylor et al., 2018). Despite the importance of providing practice-based science to students in inclusive settings (where students with and without learning disabilities are together), and understanding how teachers enact curriculum materials (e.g., Lowell et al., 2021), very little research investigates how teachers provide differentiated support through their enactment of practice-based science in inclusive settings. This study then uses a framework of teachers' classroom enactment (Lilly et al., 2023) to explore how multiple factors, such as curricular materials, teacher characteristics, and classroom context may affect how teachers use verbal supports to (1) make practice-based science activities more accessible for students (Reiser & Tabak, 2014) and (2) to help students engage in SEPs in ways that are authentic to that of scientists and engineers (i.e., National Academy of Engineering and National Research Council 2014). In particular, we ask: *To what extent and how do teachers provide verbal support of SEPs in whole-class discussions in inclusive and general class contexts?*

Methods

This study uses an embedded, single case study methodology (Yin, 2018) to explore the enactment of a four-week, practice-based science project by two teachers, Mr. Skelton and Ms. Banet (pseudonyms), in a public elementary school in the southeastern United States. Both Mr. Skelton and Ms. Banet had over five years of experience teaching science in elementary contexts, undergraduate degrees in science, prior experience implementing a pilot version of the project, and professional development in practice-based science concepts and pedagogical strategies with the project designers. Mr. Skelton was a school-wide STEM coordinator and Ms. Banet was a fifth-grade mathematics and science classroom teacher. In this study, Mr. Skelton and Ms. Banet co-taught the project to two fifth-grade science classes. One class had a higher proportion of students also in advanced mathematics courses (the General Class) and the other class had a higher proportion of students with

Individualized Educational Plans (IEPs; the Inclusive Class). Teachers supported students to engage in hands-on investigations to develop conceptual models of how water runoff relates to different surface materials, generate engineering designs to reduce water runoff on their school grounds, and create computational models to test their engineering designs. This study focuses on the enactment of three lessons over 50 minute class periods. In the science lesson, teachers supported students to *carry out an investigation* to learn how surface material relates to water absorption and *construct an explanation* of their findings (Inclusive Class: three periods; General Class: four periods). In the engineering lesson, teachers supported students to *generate and compare multiple design solutions* to determine which solution best met design criteria and then *communicated information* about their design solutions (each class: three periods). In the computer science lesson, teachers supported students to *develop computational models* to calculate total water absorbed in their different designs and then *interpret and test the model* (Inclusive Class: four periods; General Class: five periods). The teachers had a teacher's guide outlining the focal SEPs (italicized above) and pedagogical strategies. After transcribing lesson recordings, two researchers coded when the teachers spoke in whole-class discussion as teacher talk; coded turns of teacher talk as supporting the curricula or classroom management; and coded supporting the curricula talk as SEP-specific support or as not SEP-specific support. For each coding level, the researchers achieved inter-rater reliability above 80% over 20% of the data and reached consensus on disagreements (Miles et al., 2020). The two researchers worked together to note if instances of verbal support were aligned to a focal SEP as suggested by the Teacher Guide or aligned to an additional SEP. The researchers then considered themes across SEP-specific support for each lesson.

Results

Between classes, verbal support for SEPs was most different in the science lesson, somewhat similar in the engineering lesson, and most similar in the computer science lesson (Table 1). The SEPs that teachers supported sometimes differed from the focal SEPs outlined in the teacher's guide (bold, Table 1). The teachers added more support for SEPs that were not focal SEPs in both classes in the science and engineering lessons, and support in the computer science lesson focused almost entirely on focal SEPs in both classes (Table 1).

Table 1
Science and Engineering Practices Supported in Two Classes Across Three Disciplines

Science and Engineering Practices	Science		Engineering		Computer Science	
	Inclusive (n=177)	**General** (n=168)	**Inclusive** (n=74)	**General** (n=64)	**Inclusive** (n=280)	**General** (n=332)
Defining problems	2%	4%	53%	52%	-	-
Developing and using models	3%	6%	16%	9%	**54%**	**46%**
Planning and carrying out investigations	**15%**	**21%**	-	-	-	-
Analyzing and interpreting data	**20%**	**14%**	-	-	2%	4%
Using math & computational thinking	10%	10%	-	-	**44%**	**50%**
Constructing explanations	**-**	**19%**	-	-	-	-
Designing solutions	-	-	**15%**	**17%**	-	-
Engaging in argument from evidence	**50%**	**26%**	-	-	-	-
Obtaining, evaluating, & communicating information	-	-	**16%**	**22%**	-	-
Percentage on Focal Practices	**85%**	**80%**	**31%**	**39%**	**98%**	**96%**

Science lesson

In the science lesson, the Inclusive Class received nearly twice as much support towards *engaging in argument from evidence* (50%) as the General Class (26%; Table 1). For example, Ms. Banet supported the Inclusive Class to engage in argument from evidence by first supporting their understanding of what can be used as scientific evidence, saying "And when you tested it, how much water did grass absorb? Is that evidence?" This enacted verbal support for *engaging in argument from evidence* aligned with the teacher's guide, where teachers were prompted to support students to find evidence in their data to help them to answer a scientific question. Meanwhile, in the General Class, the teachers gave instructions to students to *engage in argument from evidence* in small groups without giving this support for defining evidence. For example, Ms. Banet said, "With your partners, answer *how do different surfaces affect where water goes*. You're going to make a claim, and then going to give evidence. I'm going to let you guys go for it. Talk with your table." The verbal support offered to the General Class was also in line with the teacher's guide suggestion of "Depending on your students, and their experience with explanations, you could do this in small groups." Thus, the teachers choose to enact different suggested support from the teacher's guide to support the Inclusive Class to understand what scientific evidence is and to support the General Class to engage in the practice themselves. Additionally, for the focal SEP of constructing explanations, the Inclusive Class did not receive verbal support (0%) while the General Class did (19%). These examples illustrate differences in teachers' verbal support of the science lesson's focal SEPs.

Engineering lesson

More than half of the teachers' verbal support in both classes supported students to engage in *defining problems* (Inclusive: 53%; General: 52%) and *developing and using models* (Inclusive: 16%; General: 9%), which were not focal SEPs (Table 1). For example teachers' verbal support focused on helping students to define constraints by understanding specific vocabulary (Table 2). These examples also show that teachers added support for SEPs that were not in the teacher's guide to help students engage in the focal SEPs. Specifically, by supporting students to understand the problem, students could then design solutions and communicate information.

Table 2
Examples of Teacher's Verbal Support for Defining Problems in the Engineering Lesson

Inclusive Class	General Class
Mr. Skelton: What were the four things asked for? Student: Prevent water runoff. Mr. Skelton: Prevent means none at all… Student: Reduce. Mr. Skelton: Preventing is really hard to do. So reduce water runoff. What else? Student: To withstand heavy storms. Mr. Skelton: You used the right word. Withstand, be able to tolerate or handle heavy storms.	Mr. Skelton: Tell me one criteria. Student: Minimize budget. Mr. Skelton: What does minimize mean? Student: Stay in budget. Mr. Skelton: Stay in the budget; the word minimize is important because if one design costs $1.2 million and another one costs $1 million, a lot of times people don't want to spend extra money. So stay in budget, even minimize.

Computer science lesson

In the computer science lesson, teachers focused most of their verbal support on the focal practices of *using mathematics and computational thinking* (Inclusive: 44%, General: 50%) and *developing and using models* (Inclusive: 54%, General: 46%; Table 1). In the Inclusive Class, verbal support for *using mathematics and computational thinking* focused on supporting students to understand that familiar concepts from mathematics were present in the unfamiliar task of building computer models. For example, Ms. Banet said, "So it says equal to, is greater than, plus, minus. What do you think those green boxes represent? Do they look familiar?" After the student responded, "Yeah, I see it in math," Mr. Skelton said, "And what it's expressing here is a relationship between two things, so this plus this, this minus this. You can drag these over if you want to express a relationship between two blocks." This support was in line with the teacher's guide, which suggested asking students "Has anyone seen anything like this before? Can you tell us how it works?" Meanwhile, in the General Class, the teachers' verbal support to engage in *using mathematics and computational thinking* focused on supporting students to understand how and why mathematics concepts are used in computer science. For example, Mr. Skelton asked students to explain a loop in their program. A student responded, "So it has to run to elapsed time every time it runs. Once elapsed time is the same as the rain duration then it stops repeating." And Mr. Skelton said, "So once elapsed time is equal to this, it stops repeating because we're going to be adding to the elapsed time, every cycle. See what happens by changing the elapsed time, adding two hours. Play around with it." This support aligns with the teacher's guide suggestions for how students might describe a loop: "It tells the model to start raining, and then repeat until the elapsed time is equal to the rain duration: add the hourly rainfall to the total rainfall, then change the elapsed time by adding one (adding an hour to the elapsed time)." In the General Class, such verbal support in whole-class discussion often prepared students to work on their own models as well as to discuss their models after their individual or small-group work. In both classes, the teachers also supported students to engage in *developing and using models*. For example, teachers gave the two classes a basic computational model of water run-off and supported them to state observations and understand the model through whole-class discussion. This followed the teacher's guide which suggested that teachers ask students to observe and evaluate different output values, for example to "check the rain gauge" and "see if they match what they expected." The General Class received additional verbal support, in line with the teacher's guide, to understand how to develop code for their models. Thus, both classes were verbally supported to use a specific computational model to represent scientific phenomena, while the General Class was also verbally supported to develop their own computational model.

Discussion and conclusions

This study's exploration of the differences in teachers' verbal supports of SEPs demonstrates that teachers may need support to offer authentic practice-based science opportunities while meeting the needs of all of their students in different classroom contexts. Findings show that teachers necessarily customize practice-based science curricular materials to specific learning contexts, and also highlight the potential unintended outcomes that may arise as different classes received different kinds of verbal support. For example, the two classes were being supported to engage in different SEPs or engage differently with the SEPs than was intended by the teacher's guide. This may have afforded certain students more access to engage in specific practices. For example, although redefining the problem was not a focal SEP, the additional support was in line with authentic engineering design practices in which engineers understand the problem before ideating solutions (Crismond & Adams, 2012). Further, results are in line with prior research that suggests that general education teachers may need additional support to meet students' individual needs without limiting students' opportunities to engage in NGSS practices. Studies that examine how teachers modify their enactment of practice-based science curriculum to address their students' needs are then important to help curriculum designers to leverage teachers' expertise with the goal of creating more inclusive practice-based science curricula, to help each teacher to develop pedagogical strategies across disciplines, and to support teachers to connect classroom activities to authentic disciplinary practices (i.e., National Academy of Engineering and National Research Council 2014). Our findings show that classroom context, specifically whether students had taken advanced mathematics and their individualized needs, affected which SEPs students had opportunities to engage in. Therefore, it is important to understand how teachers modify their enactment of practice-based science projects so that curriculum designers can include supports for teachers to help all students to authentically engage in SEPs.

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The Interdependence of Identity, Belonging, and Learning: Emerging Evidence From an Out-Of-School Arts Life-Course Study

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Abstract: This article extends long standing work in the learning sciences that evidences the interdependence of identity, belonging, and learning. Informed by a grounded theory analysis of 19 interviews conducted within the geographic areas of Central Kentucky and Appalachia, with alumni from five community-based youth arts organizations, this analysis draws on subset of data from a large-scale, multi-sited and international study into the enduring effects of participating in out-of-school arts programming. By analyzing the existence of long-term effects through the narratological accounts of people at least ten years beyond program participation, this study further develops the field's understanding of the way learning, belonging and identity are deeply intertwined.

Introduction

This study builds upon and extends long standing work in the learning sciences that evidences the interdependence of identity, belonging, and learning. While learning sciences has evolved with the times from its early design-based studies in classrooms to its contemporary emphasis on learning in digitally mediated environments, what has remained constant is a persistent acknowledgement of the centrality of the constructs of identity and belonging to the phenomenon of learning. To date, however, most studies within the field that have centered their inquiries on examining learning, belonging, and identity have been *in-context* and *short-term*. Well known examples include, for instance, the development of identity within science journalism and history (e.g., Polman, 2006), the making of productive STEM identities in afterschool spaces (e.g., Tan et al., 2013), and the demonstration of math competence in basketball and track and field settings (e.g., Nasir 2012).

Less is known, however, about the relationship between learning, belonging, and identity from a long-term, longitudinal, or life-course perspective. Of note, too, recent learning sciences scholarship has tended to focus less on studies of learning squarely within the arts genre. Pursuing inquiry within this noted area of wanting is important for a few fundamental reasons. Firstly, because learning is a life-wide, life-deep, and life-long phenomenon (Bell & Banks, 2012), a retrospective/life-course methodological approach is well merited, with potential to yield novel insights into the shape and texture of learning over time. Secondly, the 'arts', broadly conceived, occupies a substantive part of afterschool programming in the United States, and as learning scientists not only do we have a long history and are well trained to study informal/non-formal/not-school settings (e.g., Cole, 1995; Sefton-Green, 2012), but the arts are "central to our understanding of learning and knowing and therefore of crucial importance to the learning sciences" (Halverson & Sawyer, 2022, p. 1). Thirdly, the first-person, narratological analysis made possible by the reflective construction of the experience of learning solicited by life-course interview questions enables opportunities for both past and present identity formation work to become highly visible and therefore able to be examined for themes and patterns. The present study, then, presents an analysis of a subset of data from a large-scale, multi-sited and international study into the enduring effects of participating in out-of-school arts programming for young people, with a particular focus on how people describe identity formation and a sense of belonging within the context of out-of-school arts learning contexts.

Theoretical perspective: Centering identity within the learning sciences

This study's conceptual framework brings together theoretical heuristics that have emerged from qualitative studies into the relationship between identity and learning. Initially pioneered by psychologists like Vygotsky (1934/1978) and Bateson (1972) and ushered into prominence by everyday cognition researchers such as Lave (1993) and Wenger (1998), the notion that a young person's identity is central to their learning experience is well documented within the field of learning and development. All situated within the camp of what is commonly called a sociocultural approach, the definitions of the three constructs brought together to constitute this theoretical perspective are as follows: *learning* as shifting participation in meaningful sociocultural activity (e.g. Rogoff, 2011); *identity* as a construction of self profoundly influenced by the multiple settings that youth negotiate daily and that emerge historically, local, and interactionally (Nasir, 2012; Wortham, 2004); and *belonging* as the sense that youths' social selves are accepted and valued and that there is room for youth to personally contribute to the activity/practice (Nasir, 2011; 2012). Indeed, these neo-Vygotskian scholars have shown, both in and outside of the classroom, how interwoven the processes of social identification and learning are—and the implications this has for how contemporary designers of learning environments should consider how, for example, to ensure the presence of 'necessary social conditions for learning'—including room for repair, the availability of multiple roles, space to personally contribute to the practice, and a sense of social belonging (Nasir, 2012). When these are present, according to this ontological model of learning, the ability for the mutual constitution of social identification and learning to take place through "the intertwining of local cognitive models and models of identity" (Wortham, 2004, p. 53) becomes possible. Put simply, this study proceeds with the guiding assumption that learning flourishes when young people feel as if their identit(ies) and ways of sense-making and being are valued in the context of the learning environments in which they are embedded.

Data and methods

This analysis focuses on 19 interviews conducted within the state of Kentucky (including the geographic areas of Central Kentucky and Appalachia) with alumni from five Kentucky-based community-based arts organizations, all of whom focused their provision of services on low to middle income youth, and whose genres ranged from music and dance to creative writing and theater. These 19 interviews are part of a larger corpus of interview and survey data with similar program participants located across five US urban locations in California, Kentucky and New York, and two large international cities in Australia and the United Kingdom. While the Kentucky participants in this sample were predominantly white, participants from the other locations were predominantly people of color.

The findings presented below emerged from moving fluidly between inductive coding attuned to low-inferential thematic chunking of prose, and theoretically informed deductive coding, focused on the constructs of identity and belonging (Miles & Huberman, 1994). Ultimately, parent level codes included central theoretical constructs like "identity" (with child level codes such as "participant description of self-formation/shift in self" and "participant identification with a genre/type/formal role") and "belonging" (with child level codes such as "participant expression of a sense of feeling accepted for who they are" and "participant expression of a sense of being valued/mattering in the space/place"). While all 19 interviews were coded using the qualitative software Dedoose to surface broader level patterns and frequencies, the following presentation of analysis highlights two cases of alumni that serve as illustrative examples of the broader phenomenon of the interdependence of identity, belonging, and learning that emerged as participants reflected on their participation from at least one decade ago.

The interdependence of identity, belonging and learning: Insights from two case studies

As the following two illustrative cases show, the entanglement of the constructs of identity, belonging, and learning emerged simultaneously and with great frequency from the data. Consider Aster, a 25-year- old biracial policy analyst from Appalachia who participated in a community-based theatre program as a teenager and now teaches circus arts in her non-working time. In the following response, Aster is talking to the first author, about midway through the interview, about her formal schooling experiences:

> "Elementary school was rough…And you know, middle school is where I got involved with [theater program] and made yeah, you know, some stronger friendships through there. So, I do think that the program kind of helped me, not, I don't think stand up for myself is the right word, but **just to be okay with who I am** and try to not worry about what other people were saying or thinking. Yeah. Yeah. Um, and then I kind of kept that mentality going into high school and still, still understanding that like I loved doing that program and **I want to continue finding ways to get that same feeling** or those same friendships. And I ended up, um, **joining the dance team** for my high school career" (**emphasis** mine).

As Aster reflects on her formal schooling experiences, she articulates them as "rough", alongside noting the contrary in the type of environment the OST program provided, in that its conditions enabled her to claim to be "be okay with who [she] is" (coded: *identity formation*) in ways that prompted her to continue to be involved in/and find new spaces that allowed her to experience *belonging* (code applied to final two sentences of above except). In addition to this, the program provided her with a context within which to "be" - to become a learner - to not only be okay with who she is but to become who she wants to be - a narrative device used to communicate the way she becomes more confident and content with herself as both a learner and community member. It helped, as Aster recounts, , her make sense of what it means to learn as part of a collective, which helps her to be okay with who she is but also serves to concretize her identity as both a critical member of a school community and consequently a member of a much larger arts world. Of note, Aster's use of an active verb tense and future-oriented claim about wanting to "continue finding ways" provide evidence of the *in-situ* identity formation work in which she is still actively engaged, and which, we conjecture, were facilitated early on by her participation in a program that made such vulnerability around identity experimentation and formation visible.

Later in the interview, when Aster is asked to reflect on if and how the program influenced her approach to how she lives her life, she recounts the following:

> **"And honestly like all the way from joining, like in my first [program experience] in 2008 to now, like it has really, it's really given me a love for teaching**. Yeah. Cause I would not be the person I am today. If someone wouldn't have said, okay, Aster, this is how you sing a song in a group. Yeah. Or, okay. Aster, when this person goes upstage, then you have to go this way. Yeah. Yeah. Um, it's just, **it's just really fulfilling for me to be able to say I'm a part of the arts**; that I perform and I teach" (**emphasis** mine).

Aster allows herself to be acted on, to become a type of apprentice, all the while developing an ambition to pass on what she has learned to others. She develops a vocation to both teach and perform - to impart knowledge and to shape the learning experiences of others but to also continue her own personal journey as a performing artist in her own right. This suggests an identity duality that is anchored in affect - affecting others through learning and teaching as well as affecting others through performance. In the above excerpt, then, the reflective construction of the experience of learning—while not named as such by Aster in either of these life-story narrative excerpts—evidences her shifting participation within an activity setting through the "intertwining of a local cognitive model and a model of identity" (Wortham, 2004, p. 53) that occurred as she moved from the periphery of the arts community (as a newcomer and novice) toward the center (as someone who "performs" and "teaches" the arts). Furthermore, this excerpt also illustrates the interdependent relationships between identity, learning *and* belonging. Aster articulates the ways in which participating in the program and experiencing a sense of belonging therein has both shaped the development of an identity (e.g., "I'm part of the arts") that is ongoing at the time of the interviews and facilitated a life-long learning that is also ongoing.

The second illustrative case is of Vance, a 65-year-old white retired grocer who was born, raised, and still lives in a rural area of central Kentucky. For three years during his adolescence, Vance participated in a youth orchestra program as a bassoon player. For his career, Vance followed in the footsteps of his family and took over the family business of owning and operating a mom-and-pop style grocery/eatery. At the time of the interview, he had been retired for about seven years. While the arts didn't become his career, his passion for and practice of the arts greatly shaped his experience of the world and his place within it. In fact, after retiring, returned to college to complete his bachelor's degree, switching from what he initially started as a teenager (Business/Management) to attaining a BA in Music. In the following excerpt, Vance responds, with a smile and a chuckle, to the question of how he lives his life and/or sees the world: "Well I have frequently told people that I'm a musician who happens to be in a grocery store." By identifying first as a musician, as making that identification known through recounting it verbally to others as well in the interview process, Vance reveals the primacy of the arts to his life's trajectory as well as his own agency to craft that narrative through a small, albeit strong, discursive identity performance.

Extending upon the influence that participating in the arts had on him, Vance went on to say, later in the interview, that he

> "...**can't imagine a life without music**. Yeah. I just can't. I, I don't know, it's just, I don't know. It's fun. Yeah. It, uh, and the friends, the, the, the **relationships that you can build**….You know, and one of the things that with age and experience is that you, your ear becomes more sophisticated and, and you can really begin to appreciate just how extraordinary, uh, some of the, uh, some, the people that you hear play and, and you can really appreciate it more. Yeah. And it, and inspires you to, you know, to continue to, uh, improve. And, um, I want, **I want to keep going as long as I can play, as long as I can**…" (**emphasis** mine).

Vance's case demonstrates the ways his sustained participation in music is intertwined with his sense of belonging as fostered through relationships, and identity as a musician. In recounting the influence of the arts on his life, Vance reflects on the centrality of the social bonds and friendship that have allowed him not only a vibrant social life as a result of the arts (which he mentioned throughout this interview), but also contribute to a sense of belonging that enriches his own artistic appreciation and inspires him to continue learning and “improve”—thereby shifting his participation in music—for as long as he physically can. As he says, quite directly, he “can’t imagine a life without music,” suggesting again his own understanding and functioning of the interdependence between his identity as a musician, his sense of belonging to the music community, and his own life-long learning pursuits. Vance’s notable articulation of his more experienced ear connotes a profound effect that is only made apparent and consequential to him through retrospective life course analysis. Of interest, he couches a justification of his age in a narrative of appreciation and expertise—two strong elements of his musical identity and his sense of self as a learner.

Discussion and conclusion

Analysis of life-course interview data from people who participated in out-of-school arts programming in their adolescence cement and extend what is already known within the field of the learning sciences about the interdependence of identity, belonging, and learning. The various aspects of what it means to form an identity, to belong and to learn are informed by both context and time. By analyzing the existence of long-term effects through the narratives of people at least ten years beyond program participation, we further develop an understanding of the way learning, belonging and identity are deeply intertwined. People articulate versions of themselves–versions that are informed by their learning experiences and consequential understandings of who they are and who they have become. Retrospective life course analysis is therefore a methodology that may help the learning sciences field further ground such theoretical insights. Whilst the study extends empirical evidence on how learning, belonging and identity are interdependent, it also sheds light on the how people experience learning over the long-term, and how learning and structured arts opportunity shapes people's lives and the stories they tell about themselves.

To be clear, the present line of inquiry is still in progress, as triangulation of these data within the extensive corpus of data from which they are situated is ongoing. What is clear, however, is the need within our design science field to further examine, problematize, and tear down the obstacles that lie in the way of actualizing the design principles for identity development and social belonging that are evidenced to consequentially and meaningfully shape the learning experiences of young people, especially those whose identities are historically and contemporarily marginalized and/or minoritized. It is toward discussion and reflection on this continually pressing problem of theory and practice that this short paper presentation is offered.

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Systematic Literature Review of Teachers' Digital Competence in K-12 Education: Defining the Concept

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Abstract: The current proposal is part of a larger study that aims to synthesize the existing research on in-service teachers' digital competence over the last ten years in the context of K-12 education. In this presentation, we will focus on the definition of 'digital competence' and its overlap with similar terms. This systematic literature review used three databases, Web of Science, ERIC, and Education Source, to store, identify and critically appraise published studies on teachers' digital competence at different levels of K-12 education. A total of 33 studies were identified as eligible to be included in this review. Results reveal that though many publications defined digital competence through the EU policy framework, the field still uses various multiple terms related to digital competence, and there is still no universally accepted definition.

Introduction

In recent years, there has been an increasing number of studies focusing on the role and use of digital technologies in the knowledge-based society. The advent of digital knowledge-based societies makes digital competencies the key competency essentials for teaching (Castells, 2010). In-service teachers at K-12 schools notably should improve their digital competences to meet the expanded needs of teaching and adjust to the new instructional methods compared to pre-service teachers who are expected to eagerly use technology in the classroom (Huang et al., 2021). The term "digital competence" can be broadly described as "the set of knowledge, skills, and attitudes that are required when using Information and Communication Technology (ICT) and digital media to perform tasks; solve problems; communicate; manage information; collaborate; create and share content, and build knowledge effectively" (Ferrari, 2012, p. 4). The European Union Digital Competence Framework for Educators (DigCompEdu) uses digital competence as 'digital literacy' and acknowledges it as one of the eight key competences for lifelong learning (Ferrari & Punie, 2013). This review considers different terms and definitions of digital competence, such as digital literacy (Buckingham, 2006), media literacy (Pangrazio et al., 2020), computer literacy (Nawaz & Kundi, 2010), ICT competency (NICS, 2010), ICT or digital skills (Tanhua-Piiroinen et al., 2020), information literacy (Bundy, 2004) and technological literacy (Martin, 2008).

Recently, many reviews have focused on digital competence and digital literacy (e.g., Sánchez-Caballé et al., 2020; Spante et al., 2018). Particularly, current studies have concentrated on pre-service teachers' digital competence (e.g., Basilotta-Gómez-Pablos, 2022; Torres-Hernández & Gallego-Arrufat, 2022; Zhao et al., 2021) and different practices (e.g., models, assessment, frameworks) as well as digital competence in higher education (e.g., Fernández-Batanero et al., 2021; Sillat et al., 2021). However, there is a lack of studies to better understand the digital competence of in-service teachers (McGarr & McDonagh, 2019). Although most reviews have provided qualitatively conceptual frameworks, dimensions, and models of digital competence, often in higher education, there have been almost no reviews focusing specifically on the digital competence of K-12 teachers.

In this review, we systematically explored the application of digital competence in K-12 education to give insights into the definition of digital competence. The overarching purpose of this work is to provide a systematic review of the peer-reviewed journal articles published between 2012 and 2022 that examined the digital competence of teachers at K-12 schools (e.g., elementary/primary/secondary/middle/junior high school). The review focused on the following research question: *How has the concept of digital competence been defined in terms of teachers in K-12 education?*

Method

The study was represented as a systematic review of the literature on teachers' digital competence in K-12 education and conducted according to the criteria suggested by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2015). To ensure the dependability and reliability of the data, the PRISMA checklist was taken into consideration as the selection criteria and synthesis of the selected papers (Hutton et al., 2016). The eligibility of the studies based on the inclusion and exclusion criteria is displayed in Table 1. We used three electronic databases, Web of Science, ERIC, and Education Source. The hand-searching of the topic and reference lists of included articles were conducted to identify any relevant studies missing in the database search. We searched the selected key terms in the title, keywords, subject headings, and abstract of the paper across the three databases. The quoted descriptors were associated with the Boolean Operators 'AND' and 'OR' and a Proximity Operator 'N3' leading the search to the target searched terms. The search strings for the concept "digital competence" were exemplified through ERIC as follows.

> (TI "computer skills" OR "digital skills" OR "computer competenc*" OR "ICT competenc*" OR "digital competenc*" OR "digital literacy" OR "technological literacy" OR (computer OR digital OR technolog*) N3 (skill* OR literacy OR competenc*) OR AB "computer skills" OR "digital skills" OR "computer competenc*" OR "ICT competenc*" OR "digital competenc*" OR "digital literacy" OR "technological literacy" OR (computer OR digital OR technolog*) N3 (skill* OR literacy OR competenc*))

Table 1

Inclusion and Exclusion Criteria

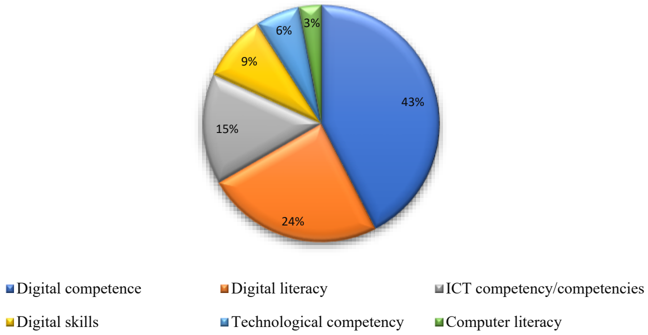
	Included	Excluded
Time frame	Articles published from 2012-2022	Articles not published from 2012-2022
Publication type	Peer-reviewed articles	Grey literature
Focus	Studies focusing on digital competence and other related terms (e.g., digital literacy)	Articles focusing on other aspects (e.g., self-efficacy, technology integration)
Language	English	Other languages
Target Population	Articles on K-12 in-service teachers at elementary/primary/secondary/high schools	Articles focusing on student teachers, pre-service teachers, future teachers

Results

Regarding the analysis of the 33 selected articles, multiple terms have been used to describe the concept of digital competence. The distribution of the concepts is shown in Figure 1. In general, these selected studies described the definition of digital competence with reference to both research and national or international policies (e.g., DigCompEdu, UNESCO) or only to policies or research, and developed their own definitions through the literature. 22 studies described the definition of digital competence by using policy frameworks. Eight articles defined digital competence by referring to the European Framework for the Digital Competence of Educators which includes six areas of digital skills and 22 competencies concerning educators' professional practices.

Figure 1

Distribution of the Concepts Used in the Included Articles (n = 33)



The six areas are divided into educators' professional and pedagogic competences and consist of (a) "professional engagement" – the ability to use digital technologies to communicate and collaborate for professional development, (b) "digital resources" – the ability to search, locate, create and share digital resources, (c) "teaching and learning" – the ability to effectively apply digital technologies into teaching and learning processes, (d) "assessment" – the ability to use digital technologies and methods to improve assessment, (e) "empowering learners" – the ability to use digital technologies to develop inclusive, personalized and engaging learning environments, and (f) "facilitating learners' digital competence" – the ability to support learners to benefit from digital technologies to obtain information, communicate, create content, solve problems (Redecker, 2017, p. 16). Four publications cited the National Institute of Educational Technology and Teacher Training (INTEF, 2017). The framework includes digital competences following other European guidelines; as such, focusing on information and information literacy, problem-solving, digital security, communication and collaboration, and digital content development. Four publications presented the ICT standards suggested by the *International Society* *for Technology in Education* (ISTE) for school teachers, organizing them into a variety of stages (e.g., basic, intermediate, and advanced) so that teachers can achieve a certain degree of technological and pedagogical competences (Romero-Tena et al., 2020). In addition to the policy frameworks set by public and private international institutions (e.g., UNESCO, ISTE), authors of 10 publications adopted definitions used in previously published research. There are three studies that defined digital competence by developing their own definition. Some example studies with their concept definition source were displayed in Table 2.

Table 2

Characterization of Sample of Articles Included in the Review

Author(s)	Year	Country	Sample Size	Grade Level	Definition (based on)
Álvarez & Mercè	2015	Spain	2,656	Secondary	UNESCO, ISTE, INTEF
Sauers & McLeod	2018	USA	922	Secondary	Research
Olofsson et al.	2020	Sweden	25	Upper secondary	Framework by Swedish National Agency for Education
Lucas et al.	2021	Portugal	1,071	Primary, secondary	DigCompEdu
Cattaneo et al.	2022	Switzerland	1,692	Secondary	Research, DigCompEdu

Discussion

The synthesis of the definitions in the included studies revealed that the concept of digital competence has been defined in various ways in the context of K-12 education. This indicates the complexity of the term, digital competence, which has been used in multiple contexts across different countries and thus led to the deficiency of a universally accepted definition. Furthermore, the relative lack of literature focusing on in-service teachers' digital competence in different levels of K-12 schools does not help us conduct a comprehensive examination of literature to better understand teachers' digital competence. It should be noted that teachers' need for using digital technologies might change in terms of subject and grade taught, individual (e.g., age, teaching experience, self-efficacy, motivation), and contextual (e.g., access to digital resources, collegiality, school climate) factors. Thus, there is a need for a benchmark of digital skills that can address teachers' needs and enable sound measurement of teachers' mastery of digital competence in K-12 education.

Endnotes

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Co-Designing Elementary-Level Computer Science and Mathematics Lessons: An Expansive Framing Approach

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Abstract: This study examines how a rural-serving school district aimed to provide elementary-level computer science (CS) by offering instruction during students' computer lab time. As part of a research-practice partnership, cross-context mathematics and CS lessons were co-designed to expansively frame and highlight connections across – as opposed to integration within – the two subjects. Findings indicated that most students who engaged with the lessons across the lab and classroom contexts reported finding the lessons interesting, seeing connections to their mathematics classes, and understanding the programming. In contrast, a three-level logistic regression model showed that students who only learned about mathematics connections within the CS lessons (thus not in a cross-context way) reported statistically significant lower levels of interest, connections, and understanding.

Introduction

There is broad consensus among policy makers, educators, and researchers that it is essential for all students to have opportunities to learn foundational ideas of computer science (CS) and explore computational thinking (Vakil, 2018). Yet, many school districts face barriers in providing equitable and high-quality access to elementary-level computer science instruction given constraints in their local educational infrastructures.

In this paper, we describe how one rural-serving school district aimed to address these barriers as key problems of practice in their elementary schools. In particular, the partner school district decided to offer CS instruction in elementary school during students' weekly computer lab time, which is required and thus a part of all students' elementary experiences. To address this problem, a design team, comprised of teachers, paraprofessional CS educators, district administrators, and researchers, collaboratively designed and tested an approach in which CS connections were highlighted and identified *across* subject contexts, as opposed to integrated *within* (National Research Council, 2014; Weintrop et al., 2016). The cross-context design was informed by the theory of expansive framing, in which disparate contexts are reframed into a single, unified frame so that ideas in one context are extended through the entire frame (Engle et al., 2012). Mathematics was chosen as the subject area for making connections by framing mathematics as a context to learn CS concepts.

In particular, we examine the cross-context approach as it applied in practice for upper elementary school students. We address how critical it is for students to make the cross-context connections in both the mathematics and CS lessons or whether it is sufficient for them to only make connections during their computer lab instruction. In this paper, we present the results of implementing these lessons in elementary school contexts. In one school, the cross-context group, students participated in the cross-context lessons during both regular mathematics classroom and computer lab instruction. In two other schools in the school district, the CS-only group, lessons were only taught in the computer lab led by the paraprofessionals. Thus, the CS-only group participated in the CS lessons that integrated mathematics; however, these lessons were only taught in the computer lab setting and not also in the regular classrooms. Our research was guided by the following question: *Did students' perceptions in the cross-context group differ from their peers in the CS-only group?*

Theoretical framework: Expansive framing

Expansive framing is both an instructional approach and a theoretical framework to explain transfer of learning from a situated and sociocultural perspective (Engle et al., 2012). Expansive framing posits that broadly framing curricula across contexts (e.g., time, place, people, role, and topic) can foster expectations that content learned in one setting will be useful in other settings. The theory advocates for the importance of interleaving contextual features to promote transfer between the contexts. Additionally, framing expansively helps promote student creation of and authorship in their own learning by inviting students to draw upon their prior knowledge, holding them accountable for their own learning, and portraying them as independent knowledge generators (Engle et al., 2012). Use of this theory has been growing in instructional settings, including CS education (Grover et al., 2014).

In this study, we drew upon expansive framing to inform the collaborative design of cross-contextual CS-math lessons. Specifically, CS concepts were framed within the mathematics lessons through prompts that linked mathematics and CS ideas. Mathematics was also framed within lessons in the computer lab that reified conceptual understanding of mathematics topics and supported student creation through programming.

Cross-contextual, expansively framed CS-mathematics lessons

For the design of the instructional unit, mathematics was identified as an ideal subject area for making connections with CS concepts as there is a long history investigating such synergies (e.g., Papert, 1980; Weintrop et al., 2020). Further, a recent literature review (Shehzad et al., 2023) of CS-math integration found that connections between math and CS concepts need to be explicitly made through instruction. Thus, the proposed solution involved identifying and highlighting CS connections across subject contexts (as opposed to only integrating CS in math lessons) in mutually supportive and expansively framed ways. Thus, math-integrated CS instruction was added to students' weekly computer lab time; CS instruction also occurred in the mathematics class through mini-lessons that were embedded into existing standards-aligned mathematics routines with an emphasis on highlighting computing concepts. These expansively framed mini-lessons also helped classroom teachers see and articulate mathematical connections to CS ideas, an important goal in efforts to create cross-contextual connections (Fisler et al., 2021).

Lessons were designed to build connections between math routines in class and CS instruction in the computer lab. For example, in one math routine, teachers used if-then-else conditional logic within the following kinds of prompts to help students recall their knowledge of quadrilaterals: "if a quadrilateral is regular, then it has four **<blank>** sides, else it is not regular." The correct answer was congruent or equal. The goal was thus to expansively frame CS and math concepts rather than learning to program in Scratch in isolation (Grover et al., 2014). Table 1 shows key principles of expansive framing and examples of how each principle was instantiated in classroom math routines and lab coding activities. These features of the lessons that connected concepts across contexts and promoted student authorship were intended to foster transfer of content between settings.

Table 1
Examples of Expansive Framing Principles Instantiated in Lessons

Expansive Framing	Instantiation in Mathematics	Instantiation in Coding
Connecting contexts	Use conditional statements (CS) to classify quadrilaterals (math) Script teacher statements with physical and temporal references Use images from coding activities to demonstrate math concept	Embed math content in coding activities Add educative elements to Scratch cards
Promoting authorship	Engaging in think-pair-share math routines hold students accountable for their learning Engaging in shape sorting activity supports multiple correct answers and creative thinking	Students create and code their own quiz

While we co-designed two instructional units, the present study focuses on the geometry unit. The mathematics unit was designed as a menu of six math routines that teachers could choose from as a warm-up to typical mathematics lessons in their geometry unit. The CS lessons were designed as extension activities to existing instruction and contained two math-integrated lessons. Table 2 summarizes topics covered in the geometry unit, specifically the two lessons on quadrilaterals and triangles.

Table 2
Cross-Contextual and Expansive Framing of Mathematics and Computer Science in Geometry Unit

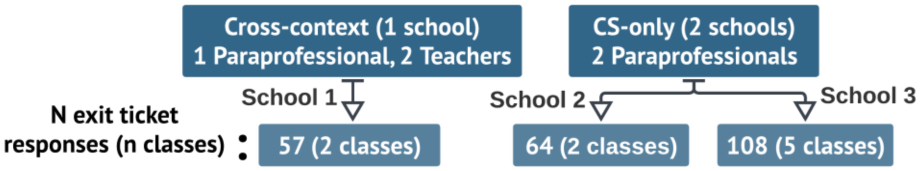
Math Topic	Math Big Ideas	Computing Big Ideas	CS-Math Connections
Quadrilaterals	Reasoning with polygons Classifying shapes	Conditionals, variables, abstraction	Use conditional statements to reason about polygons and attributes
Triangles	Classifying triangle types	Conditionals, variables, loops	Program shapes with exterior angles

Methods

This research took place in a rural-serving district in the western United States. We collected student data in three elementary schools. In School 1, the math lessons were taught during regular math time by two classroom teachers and the CS lessons were taught during computer lab time by the school's paraprofessional (the cross-context group; N=57 students). In the other two schools, only the CS lessons were taught by the two schools' paraprofessionals (CS-only group; N=172 students). Figure 1 shows the number of teachers, paraprofessionals, and responses from students who participated in the study.

Figure 1

Number of classes, teachers, paraprofessionals and exit tickets collected by lesson, implementation, and school



Immediately following each lesson in the computer lab, students completed a short three-question exit ticket survey about their perception of the lesson. Table 3 shows the constructs addressed and questions asked of students in these exit tickets. Students were asked to either respond with "yes" or "no" to each statement.

Table 3

Exit Ticket Items. Students Responded Either Yes or No

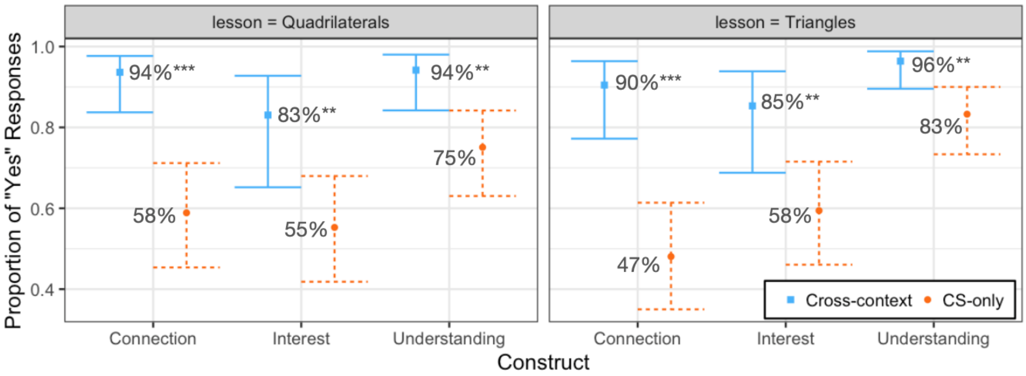
Construct	Exit Ticket Prompt
Interest	I found today's computer lab lesson interesting.
Connection	Today's computer lab was related to what I do in math class.
Understanding	I understood what we did in computer lab today.

As students' responses were binary (yes/no), to address the research question we compared the differences between responses of the cross-context students to the CS-only students using a three-level logistic regression model where survey items were treated as level-1 units, individual students were treated as level-2 units, and individual classes were treated as level-3 units. The CS-only group was treated as the reference group.

The study comes with limitations. First, we were working with unidentified student data; thus, we could not match student data collected across the two lessons, resulting in loss of power and inability to take student-specific differences across lessons into account. Second, the surveys used self-reported measures, which may suffer from bias due to respondents' subjective frames of references. Despite these limitations, exit ticket measures are increasingly being used in implementation research in education (Yeager et al., 2013) due their simplicity and ease of administration.

Figure 2

Estimated marginal means of "Yes" responses modelled using multilevel logistic regression



*** p<.001, ** p<.01, p-values were adjusted using the method of false discovery rate

Findings

To address our research question, we contrasted the perceptions of students in the cross-context group to students in two other schools where the CS-math connections were only taught in the CS lessons during computer lab time. Results from a three-level logistic regression model with random intercepts across exit ticket items (level-1), students (level-2), and classes (level-3) are presented in Figure 2. Across both the quadrilateral and triangle lessons and compared to their peers in the CS-only implementation, more students in the cross-context implementations found the lessons interesting, saw connections to their mathematics classes, and understood the programming, and these differences were significantly higher. For example, on the question related to *perceived connection between the CS lesson and their mathematics* class, the average probabilities of responding "yes" by the cross-context students were 94% and 90% for the quadrilaterals lesson and the triangles lesson respectively and were significantly higher than their peers in the CS-only group. This suggests that encountering CS and mathematics content in both the classroom and the computer lab helped students better see the connections. The average probabilities of responding "yes" were also significantly higher for students in the cross-context group on the questions related to *perceived interest in the lesson* and *perceived understanding of the lesson* (see Figure 2).

Conclusion and implications

This paper describes the co-design of fifth-grade cross-contextual mathematics and CS lessons. The approach involved identifying and highlighting CS connections across mathematics and CS contexts in expansively framed ways. This work thus contributes to a reconsideration of what CS integration can look like in elementary schools.

The paper also reports findings examining students' experiences of these lessons. Most students in the cross-context group reported that they found the lessons interesting, saw connections to their mathematics classes, and understood the programming; moreover, these perceptions were significantly higher than students in the CS-only groups. These findings show the value in building connections into classroom lessons and the importance of making and highlighting the connections, as suggested by the theory of expansive framing, between both the CS and mathematics contexts. While not the focus of the present study, helping students see the connections between mathematics and CS also has the potential to help them more deeply understand the content in both disciplines.

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International Society of
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Understanding and Predicting Teachers' Intention to Use Educational Chatbots

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Abstract: Less is known about factors affecting teachers' educational chatbot use. Therefore, the current study attempted to extend Technology Acceptance Model (TAM) constructs (ease of use, perceived usefulness, and attitude) by adding subjective norm and trust; then, investigate how these constructs influenced teachers' intention to use educational chatbots. Results indicated that together ease of use and perceived usefulness contributed to attitude towards using educational chatbots, in turn, a positive attitude led to an increase in the intention to use. Whereas perceived usefulness is found to have positive effect on intention to use, no relation is seen between ease of use and intention to use. Further, subjective norm and teachers' trust in educational chatbots are found to be positive determinants of the intention to use educational chatbots. Our study implies that developers of educational chatbots should consider not only the technical but also the pedagogical features of chatbots.

Introduction

Artificial intelligence (AI) has become widespread in everyday life. In fact, whether we are aware or not, various technologies are operated with the help of AI, and these are described as AI-based tools. The chatbot is regarded as one of the most frequently utilized AI technologies (Wang et al., 2021). Today, many sectors such as business and health benefit from chatbots for several purposes. Recently, educational scientists noticed the pedagogical assets of chatbots in K-12 education (Luckin & Cukurova, 2019). The affordances of chatbots are expected to transform K-12 education into a more learner-centered approach (Celik, 2023). Specifically, chatbots offer personalized learning opportunities (Cox, 2021), and help teachers reveal learner needs (Luckin & Cukurova, 2019). Consequently, chatbots can reduce teachers' workload during the planning, implementation, and assessment stages of teaching (Celik et al., 2022).

Despite its demonstrated advantages, the integration of chatbots in K-12 education is lagging compared to other sectors such as business and health (Miao et al., 2021). This is explicitly related to the role of teachers in the educational integration of AI-based tools, which has been overlooked and neglected until now (Seufert et al., 2021). Indeed, teachers are considered as important end users of AI technologies and stakeholders of AI integration in K-12 education (Luckin & Cukurova, 2019). Therefore, the underlying factors that affect their intention to use chatbots are critical in terms of effective AI integration. However, little is known about such factors regarding teachers' chatbots use. Therefore, the current study aims to investigate factors affecting teachers' intention to use educational chatbots. To achieve this aim, we draw upon Technology Acceptance Model (TAM) since it is a robust framework in explaining user acceptance of emerging technologies (Arpaci, 2016). We created a research model of hypothesized relations using TAM constructs (perceived usefulness, attitude, and ease of use). In addition to these constructs; the research model incorporated two additional constructs namely *trust* and *subjective norm* to better explain the intention to use chatbots. Each hypothesis in the research model is detailed below.

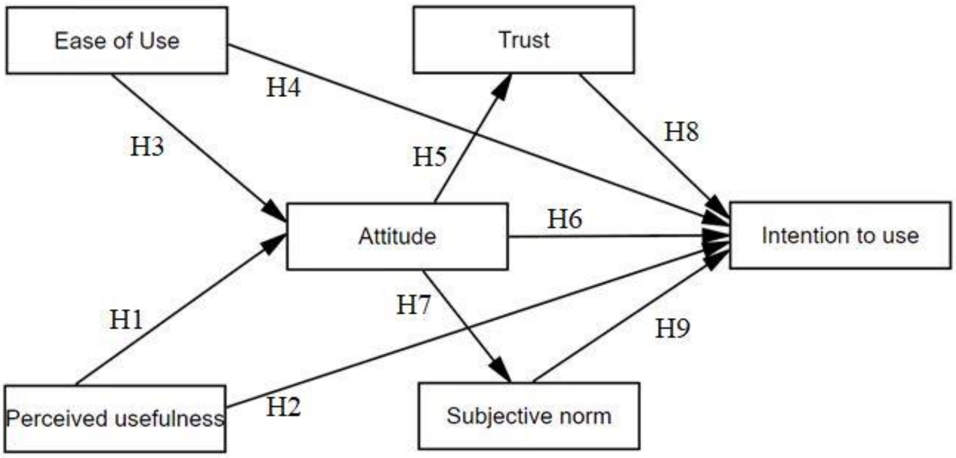
Research model and hypotheses

TAM refers to a theoretical framework that is validated to explain factors that determine the acceptance of information systems (Davis, 1989). Perceived ease of use and perceived usefulness are considered the main constructs that directly or indirectly predict behavioral intention for using technology. In the current study context, perceived usefulness refers to the degree to which a teacher believes that using educational chatbots enhances his or her work performance (Davis, 1989). The more teachers perceive chatbots as a useful tool (such as through searching for educational material on the Internet), the more likely they could have intention to utilize chatbots in their teaching. Meanwhile, ease of use is described as the degree to which a teacher believes the chatbot is effort-free to use (Davis, 1989). In this regard, as teachers perceive educational chatbots as easy to interact with, they might exploit these tools for teaching purposes. TAM posits that both perceived usefulness and ease of use are positively associated with attitude towards using chatbots, which is defined as a teacher's general affective response to the use of educational chatbots. Therefore, in light of TAM, we also hypothesize that attitude towards using a chatbot is a positive and significant determinant of teachers' intention to use such AI-based tools.

In order to contribute to the power of the TAM for explaining the intention to use chatbots, we added two research variables to the research model, subjective norm and trust. The extension of TAM with additional construct is also common in previous research (e.g., Arpaci, 2016). Trust refers to teachers' confidence in the reliability and trustworthiness of the suggestions and decisions offered by educational chatbots. Trust in using chatbots depends on the privacy issues and educational appropriateness of the chatbot suggestions. Subjective norm could be determined as teachers' perception of whether their counterparts who are important to them suggest they ought or ought not to use educational chatbots (Fishbein & Ajzen, 1975). We also argue that both trust and subjective norm are positively related to teachers' intention to use chatbots. In other words, when teachers trust in the chatbot suggestions and recognize their friends use chatbots, it is more possible for them to use chatbots. In this study, we propose the following hypothesis based on TAM and previous research. The hypothesized research model is illustrated in Figure 1.

- **H1.** Perceived usefulness positively influences teachers' attitudes toward using educational chatbots.
- **H2.** Perceived usefulness positively influences teachers' intention to use educational chatbots.
- **H3.** Ease of use positively influences teachers' attitudes toward using educational chatbots.
- **H4.** Ease of use positively influences teachers' intention to use educational chatbots.
- **H5.** Attitude positively influences teachers' trust in educational chatbots.
- **H6.** Attitude positively influences teachers' intention to use educational chatbots.
- **H7.** Attitude positively influence teachers' subjective norm about educational chatbots.
- **H8.** Trust positively influences teachers' teachers' intention to use educational chatbots.
- **H9.** Subjective norm positively influences teachers' intention to use educational chatbots.

Figure 1
Research Model



Methodology

Participants

In Turkey, the Ministry of Education developed an interactive environment for online distance education during the COVID-19 pandemic, namely EBA platform. All teachers working at the K-12 level in Turkey used the platform. In the process of distance education, a chatbot entitled *EBA assistant* started to serve as a conversational agent in the platform (Cbot, 2022). We collected self-reported data from 163 teachers (92 female, 71 male) with experience in using EBA assistants.

Data collection tool

To collect self-reported data, we developed an instrument based on previous research in TAM and chatbot acceptance. An online survey questionnaire was designed using the questionnaire items that had been successfully validated in previous research of perceived usefulness and ease of use (e.g., Davis, 1989), subjective norm, attitude, and intention to use (e.g., Ajzen, 1991), and trust (Arpaci, et al., 2015). Cronbach's alpha coefficients with number of items of the sub-scales: perceived usefulness (4 items, 0.87), ease of use (3 items, 0.78), subjective norm (3 items, 0.82), attitude (4 items, 0.75), and intention to use (4 items, 0.82).

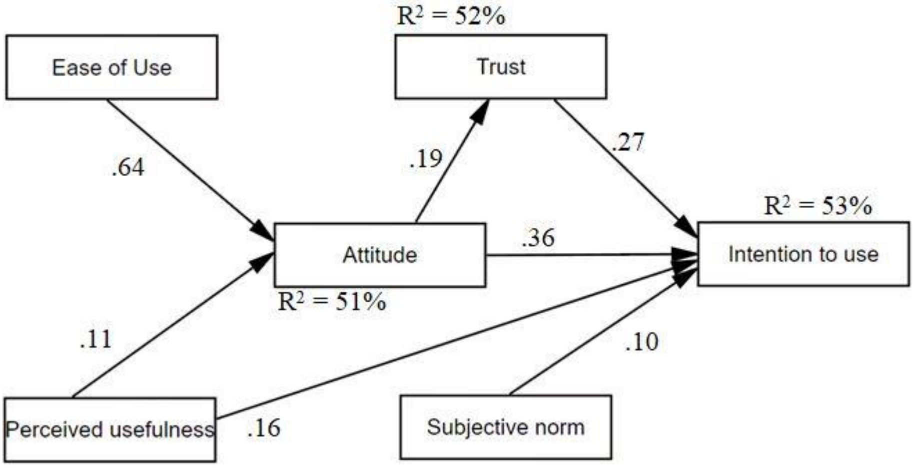
Data analysis

In this study, we performed the structural equation modeling (SEM) approach to test hypothesized relations that exist among the six research constructs. SEM analysis is a statistical approach to reveal the causal relationships among the variables (Bentler, 1990). To test the research model, the path coefficients, namely, the standardized regression values (betas) were determined. SEM analysis was performed through SPSS 22.0 and AMOS 18.0 software.

Results

SEM is performed to assess the relationships among the research variables: perceived usefulness, ease of use, attitude, trust, subjective norm, and intention to use chatbots. After removing the insignificant paths from the hypothesized model, the research model is acceptable with the standardized estimations showing a robust fit: $\chi2 = 2.548$, df = 2, p = 0.459; GFI = 0.998; AGFI = 0.986; CFI = 0.997; TLI = 0.999; NFI = 0.998; RMSEA = 0.012, according to good and acceptable fit indices suggested by Hu and Bentler,1999). As illustrated in Figure 2, perceived usefulness is found to positively influence the attitude ($\beta = 0.11$; H1 accepted) and intention to use chatbots ($\beta = 0.16$; H2 accepted). Ease of use is positively related to the attitude ($\beta = 0.64$; H3 accepted), but is no significantly associated with the intention to use chatbots (H4 rejected; $p>0.05$). Further, SEM analysis indicated that attitude towards using chatbots positively influences intention to use ($\beta = 0.36$; H6 accepted) and trust ($\beta = 0.19$; H5 accepted). However, no relationship is found between attitude and subjective norm (H7 rejected; $p>0.05$). Our analysis also reveals that the intention to use chatbots is significantly and positively related to both trust ($\beta = 0.27$; H8 accepted) and subjective norm ($\beta = 0.10$; H9 accepted). Together attitude and trust explain 53% of intentions to use chatbots. Also, 51% variance of attitude is accounted for ease of use and perceived usefulness. Attitude towards using chatbots explains 52% of trust in chatbots.

Figure 2
Research Model with Standardized Estimates



Discussion and conclusions

The current study attempted to extend TAM constructs (ease of use, perceived usefulness, and attitude) by adding subjective norm and trust; then, how these constructs influenced the intention to use educational chatbots. As we expected, both ease of use and perceived usefulness are positively associated with the intention to use chatbots. Further, whereas perceived usefulness is found to have a positive effect on the intention to use, no relation is seen between ease of use and the intention to use. This means, before using chatbots, teachers first need to recognize the educational benefits of chatbots. Further, whether a chatbot is easy to use or not, teachers should consider chatbots as useful technology; ultimately, they can use them for educational purposes. In line with previous research, in the acceptance of emerging technologies, perceived usefulness is a key determinant of the intention to use (Chocarro et al., 2021).

Together ease of use and perceived usefulness contributed to attitude towards using educational chatbots, in turn, a positive attitude reflected in more increased intention to use. Accordingly, as teachers believe that educational chatbot would foster their productivity and performance, and the chatbot is effort-free to use, their emotional reaction to chatbots is positively promoted. Supporting this finding, Bernard and Arnold (2019) suggested that emotional engagement with the virtual and intelligent agents has led to an increase in behavioral intention for using these agents. Teachers' trust in educational chatbots is found to be a positive determinant of intention to use educational chatbots. Indeed, teachers are reluctant to use chatbots when they think that decisions and suggestions of chatbots are not reasonable and meaningful (Nazaretsky et al., 2022). Further, if teachers have some concerns about data privacy, they can hesitate to utilize chatbots (Nazaretsky et al., 2022). Our study implies that developers of educational chatbots should consider not only the technical but also the pedagogical features of chatbots. SEM analysis also indicated that subjective norm is positively related to intention to use, meaning that if important people according to teachers use and suggest educational chatbots, teachers are also more likely to utilize chatbots for professional purposes. Collaboration and communication among teachers play an important role in the acceptance and integration of educational technologies (Watson & Rockinson-Szapkiw, 2021). In such a process, teachers might be aware of emerging technologies and the educational use of these technologies. As empirically evidenced in this study, the community influence on teachers' choice to use chatbots.

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Scaffolding the Conceptual Salience of Directed Actions

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Abstract: As the grounded and embodied cognition (GEC) paradigm continues to inform teaching and learning research, action-cognition transduction (ACT) suggests that performing cognitively relevant movements can enhance students' conceptualizations. For learning mathematics, participants' awareness of the relationship between the cognitively relevant movements and the geometric conjectures they are reasoning about remains underexplored. Research in analogical problem-solving underscores the importance for problem solvers to notice similarities between two analogous domains before adapting the solution from one problem to the other. This pilot study investigates differences in participants' reasoning and gestures before and after receiving a hint drawing their attention to the cognitive relevance of the movements they performed. The data suggest that when correctly reasoning about the geometric conjectures, participants explicitly leveraged spontaneous replays of the cognitively relevant movements in their explanations after receiving the hint.

Introduction

Theories of *grounded and embodied cognition* (GEC) represent an emerging paradigm in cognitive sciences that increasingly inform research on teaching and learning (Nathan & Walkington, 2017) by describing the relationships between cognitive processes to learners' bodies and their environments. In particular, GEC research examines the role of sensorimotor processes, such as movement and gesture, and how they both influence and are influenced by cognitive processes. While several studies provide experimental evidence suggesting that movement can enhance cognitive states, not all movement has been shown to be equally beneficial (Nathan et al., 2014; Walkington et al., 2022). To construct suitable interventions leveraging these insights, it is necessary to understand what makes certain movements more effective than others in supporting learning.

Some GEC theories, such as *action-cognition transduction* (ACT) (Nathan & Walkington, 2017), suggest that body states that appropriately and reciprocally map to a concept improve performance on specific tasks like mathematical proof production (Nathan et al., 2014; Walkington et al., 2022). In this context, *body states* can refer to movements, poses, or preparatory motor programs (i.e., planning) that are activated. Some body states, such as gestures, have been shown to carry representational content useful in learning contexts. For example, Walkington and colleagues (2022) found that gestures can support an individual's ability to reason geometrically by focusing students' "limited cognitive resources on task relevant information gleaned from effective actions, which can facilitate the construction of schemas used in future task performance" (p. 27). Operationalizing these findings prompted the following research question: What factors can scaffold a learner to better "glean" the relevant information from these actions?

Theory

A growing body of research suggests that cognitive states can also be influenced by body states. Abrahamson and colleagues showed how eliciting a child's coordinated proportional movements (e.g., raising one's hands at rates in a ratio of 1 to 2) offers a sensorimotor basis for multiplicative reasoning (Abrahamson & Bakker, 2016). One theoretical model describing this bi-directional relationship between body states and cognitive states is *Action-Cognition Transduction* (ACT) (Nathan & Walkington, 2017). Demonstrating this relationship, Nathan and Martinez (2015) manipulated readers' gesture production while they learned from a scientific text. When participants' gestures were experimentally inhibited, their inference making in a subsequent learning assessment was also impaired

Scholars highlight that gestures can reveal the "leading edge" of what a speaker knows before they can verbalize that knowledge (Church & Goldin-Meadow, 1986). In a qualitative study of gesturing by students solving problems in mathematics classrooms, Garcia and Infante found students made two distinct types of gestures: *static (non-dynamic) gestures* -- gestures illustrating either an imagined mathematical object or a fixed length -- and *dynamic gestures* -- gestures that depict both an imagined mathematical object and perform transformations upon that object (Garcia & Infante, 2012). In support, Nathan and colleagues (2021) found that performing non-dynamic gestures predicted mathematical insight and intuition that was not well articulated verbally, while performing dynamic gestures was strongly predictive of a student's ability to produce valid mathematical proofs.

Learning scientists have investigated how eliciting gestures during educational experiences can foster learning. *Directed actions* are purposeful movements integrated into curricular activities that are given to learners to intentionally ground body movements to novel concepts. In mathematical thinking, researchers have explored the reciprocal effect of body states on cognitive states under the ACT framework by observing the effects that performing directed actions has on participants' cognition, their mathematical thinking, and performance on mathematical tasks (Nathan & Walkington, 2017; Walkington et al., 2019; Zhang et al., 2021). Evidence from these studies suggests that inducing body states through directed actions can, like gestures, impact learners' subsequent performance on cognitive tasks.

There is increasing evidence that directed actions can positively impact learning. Walkington and colleagues (2022) found that *cognitively relevant* directed actions significantly impacted students' proof performances compared to cognitively irrelevant actions (scrambled versions of the relevant action poses), and this effect was *moderated* by gesture. Specifically, participants who performed gestural replays of relevant directed actions as they were reasoning had superior explanations than those performing no gesture. Walkington and colleagues (2022) proposed that performing cognitively relevant directed actions leads participants to generate more accurate embodied simulations of the world around them. Though all learners performed directed actions throughout the experiment, only a subset also performed gestural replays. Identifying which factors encourage learners to replay directed actions remains understudied.

Participants might not replay directed actions because the movements do not activate an embodied simulation of the target concept (i.e., not activating an aligned embodied schema). The embodied schema might not be activating the *salient* features of a representation. Working memory theory (Baddeley, 2012) posits that attentional allocation to audible (verbal) and visuo-spatial (visual) information loads perceptual information into working memory. According to Mayer's (2014) Multimedia Learning, multimodal representations must complement one another while minimizing cognitive load. Since there is no guarantee that directed actions, as a pedagogical tool, will be taken up by the learner and used to scaffold their conceptualization, design features are *conceptually salient* when they convey information relevant to a target concept (Rau, 2020), that is, they must sufficiently activate an embodied action schema that does not anchor learners to non-salient features or disrupt the processes of conceptualization.

Research in analogical problem solving suggests that individuals solving a target problem fail to spontaneously notice the relevance of a semantically remote source analog (Gick & Holyoak, 1980). Research supports the importance of problem solvers noticing similarities between two analogous domains (Thomas & Lleras, 2007). Directed actions that are cognitively relevant to the target domain are designed to be better tools for fostering insights. Thus, we hypothesize that providing a verbal hint connecting movements (i.e., directed actions) to concepts may improve problem solving and proof production. In the current study, we use a new online platform built to invoke embodied geometric reasoning to address the following research question: How do participants' gestures and answers change after being provided a hint regarding the cognitive relevance of the directed actions?

Methods

A convenience sample of 27 university students were recruited for this study. Participants played through an online augmented reality game built for this experiment to capture evidence of learners' connection between movements, mathematical thinking, and verbal reasoning (Fogel et al., 2022). The game, *The Hidden Village-Online* (THV-O), takes players through an eight-chapter story about a two-dimensional world populated by different shapes. Using a webcam, THV-O detects participants' bodies in real time and leverages the positional data to project a real-time animation of the player into the fictional world of shapes with an on-screen avatar that is effectively a mirrored image of the player.

To investigate the influence of movements on cognitive states, players were directed to perform the directed actions before they began reasoning about each geometry conjecture. To avoid ordering effects, tasks were ordered using a Latin-square factorial design. The directed actions for each conjecture were designed to be cognitively relevant (ref. Nathan et al., 2021; Nathan & Walkington, 2017; Walkington et al., 2022) to reasoning about the statement. Participants were to indicate whether a conjecture was true or false, then explain *why* they believed the statement to be true or false. Participants were video recorded as they played THV-O. For the intervention, after the fourth conjecture, players were given a semi-structured interview, at the end of which they were given the following hint (inspired by those provided in analogical problem-solving experiments): "*performing some movements can be helpful while reasoning about abstract concepts, like geometry*", before playing through the remaining 4 conjectures.

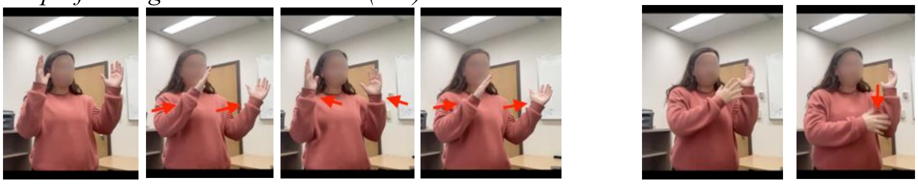
We analyzed the video and transcript data qualitatively using a coding scheme developed through a grounded approach informed by prior analyses (Nathan et al., 2021) on similar data. Specifically, we identified when individuals performed a REPLAY GESTURE, indicating when a participant (unprompted) spontaneously recreated the directed action as part of their explanation; this gesture could be a dynamic or a non-dynamic reproduction of the directed action. Cohen's κ was estimated for the code, with agreement exceeding the conventional κ = 0.65 threshold for inter-rater reliability.

Results

Before receiving the hint, some participants performed a REPLAY GESTURE as they reasoned about the conjecture. However, the verbal rationale accompanying the gesture did not explicitly reference how their movements informed their thinking. After receiving the hint, some used a REPLAY GESTURE, or a precise recreation of the directed actions, as a grounded warrant to support their evaluation of the conjecture. For example (Figure 1), participant Jill (a pseudonym) explicitly referenced the directed actions in her explanation and performed a REPLAY GESTURE raising her hands in front of her face (Figure 1A), then moves arms to the side (Figure 1B), then back (Figure 1C) and forth (Figure 1D) again.

Figure 1

Jill performing a REPLAY GESTURE (A-D)



(A) (B) (C) (D) (E) (F)

[1] The area of a parallelogram is the same as the area of a rectangle with the same base and height. True
[2] So this one with the movement... <performed REPLAY GESTURE, shown in (A)-(D)>
[3] These are the same length. So that's why I would think it's true. You're just moving them...
[4] But the length of my hand isn't changing. <performed a *static* depictive gesture, shown in (E)-(F)> So…

In line [1], Jill restated the conjecture she was reasoning about and correctly evaluated that the statement was true. Having provided correct intuition, Jill referenced the directed actions she had performed just before and performed a REPLAY GESTURE, emphasizing that the length of the two shapes represented by the discrete poses she moved between "are the same length...you're just moving them" (line [2]), suggesting that she had gleaned relevant information from the directed actions in justifying her response.

Discussion

Consistent with findings from prior studies (Walkington et al., 2022), some participants performed REPLAY GESTUREs while providing an explanation before receiving an explicit hint. After receiving a hint, some participants' REPLAY GESTUREs explicitly supported their correct verbal evaluation of the geometric conjectures. Explicitly supporting their evaluation with REPLAY GESTUREs suggests that the hint could help lead people to consciously leverage the cognitive relevance of the movements. Additionally, scaffolding the conceptual salience of the directed actions through scaffolds like hints can help optimize the efficacy of interventions using directed actions. We suggest that directing people to make cognitively relevant body movements can help improve their mathematical reasoning, especially when the salience of movements remains outside of conscious awareness.

Future studies will use sets of related conjectures to attempt to further isolate changes in behavior as a result scaffolding interventions. Admittedly, performing the cognitively relevant movements is not guaranteed to improve performance (ref. Walkington et al., 2022), and students did not perform REPLAY GESTUREs when evaluating every conjecture. Just because a subject matter expert selects a series of movements they deem relevant does not guarantee that the learner perceives what is salient. Moreover, whether hints or other scaffolds are the best type of intervention remains unclear.

Not without limitations, this study, as most pilot work, had a small sample size. Thus, we can only provide qualitative evidence to support these claims. Collecting more data and conducting further qualitative data analysis, including quantitative and quantitative ethnographic techniques, will strengthen our ability to make these claims. Nonetheless, a growing corpus of evidence suggests that when directed actions are cognitively relevant, they can be effective at reinforcing a grounded understanding of abstract concepts like universal geometry theorems and improving mathematical reasoning. Individuals do not have to be aware of the relevance of the directed actions for there to be benefits for problem solving—they can make that deductive leap as they reason about the mathematics. Investigating guidelines and best practices for how to design and deploy effective directed actions could help address this issue. Overall, designing cognitively relevant directed actions seems to hinge on the participant's recognition of such. Refining the design and presentation of cognitively relevant directed actions to improve mathematical reasoning allows us to better integrate them as pedagogical tools in embodied and grounded curricula.

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Assessing Students' Competencies With Mathematical Models in Virtual Science Inquiry Investigations

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Abstract: Developing models and using mathematics are two key practices in internationally recognized science education standards such as the Next Generation Science Standards (NGSS, 2013). In this paper, we used a virtual performance-based formative assessment to capture students' competencies at both *developing* and *evaluating* mathematical models in science inquiry contexts aligned with the NGSS (2013). Results show that model development and evaluation competencies are correlated, but students who demonstrate proficiency with model development often struggle with evaluation. Nuanced data illustrate how components of modeling competencies differ and how they may be related.

Introduction

Standards such as the Next Generation Science Standards (NGSS, 2013) emphasize that students must become competent at key science practices, including "Developing and Using Models" (Practice 2) and "Using Mathematics and Computational Thinking" (Practice 5). Here, we define *mathematical models* as mathematical representations, such as equations and graphs, that illustrate and predict scientific phenomena (Harrison & Treagust, 2000). The NGSS (2013) expects that students will "develop and/or use [models]…including mathematical models…to generate data that support explanations, predict phenomena, analyze systems, and/or solve problems" and evaluate the limitations of those models because they "contain approximations and assumptions that limit the range of validity and predictive power" (NGSS 2013, Appendix F, p. 6). However, students often struggle in many ways, such as: labeling axes and selecting data for graphical models (Lai et al., 2016), explaining the underlying assumptions and limitations (Nixon, et al., 2016), and ascertaining validity by comparing models to real-world data (Wilensky & Reisman, 2006).

To help students become more proficient at mathematical modeling, we are iteratively designing virtual labs that require students to build mathematical models as part of their investigative process within the Inquiry Intelligent Tutoring System (Inq-ITS; Dickler et al., 2021; Olsen et al., 2022). Inq-ITS labs are designed to be performance-based formative assessments, using educational data-mined and knowledge-engineered algorithms to automatically assess students' competencies (Gobert et al., 2013; Sao Pedro et al., 2013b). In recent work, we developed algorithms to auto-score how students create graphs and build best bit curves through data.

In this study, we explore what kinds of challenges students have when building mathematical models to better understand what kinds of support students may need to be successful. We expect that students with the highest proficiency can: (1) effectively develop mathematical models of scientific phenomena, (2) articulate the assumptions they made when building their model, (3) articulate how the assumptions impose limitations on how well the model can make valid predictions, and (4) richly integrate understanding of the scientific phenomenon (Schwarz et al., 2009; Windschitl et al., 2008). Given the complexity of mathematical modeling, many students may fall in the "messy middle," where they have "some pieces of knowledge and ability to respond to complex science tasks, but not all" (Gotwals & Songer, 2010, p. 277). To better understand students' competencies with mathematical modeling, we address the following research questions: (1) To what extent are students' model development and evaluation competencies correlated, and (2) When students' model development and evaluation competencies differ, what difficulties do students seem to demonstrate?

Method

Forty-one middle and high school students from four different teachers completed an Inq-ITS momentum virtual lab (NGSS DCI PS2.A). Its goal was to have students develop a mathematical model (i.e., graph and corresponding equation) that illustrates how the mass of a moving car affects its momentum before colliding into a stationary car. During the first three stages of the investigation (Collecting Data, Plotting Data, and Building Models), students collect data using a simulation, select the x- and y-axes for their graph, select which data to plot on their graph, determine the type of mathematical function (i.e., linear, inverse, square, inverse square, or horizontal) that best fits the shape of the plotted data, and select a coefficient and constant for that mathematical function that best fits the data on the graph. Students' scores on these stages were calculated using previously developed algorithms (Dickler et al., 2021). The activity then prompts students to write in their own words a reflection on their model development process. Specifically, students are asked the following question:

> "Your mathematical model makes predictions about the momentum of Car #1 before the collision when you change the mass of Car #1. Do other conditions need to be met in order for your mathematical model to make good predictions? For example, do other variables like the mass of Car #2, or the velocity of Car #1 before collision need to be specific values? Can they be different values? Please explain and provide enough detail so that a friend who did not build your mathematical model could reconstruct it and could understand how to use it."

Measures

We refer to students' performance on the first part of activity as their *model development competencies* because the tasks require students to construct a mathematical model (best-fit curve) from data they collect. We measure these competencies as the sum of fine-grained, sub-practice scores, which were automatically assessed as either 0 (incorrect) or 1 (correct) using educational data-mined and knowledge-engineered algorithms that generate scores based on students' interactions within the Inq-ITS environment (Sao Pedro et al., 2013b; Olsen et al., 2022). We note that performance on these tasks may also indicate competency in other practices as well.

We refer to how students evaluate their models through writing as their *model evaluation competencies* because this task requires students to evaluate the limitations of the mathematical model they developed. Automated scoring was not available for this prompt as this activity is still in pilot testing. Thus, two of the paper's authors independently hand-scored all students' responses across two dimensions: correctness (0 for incorrect or non-answer, 1 for partially correct, 2 for fully correct) and relevance (0 for not relevant, 1 for relevant). Authors agreed 100% for the *relevance* dimension and 82.9% (unweighted Cohen's kappa = 0.70) for the *correctness* dimension. Disagreements were discussed, and the agreed-upon scores were used for analyses.

Results

RQ1: Comparing students' model development and evaluation competencies

We first examined the relationship between students' scores on the two types of competencies using a Pearson's correlation. Students' model development and model evaluation competencies were moderately positively correlated, $r(39) = .58, p < .001$, suggesting that students tend to be proficient (or not) at both competencies together. Though a correlation was performed, it is likely that model evaluation is, at least in part, dependent on students' competencies with model development, as suggested by learning progressions (Schwarz et al., 2009).

Table 1

Raw count and percentages of students (N = 41) with each categorical competency level. Note: The "Medium" (7-8) range for model development had no students and is omitted.

		Model Development Competency Level	
		Low (Scores: 0-6)	High (Scores: 9-10)
Model Evaluation Competency Level	Low (Scores: 0-1)	8 (19.5%)	10 (24.4%) *Messy Middle Group 1*
	Medium (Score: 2)	2 (4.9%) *Messy Middle Group 2*	18 (43.4%) *Messy Middle Group 3*
	High (Score: 3)	0 (0.0%)	3 (7.3%)
	Total	10 (24.4%)	31 (75.6%)

We further disaggregated their performance on each competency into "high," "medium," and "low" categories (Table 1) to examine cases where students performed well at one competency and not another. Most students (75.6%) performed "high" on model development, indicating that these students have the inquiry competencies (e.g., collecting unconfounded data) and mathematical/graphical competencies (e.g., determining the best-fit curve) to complete the activity. However, very few students (7.3%) performed "high" on model evaluation, suggesting that students may not fully understand the importance of collecting and plotting controlled data, or they may struggle with describing how to evaluate models. These findings suggest a need for supports, like embedded real-time scaffolding, that can address these difficulties.

RQ2: Differences between model development and evaluation

As shown in Table 1, there were three groups of students in which competencies did not align. For each group, we triangulated the interaction logs of how students built their models with the written text of how they evaluated their models to identify any commonalities for how students struggle.

Group 1: High model development, low model evaluation

Students in Group 1 (24.4%) were proficient at developing models but stated incorrect and/or irrelevant responses when evaluating their model. For example, Student A, who had no errors when developing their model, stated, "no nothing else needs to be added because its [*sic*] very accurate." Another student, Student B, with no errors simply responded, "The line best fits the dots." These responses suggest that although these students can execute the procedures of developing mathematical models, they may lack conceptual understanding about how that process embeds assumptions and limitations about their model. For example, by stating that their models are "very accurate" and "fits the dots," they may believe that their model does not have any limitations. They may not recognize that their model will only predict well when the other variables for which they controlled have the exact same measurements. Such students may require supports that highlight the importance of the variables they controlled and how those controls impact the general applicability of their models.

Group 2: Low model development, medium model evaluation

Only two students (4.9%) demonstrated poor model development competencies. Student C plotted uncontrolled trials, and Student D selected the incorrect variable for x-axis. Both students did not recognize their errors when looking at the graph, which could suggest that they may be struggling with interpretation (Glazer, 2011). Therefore, students in this group may require more targeted support on specific sub-practices (e.g., plotting controlled trials for Student C and choosing the axes for the graph for Student D).

Group 3: High model development, medium model evaluation

Students in Group 3 (43.4%) were proficient at developing models but gave only partially correct answers when evaluating their models. One consistent error made by these students was stating that the "mass of the stationary car" needed to be a certain value for the model to be used to make predictions. However, students should recognize, either through prior scientific content knowledge or the virtual lab investigation, that only the *velocity of the moving car* needs to remain constant since this is the only other simulation variable that would affect the moving car's momentum *before* the collision with the stationary car. This finding aligns with previous research showing the need to support students in defining the boundaries of their models (Eidin et al., 2020), which may help students to develop a deeper understanding of the scientific phenomenon being modeled (Wilensky & Reisman, 2006; Windschitl et al., 2008), as envisioned by the NGSS (2013).

Discussion

Developing and evaluating mathematical models in science inquiry contexts is important for science learning (NGSS, 2013). However, teachers rarely provide students with the opportunity to construct and evaluate their *own* models (Schwarz et al., 2009). Furthermore, assessing these competencies is challenging (Furtak et al., 2017). Here, we presented a novel design for Inq-ITS virtual labs to formatively assess students' competencies on fine-grained components of NGSS-aligned mathematical modeling practices. By unpacking NGSS Practice 2 (Developing and Using Models) and Practice 5 (Using Mathematics and Computational Thinking), assessments can provide important information on students' modeling competencies. We used the virtual labs to investigate how students develop and evaluate mathematical models, and what specific difficulties they encounter when doing so. Consistent with prior work on constructing and critiquing graphs (Vitale et al., 2015), we found that students' model development and evaluation competencies are correlated, but that many students who performed well on model development still struggled with model evaluation. More specifically, students in the "messy middle" who performed well on model development tended to struggle with understanding how the development process affects the limitations of the model (e.g., Group 1) or how the boundaries of the system can also affect the limitations of the model (e.g., Group 3). Our findings also shed light on the importance of *fine-grained* assessments that can specifically target the sub-components of modeling practices. Namely, we found that students in Group 2 had different difficulties with the model development stages, which teachers would need to address differently when providing support. These findings suggest that students' difficulties with facets of modeling are likely varied. As such, it is vital that formative assessments are operationalized at a fine-grained enough level to identify exactly how students are struggling so that optimum support may be provided.

Overall, the design work presented in this paper sheds light on how online formative, performance-based assessments can be used to capture rigorous, rich, and nuanced data on students' competencies. With this data, systems, like Inq-ITS, can be further augmented to provide targeted, real-time support to students on the specific sub-practice for which they are struggling as well as to teachers on how best to support their students. Furthermore, this work contributes to and deepens the existing literature on general scientific modeling (e.g., Schwarz et al., 2009; Windschitl et al., 2008) by drawing a deeper attention to *mathematical* modeling done in the context of science inquiry, important to NGSS (2013) Practices 2 and 5. By developing scalable formative assessments that address students' competencies with both *developing* and *evaluating* mathematical models in science inquiry contexts, we can begin to address inter-dependencies between these aspects of modeling to develop a learning progression that includes components of scientific mathematical modeling competencies. Furthermore, unlike previous work on science graphing (e.g., Vitale et al., 2015), we assess students' competencies with evaluating models they developed themselves, capturing a more authentic, integrated version of the science practice envisioned by the NGSS (2013). Although the virtual lab in this study focused on only one physical science topic (i.e., momentum) and one type of mathematical relationship (i.e., linear), future work will investigate mathematical modeling across a broader range of science topics.

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Factors That Impact the Implementation of a Game Based Curriculum and Adaptations Teachers Design to Address Them

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Abstract: Teachers play critical roles in both co-design processes and intervention studies, yet both approaches have distinct theoretical underpinnings that impact how teachers interact and what they contribute. In this paper, we analyze the co-design and implementation of an intervention called *Fraction Ball (FB)*, a game-based curriculum that teaches fractions and decimals to elementary students. We present preliminary analysis of the contributions from teachers who participated in the co-design or intervention study. We argue participating in different aspects of the project will illuminate different factors that might affect the implementation, and lead to different adaptations to address these factors. Teachers identified nine factors as influential in the implementation of *FB* across four levels, including school, teacher, students, and intervention levels. The findings demonstrate that teachers contribute differently based on their role in the project and has implications for how we co-design interventions and frame teachers' roles in the future.

Introduction

Teachers play critical roles in both co-design and intervention studies such as Randomized-Control Trials (RCT). In co-design, teachers and researchers engage in a collaborative process to develop curriculum that fit into the learning context and address their unique needs (Penuel et al., 2007). Such curricula can then be used as classroom intervention materials. In RCTs, teachers are positioned as participants that enact interventions designed by researchers and their collaborators. Co-design and RCT processes have different theoretical assumptions, affecting how they are typically developed and studied and teachers' roles within them. In our paper, we present a study that examined teachers' contributions in the co-design process and intervention study of *Fraction Ball (FB),* a game-based curriculum that teaches fractions and decimals to elementary schoolers (Bustamante, 2022). We co-designed the *FB* intervention with two schools and implemented an RCT with four different schools, all in the same school district. We describe the factors that teachers identified as important for the success of *FB* and discuss what they did or suggested to address them (i.e., adaptations).

Perspectives and theoretical framework

Traditional RCT studies prioritize fidelity, reflecting how researchers want participants to implement their interventions as designed with minimal deviation (Carroll et al., 2007). Yet, there is a growing movement to examine the adaptations that inevitably emerge when interventions are implemented (Durlak & DuPre, 2008). There is a long history of education research that observes that teachers, almost always, make modifications to new interventions in their classroom (Lipsky, 2010). Such adaptations have been shown to improve learning outcomes, as teachers typically make adaptations based on their experiences and knowledge of their students and learning environments (Durlak, 2010). Durlak and DuPre (2008) highlight the factors that often affect interventions including community factors, personnel characteristics, and innovation characteristics. These topics are often the focus of the co-design, wherein researchers begin by understanding the community context, the teachers' needs and the learning context to create innovative learning materials.

Scholars who study interventions argue that community participation in designing innovations can improve outcomes and inform fidelity and adaptations (Durlak & DuPre, 2008). Theoretically, co-design processes argue for the process of mutual adaptation from the beginning. Mutual adaptation is the process of researchers and stakeholders dynamically altering the intervention to improve and strengthen the innovation (Lotan et al., 1986). Co-design foregrounds mutual adaptations by asking teachers to engage in design with researchers while explicitly addressing their unique learning goals and context (Fishman et al., 2013; Penuel et al., 2014), whereas intervention studies prioritize mutual adaptation less often. Whether interacting in the co-design process or intervention studies, teachers have different pedagogical preferences, organizational politics to navigate, along with classroom needs, values, and norms that affect how they design and implement curriculum.

In this paper, we present a preliminary analysis of the different contributions toward the *FB* intervention from teachers who participated in the co-design or the RCT. We argue that implementing an intervention compared to imagining what implementation might be like includes different assumptions and processes, therefore, leads to different factors that affect the implementation, and in turn, different adaptations to address them. We ask the questions, *what factors do teachers identify that might influence the implementation of FB* and *what adaptations do teachers create to address these factors?*

Methods

FB is a learning activity that utilizes a basketball court painted into equal segments to reinforce fraction and decimal learning (see Figure 1). The spatial layout of the court is designed to reinforce fraction magnitude understanding, and students' shots are translated into fraction and decimal points and tallied on a number line. Students work in groups to play a series of games shown to improve students' rational number understanding. This study was completed as part of a multi-year research-practice partnership with a public school district in a low-income, predominantly Latine community in Southern California. We worked with six elementary schools: two schools in the co-design ($N = 20$ teachers) and four different schools in the RCT ($N = 16$ teachers).

Figure 1

Left: FB court. Middle: Students keeping teams' score on the number line. Right: Students working on a collaborative classroom lesson.

We collected video data, observation notes, and artifacts during co-design sessions where the focus was to create classroom lessons for *FB*. We held five 90-minute co-design sessions, repeating the first twice and the second three times. In the first session, we play-tested an existing game and lesson and generated new lesson ideas. The second session consisted of a gallery walk of the lessons that teachers created, with small group work to iterate and develop a cohesive lesson.

We conducted an RCT with four schools and 16 teachers using the co-designed curricula as the intervention. Eight teachers taught *FB* and eight taught their class business-as-usual. Teachers were supplied with an activity guide, lesson scripts, slide decks, worksheets, and materials needed to facilitate the intervention that were developed through our co-design process. After the intervention, we recorded hour-long focus groups with the eight teachers who implemented *FB*. Control teachers were not interviewed.

To analyze the co-design and intervention data, we first conducted affinity diagramming (Hanington & Martin, 2012). We examined all data and pulled ideas and feedback into design ideas and inductively clustered data into themes. We analyzed 305 data points from the co-design sessions and 345 from the implementation. To achieve reliability, two researchers analyzed the co-design data, and three researchers analyzed the implementation data, negotiating themes and reviewing the data until consensus was reached. We then leveraged those themes to identify factors that impacted *FB*. Through an iterative process of clustering, three researchers synthesized findings into nine preliminary factors within four levels.

Findings

We identified nine factors, across four levels including school, teacher, students, and intervention levels (see table 1 for definitions and examples of adaptations that emerged). At the intervention level, teachers highlighted three factors – management and facilitation in the classroom and on the court and the sequence of the lessons. Teachers differentiated the classroom and court because the routines and materials are different working within the boundaries of their classrooms compared to outside on the court. Student level factors included their prior knowledge around the math concepts and basketball, sense of belonging and representation, and inclusion. While much of the focus of the co-design and implementation was on the intervention and how it might support student learning, teachers described factors regarding their needs and the school logistics. At the teacher level, two factors emerged – community and support, and preparedness. Teachers emphasized that a teacher community was critical so they could collaborate and learn from each other and highlighted the need for materials to help them learn the games and implement *FB* with ease. Lastly, teachers called attention to the school factors, or contextual details at the schools that might affect *FB*. These factors varied from school to school but included booking courts, handling noise on the court, and managing schedules. In table 1 we describe examples of how teachers suggested or implemented adaptations to address these design factors. First, we note that not all factors had adaptations. For instance, making *FB* inclusive for all students, especially those with different learning abilities was a high priority for our co-design teachers, compared to our intervention teachers where it was not a focus. Similarly, students' sense of belonging was not a focus of our co-design sessions, however several teachers who implemented the intervention made it a priority in their classrooms.

Table 1
Factors teachers identified that might influence FB, and their adaptations to address them.

Level	*Factor*	**Definition:** Definition of factors	**Adaptations:** What teachers did or suggested to address these factors
Intervention	*Classroom management and facilitation*	The routines and materials needed for teachers to ensure the instruction is delivered in the classroom.	Co-design: Create scripts that are detailed but not overwhelming for classroom lessons. Intervention: Teacher consolidated a worksheet into one page to consolidate activity.
	Court management and facilitation	The routines and materials needed for teachers to ensure the instruction is delivered on the court.	Co-design: Adding a tracking sheet on the court so more students can document shots. Intervention: Teacher created a roles chart, so students know where to go.
	Sequencing	How concepts and aspects of *FB* are ordered.	Co-design: Front loading instructions about the game before moving to the outdoor court. Intervention: Finish intervention with games that are particularly fun.
Student	*Prior knowledge*	How students' background knowledge on math or basketball affects *FB*.	Co-design: Simpler activities for students who have less fraction knowledge. Intervention: Teacher connected past lessons with current lesson to build connections
	Student belonging and representation	Helping students see themselves in the curriculum and game play.	Co-design: N/A Intervention: Teacher built a bulletin board so kids could see themselves playing the game.
	Student inclusion	Sensitivity to students of all physical and learning abilities.	Co-design: Refashioning *FB* into Cornhole increases accessibility. Intervention: N/A
Teacher	*Teacher community & support*	Creating a community for teachers to support each other through *FB* implementation.	Co-design: PE teachers and math teachers need should be in close communication to make sure learning goals are aligned. *Intervention*: Call for conversations between teachers about their experiences with *FB*.
	Teacher preparedness	Training and readiness so that teachers are prepared and ready to deliver instruction	*Co-design*: Wanting digital worksheets so that there is no paper preparation. *Intervention*: Video of students playing FB to teach teachers.

School	*Logistics*	Fixed contextual details at the school level that affect the implementation of *FB*.	*Co-design*: Book courts in advance when space is limited, using megaphones to counter noise. *Intervention*: Rescheduling *FB* when it conflicts with a school-wide event.

Discussion and conclusion

Our study identified factors that affected the *FB* intervention from both co-design and RCT teachers' perspectives, and adaptations they suggested or implemented to address them. The high-level factors that emerged mirror findings from Durlak and DuPre (2008) regarding aspects that affect interventions (e.g., community, personnel, and intervention factors). The factors highlight elements that emerged for teachers, including potential tensions, areas for improvement, and sometimes fixed constraints at different levels. The adaptations that teachers made or suggested illuminate possible solutions to those factors, and ideas that make our intervention more usable and flexible in the classroom (Lortan et al., 1986). However, we also acknowledge that not all factors have adaptations to address them. Due to the theoretically different approaches to co-design and RCT studies (Durlak & DuPre, 2008), some teachers in the intervention felt constrained by the materials and that they could not make adaptations to the materials so as not to alter the research findings. As opposed to the co-design teachers, who were encouraged to make changes from the start. Additionally, because this is an innovative, game-based intervention that was new to teachers, coming up with adaptations can be challenging. Identifying the differences between teachers participating in the co-design or RCT informs how we might co-design interventions in the future, how we might frame teachers' roles differently to support adaptation and highlights the differences in contributions teachers make at different stages in the project. Our future work will apply this code book to the entirety of the dataset to explore the frequency of these factors, all adaptations that emerged to address them, and the differences between teachers' who engaged in the co-design and intervention.

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Fostering Youth Identity Development Through Critical Pedagogical Practices and Agentive Action in Sustainability Learning

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Abstract: This DBR study examines how critical pedagogical practices of testimonios and intersectional modeling coupled with agentive techniques engaged youth in holistic identity development. We qualitatively analyzed observations, interviews, and artifacts related to seven youths' participation in an informal program focused on community-centered renewable energy engineering framed by sustainability learning. Findings suggest that coupling of student agency with critical pedagogical practices allowed youth to connect their agentive action in their community and fostered youth holistic identity.

Introduction

Normative cultural education practices rarely address different cultural knowledge as an asset and often limit opportunities for youth from minority communities to have meaningful learning experiences that foster identity development. Innovative instructional practices are needed to engage youth from minority communities in agency and identity development. This study is concerned with these issues in relation to sustainability learning experiences for high school youth from the same Latin@ community. Youth from minority communities in particular often operate in educational spaces that deny their cultural knowledge and experiences and limit their agency in their community and academic spaces, particularly with sustainability issues in which minority communities are disproportionately impacted by environmental issues (Beltrán et al., 2016). *Sustainability* in this context is defined as meeting the environmental, social, and economic needs of the present while supporting the needs of the future (Trott & Weinberg, 2020). Consequently, it is recognized as a larger social issue where youth, especially minority youth have an impact. Although *agency* has been well researched in the field of sustainability education, more attention to critical pedagogical perspectives and its effect on agency is needed. Along with engagement with sustainability, there is a need to design learning experiences from a critical perspective that examines the intersections of youths' identities as a resource for sustainable practices (Maina-Okori et al., 2018). Thus, the purpose of this design-based study was to design and test an approach to fostering youths' holistic identities in an informal learning program, exploring how critical pedagogical practices and agentive practices foster identity development and help youth relate their identity to sustainability.

Literature review

Critical pedagogy is a field of research that aims to analyze power and oppression and their relation to education. Over time, researchers have critiqued this framework and extended its pedagogical practices. For instance, *border pedagogy* engages students in critical thinking around power, meaning, and identity (Cervantes-Soon & Carrillo, 2016) using pedagogical practices such as *testimonios* to challenge dominant education narratives of knowledge and allow learners to use their knowledge to debate power issues using their history, experiences, and identity. Testimonios practice was centered in the current study's designed learning environment because it allows individuals to engage in discourse around their personal experiences and co-create an understanding of cultural and social influences on "our material realities and perspectives of life" (Cervantes-Soon & Carrillo, 2016, p. 292), while reframing dominant knowledge related to sustainability.

In conjunction with critical pedagogical practices, fostering youth agency is an essential commitment that guides the designed learning innovation that is the focus of this study. Individual agency is needed to promote transformational action in communities (Stetsenko & Arievitch, 2004). People's identities are created and shaped by these agentive actions. Agency is an essential aspect of sustainability education because it fosters youths' abilities to change the social norms that challenge youths' involvement in their community. Therefore, to engage youth in identity development, designs must engage participants in consequential learning and position them with rightful presence (Calabrese Barton & Tan, 20191). Moreover, positioning youth as contributors to their local community by engaging in real work with real consequences can facilitate opportunities for identity development and agency (Jordan et al., 2021).

In this study, we frame identity using a holistic identity lens. *Holistic identity* pertains to the co-development of social (e.g., race, ethnicity, gender) and role (e.g., student, engineer, mentor) identities (Stets & Burke, 2000). Examining multiple factors of identity is important as individuals belong to multiple identities at once, and these intersections create unique experiences of privilege and oppression (Crenshaw, 1989). As a result, researchers have developed models to allow individuals to examine their intersecting identities and acknowledge that multiple intersecting identities influence how individuals understand other aspects of their identity and themselves as a whole. Additionally, individuals' identities are simultaneously being shaped and are shaping social interaction in their communities, including interactions related to sustainability efforts.

Method

This study took a design-based research (DBR) approach (Mckenney & Reeves, 2019) to enact multiple iterations of a co-designed innovation coupling critical pedagogical practices with youth agency. We conjectured that the intertwining of critical and agentive practices in the design of sustainability learning environments would allow youth to critically reflect on their identity and how it relates to their community and their idea of sustainability. Further, as youth develop their holistic identity, they will be able to connect their identity to the sustainable agentive actions they undertake within their communities. The research question guiding our qualitative interpretive analysis was as follows: *How does coupling critical pedagogical practice with agentive practices engage youth in holistic identity development related to sustainability practice?*

Participants and context

This study was part of a larger design-based innovation designed to engage high school scholars intentionally recruited from the same local community in energy engineering research. In the instantiation of the program that is the focus of the current analysis, seven youth participants participated in the program, five of whom identified as Latin@, one identified as White, and one as Asian. Six of the youths identified as female and one as male. These youth scholars initially spent six weeks in a summer research experience program, collaborating with university researchers to learn about sustainable energy transitions, develop research questions, build solar energy monitoring systems, and mediate between scientists and middle school partners who would implement the project in their shared community during the subsequent school year. This initial intensive learning experience was followed by monthly meetings across the school year, during which the youth engaged in the focal activities of the current study, described below. Both authors were co-designers of focal activities. The first author is a master's degree student in a learning sciences program who identifies as an Afro-Latina female. The second author is a university professor who identifies as a White female.

The critical pedagogies that comprised the focal activities for this study were enacted across two workshops that occurred over four sessions during the second half of the school year. Workshop 1 began with framing the connection between youths' identity, their community, and sustainability in their work on their collective project. We invited youth to connect sustainability, community, and identity through a photovoice-inspired testimonio project. The first author led the youth in reviewing the UN Sustainable Development Goals (SDGs) and introduced the challenge: Take and post a photo that represents a solution to address one of the UN SDGs in your community; explain why you chose that goal and how your solution contributes (or not) to the social transformation of sustainability. During the subsequent session, the youth reported on their solutions and reflected on how sustainability is related to their community-engineering project and their identity. Youths then reflected on how their actions contributed to social transformation in their community using contradictions and resistance as a frame (McWilliams & Penuel, 2017) to understand the impact of their testimonio-proposed solutions and their collective project.

During Workshop 2, youth completed intersecting identity models (Jones, 2016), which included aspects of their social and role identities (e.g., race, gender, career goals), and compared them to their middle school partners' models. This activity also informed their subsequent feedback as critical friends to the middle schoolers on a similar SDG activity. The feedback session was framed by having the youths connect to the conversations about the contradiction and resistance of sustainability efforts in the first workshop. Youths were tasked with providing feedback on how the middle schoolers could address their holistic and community identities in the activity and how their work could address contradictions in sustainability efforts. This pedagogical practice allowed youth to reflect critically on the relationship between their own and community members' identities. The workshop highlighted why it is essential to understand our identity and our community identity when working on community-centered sustainability projects.

Data collection and analysis

Data sources included audio-video recordings, transcripts, and chat files from Zoom from four workshop sessions. Youths' photovoice slides, intersecting identity models, and critical friend feedback were also collected. Pre-post semi-structured interviews were conducted to elicit youth's reflection on identity and agency.

The first author used interaction analysis to create content logs and conduct initial qualitative analysis of recordings of the workshop sessions (Jordan & Henderson, 1995). Making extensive memos across multiple viewings, she identified representative vignettes in which the group was engaged with critical pedagogical practices coupled with agentive practice, as defined by the frameworks above. Both authors met to interrogate these vignettes, interpreting their influence on holistic identity development (i.e., social and role; Stets & Burke, 2000) for each participant across time and between participants. We also analyzed the photovoice-inspired testimonios to understand how youth were engaging their identity and agentic positioning in relation to their community-centered sustainability efforts. To further interpret holistic identity development, the first author led data-driven coding (Decuir-Gunby et al., 2011) of interview transcripts and recorded workshop sessions to examine what aspects of identity were expressed by each participant (e.g., Gender, Career goals, Engineer, Age) and how they were expressed over time. Examining the relationship between (a) identities expressed by youth, (b) their agentive positioning in their community-centered sustainability project, and (c) the critical pedagogical practices of testimonios and contradiction and resistance (Workshop 1), and intersecting identity modeling and critical friend feedback (Workshop 2), we created tables and compared experiences within and across the youth.

Findings

Connecting identity, community, and sustainability in photovoice-inspired testimonios

Overall, youths developed holistic identity to some extent over the four workshop sessions. Six of seven youths reported that the critical practices coupled with agentive practices of social change allowed them to reflect on their identity and its connection to sustainability and community, and to consider how their identities interact within themselves as well as with others in their community. Holistic identity development was first exhibited in identities beginning to be expressed by youth in their photovoice-inspired testimonios.

As one illustrative example representative of other participants' connection of youths' role identities to their sustainability efforts across the dataset, we offer Christopher's photovoice-inspired testimonio. His contribution featured a photograph he took of his high school and description of his effort to create an essential life skills class to would help other students learn practical and useful skills for the future (e.g., *"how to manage their time and selves, finances…"*), a solution to address UN SDG 4, Quality Education. In his testimonio, Christopher illuminates the personal and cultural experiences of Hispanic students at his school and deconstructs the school's educational culture (e.g., *"they've had bad experiences because of how flawed it is"*). In his explanation, he connects his personal and community identity to sustainability for quality education for all:

> *I believe that good education can make good people, but I also have a friend who hates school… Obviously, I feel included in this [Hispanic] community, and I want to help out to improve the quality of the education that students are receiving here by trying to implement a new class that…would be very helpful to them because it'll teach them real-life practical skills...*

This personal account showcases Christopher's agency not only in creating the life skills class but also in countering the dominant narrative of the current education system, which he saw as under-serving its largely Hispanic student population (80%), with whom Christopher identified. He related his experience of wanting to create this class due to his own experience and his friend's experience at his high school.

According to Stetsenko and Arievitch (2004), the conceptualization of the self as a process allows an individual to express agency and simultaneously contribute to social practices that can change the world. We interpreted Christopher's agentive positioning of his identity in relation to other members of his community, along with his strong stance for change of education quality for his community, as allowing him to engage in individual agency toward social change. His identity was influenced by his community and agentive action toward social change in the low-quality education system at his school. The critical pedagogical practice of testimonio and examining contradictions of the educational system as it serves some communities, coupled with Christopher's resistance to poor quality education and his agentive positioning of himself as a leader in the community sustainability project, indicates these practices started to foster his holistic identity development.

Generally, all the youths identified or positioned themselves in relation to their photovoice-inspired testimonio by connecting their role identities (e.g., student, mentor, engineer, designer) to sustainability projects and critically reflecting on the contradictions and resistance related to these sustainability efforts. However, they struggled to connect their social identity (e.g., race/ethnicity or socioeconomic class) with sustainability.

Intersecting identities modeling for holistic identity development

Completing the identity model allowed the youth to reflect on aspects of their identity that they were unsure about. By the end of Workshop 2, most of the youth connected their social identities, directly or indirectly, to their role identities. Additionally, the intersecting identity modeling helped the youth understand different aspects of their identity and the identities they share with their community. While most youth reported feeling that completing the models was "easy", four youths also expressed difficulty relating to the difference between race and ethnicity (e.g., "*...the only thing I did struggle with the tiny bit was just, like, the race versus ethnicity… because I wasn't* *sure what to put.")*. Although similar struggles with social identity were expressed by four of the five youths, who identified as "Hispanic", each revised their identity model to accommodate this difference following the group discussion. Framing of race and ethnicity thus provided new awareness, thus contributing to the youths' understanding of holistic identity development.

While all the youths were able to identify the importance of thinking about social and role identities, responses varied in the extent to which they were able to connect their own social identity with their role identity. As an example of one of the youths who struggled with this connection, Jessica expressed:

> *I'm not sure how those things, specifically, have affected…my experiences…I'm sure my experiences have been affected by my gender, age, and race [but] I'm not really sure about the connection there.*

It was evident throughout the session that Jessica recognized that social identities can influence the role identity of an engineer. However, she did not explicitly frame this concerning her identity. When asked to clarify this connection, Jessica struggled to connect her social identity to her community sustainability work. Although she struggled with this connection, she did develop some awareness of holistic identity, expressing that her social identity influenced her experiences. Before the intersecting identity modeling activity, when addressing identities, Jessica talked about aspects of her identity as independent factors (e.g. "*things like ethnicity, race, and gender are, I guess, important to always address when we're working with people*") but did not explore these factors in terms of intersectionality. Not until the final reflective interview did she begin to reflect on their interdependencies (e.g., *"My age, race, and gender influence my experience, or class and race and relevant aspects for our community-engineering project"*). Thus, there is evidence of some holistic identity development, but the innovation did not fully support Jessica's connecting these identity intersections.

Significance

Our interpretive analysis suggests that critical pedagogical practices coupled with agentive practices allowed youth to think about how their identities interact with each other and others in their community. Moreover, introducing youth to the idea of contradiction and resistance concerning their sustainability project allowed them to think further about the relationship between themselves and sustainability efforts in their community, furthering their holistic identity development. Nonetheless, youth who struggled to connect their role and social identities also struggled to connect their individual contributions to the larger system of social change. Findings suggest that understanding youths' perspectives on sustainability, community, and their relationship to their identity can help educators and researchers design more productive opportunities for youth.

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Drawing Upon Computational Experiences to Navigate Ontologies

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Abstract: STEM students experience challenges when reasoning about complex systems that combine multiple ontologies. Computational environments, however, support students because these environments distinguish between aggregate patterns and individual interactions. This investigation explores students learning about a complex system that combines two ontologies: chemical and electrical potentials in biological cells. We conducted a training-study that involved pre and posttests and a computational environment (NetLogo) to visualize the system. To gain insight into how students learned from the environment, we assessed students' drawings. We found that computational experiences inspired changes to students' drawing style and prompted them to draw new physical entities. By incorporating these new entities, students demonstrated one step toward their learning to navigate multiple ontologies in STEM education.

Introduction

Multiple ontologies in STEM education

When STEM scholars draw firm or flexible distinctions between how they classify nature, they highlighttheir ontological commitments. *Ontologies* refer to broad categories that exist in nature—e.g., Things or Processes (Chi, 2005). In advanced science, ontologies sometimes demand flexibility. For example, in genetics, students learn to characterize genes as both molecular *matter* and as hereditary *information* (Duncan & Reiser, 2007). When students adopt a molecular lens, they consider a gene as *a segment of a DNA molecule* whereas adopting a classic genetics lens entails reasoning about *hereditary patterns*. To solve the pressing problems of their time, scientists needed to use multiple ontologies to understand natural entities. Today, the normative undergraduate science curriculum demands ontological flexibility from students.

Multiple ontologies in quantitative biology education

We introduce a new ontological challenge that manifests at an intersection between the life and physical sciences. The challenge involves students learning to recognize two ontologies—one *deterministic physical force* and one *probabilistic process*—that influence the movement of *ions,* or charged atoms, across the membrane of a biological cell. This phenomenon is called the Resting Membrane Potential (RMP). *Resting* refers to *dynamic equilibrium* or equal rates of two processes that occur in opposite directions. The *membrane potential* reflects an electrical driving force—measured as a voltage—that exists across cells. This electrical force prevents ions from diffusing until they reach equal concentrations.

The RMP poses an ontological challenge because students must recognize that the same individual ion holds two physical properties that create two ontologically distinct influences upon the ion's motion. Prior investigations demonstrate that when students reason about one entity that belongs to two ontologies, they experience learning challenges (Duncan & Reiser, 2007). Our prior research determined that ontological challenges arose from the fact that students readily recognize the probabilistic influence but neglected the deterministic influence (Lira & Stieff, *accepted with revisions*). This means that students fail to recognize physical forces that exist between individual ions as has been seen in other domains (Cooper et al., 2015).

Computational environments represent individual and aggregate patterns

Computational learning environments afford students insight into how physical interactions between individual entities in a system produce aggregate quantitative patterns (Sengupta & Wilensky, 2009). To illustrate, first consider that science equations typically model aggregate quantities such as the amount of total charge (i.e., current) that flows through a resistor. In contrast, computational environments like NetLogo represent both interactions between individual entities and the aggregated patterns that emerge from these interactions. For example, Sengupta and Wilensky demonstrated that after working with a computational environment modeling electricity, undergraduate physics students shifted from reasoning only about aggregate level quantities (e.g., "*current* cannot flow …") to reasoning about both aggregate and individual levels (e.g., "... no resultant current because the *electrons* are boundtightly to *atoms* ..."). One explanation for students attending to these individual interactions is that the NetLogo environment displayed a visualization that depicted interactions between individual electrons and atoms. Equations, for instance, do not visualize this interaction.

Navigating multiple ontologies by drawing

The problem described thus far motivates having students visualize individual entities. Drawing in science refers to a representational practice whereby people use paper and pencil to visualize their ideas about a natural system. Drawings depict the systems' physical structures, spatial organization, and causal interactions. This practice proves valuable to educators and researchers because it delivers insight into students' knowledge that we otherwise might not detect from other assessment modes. For example, in writing it is permissible to say, "The forks are *beside* the knives." In drawing, however, a person must specify *left* and *right* relations (Ehrlich & Johnson-Laird, 1982). Moreover, the person must choose to depict the *number* of forks and knives. When assessing students' knowledge of systems composed of multiple physical entities and quantities that interact with one another, drawing often delivers quick insight (Cooper et al., 2015; Cooper, Stieff, & DeSutter, 2017).

This point is relevant to learning from a visual simulation like NetLogo because drawing transforms continuous and dynamic visualizations into static representations. To make this transformation, students must select specific visual features and depict those features at specific moments in time. Prior investigations into students' understandings of the RMP demonstrate that when students draw the RMP, professors assess 90 percent of their drawings as problematic. Moreover, 58 of 74 students sampled failed to depict the RMP, i.e., the electrical potential (Frankel, 2010). To contextualize these results, note that the drawing assessments occurred after some initial instruction—this demonstrates the need to consider alternative instructional modes such as computational environments. This led us to ask how do computational experiences reshape students' drawings of the RMP?

Methodology

Participant population & recruitment

Thirty undergraduate students majoring in Biology or Psychology at the University of Iowa were recruited through university mass mail (n=30; 1 male, 29 female). 25 of 30 students had been enrolled in at least one physiology course that taught them about resting membrane potentials.

Research design and procedure

Here, we report upon aspects of a larger on-going experimental design. First, students were consented to participate in the study. They then took a pretest that included a drawing task (10 mins). Next, we conducted an intervention that guided students to use a computational environment built in NetLogo. Students were prompted to predict, explain, and reflect upon three phases in the evolution of the RMP (10 mins). Participants then took a posttest that contained the same drawing task as well as other writing and calculation items (25 mins). Participants were paid 20 USD and dismissed.

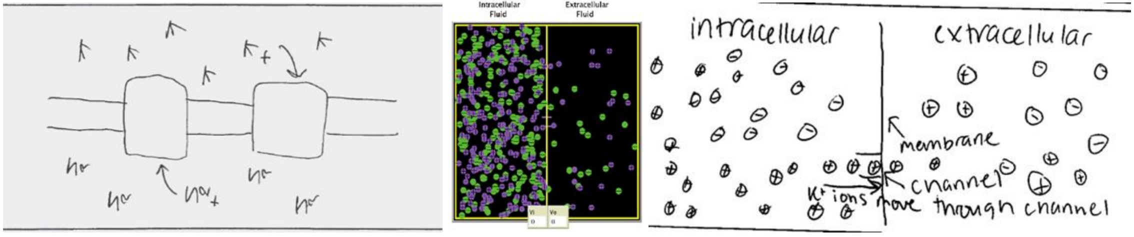
Qualitative analyses of student drawing construction

We analyzed students' drawings at pre- and posttests to assess their overall style and the presence or absence of features that we borrowed from Ryan & Stieff (2019). These include *motion*, *position*, *composition*, and *interaction*. In our context, *motion* refers to an ion's movement. *Position* refers to the configuration of ions and cellular structures. *Composition* refers to the identity or type of ions depicted. *Interaction* refers to the physical cause of an ion's motion. In the drawing task, students needed to illustrate three phases: (1) initial conditions depicting a greater *concentration* of ions inside the cell than outside, (2) the dominant transport mechanism for ions to *diffuse* across the selectively permeable membrane, and (3) the RMP or an electrical potential in *dynamic equilibrium* with a chemical potential.

We first attended to *position*. Position directs attention to the overall *style* of students' drawings. Analyzing posttests first, we found that most drawings resembled the configuration of the NetLogo interface (Figure 1b). This prompted the inductive code *NetLogo inspired position*. In these drawings, a segment of the cell membrane is depicted as a straight and vertical line. On the cell membrane, an open ion channel is depicted near the center of the membrane (Figure 1c). As we attended to *NetLogo inspired* drawings, we noticed that many of them also contained both positive and negative charges (+, -), or particles that carry charges (K^+, Cl^-). Therefore, we next attended to the drawing's overall *composition*. For composition, we attended to each type of entity depicted in the drawings. At posttest, we noticed that most students depicted both potassium K^+ and chloride Cl^- ions. This prompted the inductive code *NetLogo inspired composition*.

After developing our coding scheme, we analyzed the pretests to determine whether our intervention was influential along either of the two dimensions: Position and Composition. At pretest, however, drawing *positions* varied to a greater degree than posttests. Moreover, none of the pretest drawings resemble our NetLogo interface. In contrast to NetLogo inspired drawings, position at pretest consisted of drawings that depicted an entire cell as opposed to a section of membrane. Second, among students who drew a segment of the membrane with straight line, they oriented the drawing along the horizontal as opposed to vertical axis. These stylings prompted the inductive code: *textbook inspired positions* (Figure 1a).

Figure 1
The computational experience inspires students' drawing style and compositions. (a) At pretest: textbook inspired drawing that consists of positively charged ions only. (b) NetLogo visualization window. (c) At posttest: NetLogo inspired drawing that consists of both positively charged ions and negatively charged ions.



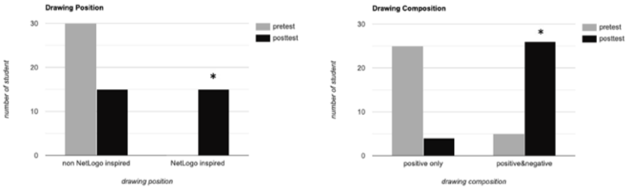
(a) (b) (c)

Results

Computational experience inspires students' drawing styles and derives new drawing composition

When we analyzed the frequency for each category across pre- and posttest, we found that computational experiences changed how students *position* physical entities in their drawing and thus inspires their overall drawing style (x^2=20, n=30, df=1, p<0.0001). Regarding Drawing Style, NetLogo inspired drawings resemble the configuration of NetLogo interface by, for example, positioning the cell membrane to orient along the vertical axis (Figure 1c). This demonstrates that students encoded and recalled the visualization from their computational experience (Figure 2a). Regarding Drawing Composition, we found a significant shift in students' drawing *compositions* (Figure 2b). That is, students incorporated new individual physical entities that possessed distinct identities and properties (x^2=29.43, n=30, df=1, p<0.0001). Students who included new drawing compositions also showed a higher overall score (m= 36.68%) compared to students who did not (m=19%). NetLogo inspired drawings that resembled the composition displayed by the NetLogo interface by, for example, inspired students to draw negative charges (Figure 2b).

Figure 2
*(a) Students' drawing position at pre- and posttest. Frequencies were compared using a chi-square test; *, p<0.0001. (b) Students' drawing composition at pre- and posttest. Frequencies were compared using a chi-square test; *, p<0.0001.*



(a) (b)

To contextualize these results, we tracked interactions between *Position* and *Composition*. Among the 15 students who produced NetLogo-inspired drawings, 14 included negative charges. Among the 15 students who did not produce NetLogo inspired drawings, 12 included negative charges. Thus, only 4 students failed to represent negative charges after experiencing the computational environment. These 4 students failed to represent any charges whatsoever. Thus, although most students readily picked up the physical entities needed to construct multiple ontologies, their use of these entities in drawing demands other requisite science knowledge.

Discussion

Some physical entities display multiple ontologies (Hoehn & Finkelstein, 2018; Duncan & Reiser, 2007). In the case we presented on the resting membrane potential, prior research demonstrated that students attend to physical entities related to a *probabilistic* ontology to the neglect of a *deterministic* one. (Lira & Stieff, *accepted with revisions*). We reasoned that one explanation for this learning phenomenon arose from the fact that students learned with representations—such as equations—that oriented students to the *aggregate* level as opposed to highlighting interactions between *individual* entities (Sengupta & Wilensky, 2009). We therefore implemented a computational learning environment that aimed to guide students to notice the deterministic influence—an electrical driving force that causes ions to move in a direction opposite to the probabilistic influence.

The findings presented illuminate a path for students to recognize two ontologies at play in a complex system. If we adopt a context-sensitive view on how students navigate multiple ontologies during STEM learning (e.g., Hoehn & Finkelstein, 2018), then one possibility is that computational experiences permit students to encode visual elements that corresponds to a given ontology (e.g., probability). This view does not, however, promise that students will construct the ontology—only that students will notice features that represent aspects of it. Moreover, students' construction of the ontology will manifest only if assessment items demand or at least facilitate their use. The drawing assessment we designed aligned with the computational environment's visualization. A context-sensitive view on students' knowledge therefore suggests that students will pick up "pieces" of knowledge from computational environments and that those "pieces" will manifest in unique ways on different assessment items (cf. Sherin et al., 2012).

Drawing therefore granted a small window into how students construct and use multiple ontologies. They incorporated new styles for modeling the cell when they shifted from drawing whole cells to drawing segments of membrane. They also incorporated critical entities—i.e., negative charges—that they neglected before their computational experience. As part of the on-going investigation, we are analyzing how other aspects of students' knowledge manifests in drawing and other assessment modes (Ryan & Stieff, 2019). Future investigations will determine how students learn to represent other physical entities such as the forces that students' drawings neglected to represent after intervention. At present, these results demonstrate that attending to the fine-grained features of students' drawings reveal that students readily pick-up critical pieces of knowledge (i.e., opposite charges) needed for them to construct the *deterministic* ontology necessary for understanding a complex system.

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Future Imaginings for Teaching: Voices of Pre-Service Teachers From Marginalized Communities

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Abstract: We explored the future plans for teaching of Preservice Teachers (PTs) from marginalized communities at a Hispanic-Serving and Minority-Serving institution. We examined positionality statements to learn how past schooling experiences guided PTs' vision for a future classroom. Our findings show PTs who described positive schooling experiences conceptualized forms of equity-as-inclusion while PTs who described negative schooling experiences articulated desires for transformational classrooms. We propose both forms of equity are valuable, but we examine existing systems as we believe DEI-informed teacher preparation programs can create opportunities for collaborative exploration that prioritize equity-as-transformation and prompt PTs to develop plans for more equitable teaching.

Introduction

Pre-service teachers (PTs) envision what their future classrooms and teachings may look like. Teacher training programs are designed develop PTs' future practice as well as guide their plans for teaching. A central focus of teacher preparation programs is helping PTs develop a deeper understanding for the students they serve including through culture- and race-explicit practices (Jupp et al., 2016) including approaches to explicitly unpack forms of internalized bias (e.g., racism, ableism; e.g., Kohli, 2014). Diversity, Equity, and Inclusion curriculum can help PTs gain perspective on the varied experiences students undergo in the existing schooling system. These efforts are intended to help PTs understand that not all students have the same schooling experiences since existing systems tend to favor those belonging to the dominant group (e.g., white, abled, cisgender, middle class). Our research sets out to understand how PTs from marginalized groups contextualize their own past schooling experiences and make plans for teaching in their future classrooms. We examine their vision for their ideal classroom environment and how their own lived experiences play a role in their future imaginings of teaching.

A framework for an undergraduate teacher prep course and the present analysis

Diversity, equity, and inclusion (DEI) efforts are common across many universities and teacher preparation programs in particular, including the program that was the focus of this study at a Hispanic-Serving and Minority-Serving Institution. In the Learning Sciences for instance, researchers have explored the idea of inclusive and transformative agency (Stroupe, 2014; Keifert et al., 2018, p. 197). We are particularly interested in cultivating transformative forms of engagement as PTs connect learning theory to plans for future disciplinary teaching.

The framework we present comes from the design of a PT undergraduate course exploring the relationship between learning theory (e.g., sociocultural theory, developmental theory) and classroom design. We present this framework as it (a) provided the context in which the PTs were emersed as they wrote the statement that serve as our focal data and (b) demonstrates how we modeled the learning designs that supported transformative futures for PTs as teachers and their future students. Our framework centers humanizing learning designs that position PTs as active sensemakers with the agency to interpret and critique learning theory. We also center horizontality in this work, recognizing that PTs live and learn across a variety of cultural communities and that those experiences should be available as sensemaking tools for themselves and their peers within teacher preparation courses (e.g., Warren et al., 2020). Specifically, we draw on the idea of entanglements—"moments during which participants engaged in collaborative sensemaking make relevant their histories, futures, and ideas about the world" (Keifert, under review)—to understand PTs' sensemaking both in-the-moment as well as through artifact analysis (e.g., assignments). Furthermore, our analysis includes a consideration of intersectionality and relationships between members of a learning community (Collins & Bilge, 2020).

Research methods

The current project is part of a larger design-based research study (e.g., Design-based Research Collective, 2003) studying how examination of prior experience, intersectionality, and sociocultural learning theory supports PTs to create transformative visions for future teaching. The course was taught at a Hispanic Serving Institution, Majority-Minority and in a conservative political climate in the Southwestern region of the United States.

Three instructors' sections of this course were included in the present analysis. All three instructors belong to the dominant community in the US (white, middle class), but were committed to power-explicit conversations about teaching, learning, and school systems through their membership in the dominant community and were recognizing, naming, and disrupting oppressive systems.

The present analysis was conducted by the full research team, including multiple international students, two LGBTQIA+ members, members of neurodivergent communities, and disabled members. This team was led by Denisse Avila: a Hispanic, cisgender female, first-generation college graduate who was in the first half of her doctoral studies. Her work was supported by the senior scholar of the group Dr. D Teo Keifert: a white, European-heritage, disabled, queer, non-binary assistant professor. We share these identities here because the broad range of perspectives of our research group informed the ways we saw and approached our analysis.

To learn more about PTs' future plans for teaching, our research team focused on positionality statements where PTs reflected on how their own personal histories shaped their decision to pursue a career in education. The research team selected statements where PTs identified as belonging to a marginalized group (i.e., race / ethnicity / neurodivergence / socioeconomic status) explicitly. Of 19 consented statements, 12 met the criteria.

Our team followed an open coding process (e.g., Creswell, 2007), looking for phrasing showing key connections between prior schooling experiences and plans for future teaching. All statements were compared to finalize codes and themes. Our lead author identified differences between the assignments in terms of how equity was conceptualized that were connected to stories of past learning. Our first two authors re-engaged with the literature presented to consider how these differences in conceptualization of equity could be understood within the theoretical frames of the course as presented through media. We present our findings according to codes of positive and negative schooling experiences and discuss patterns across that led to our understanding about PTs' conceptualization of equity and equitable learning.

Findings

Positive schooling experiences and future teaching

Four PTs' statements cited primarily positive schooling experiences. Positive experiences included retellings where PTs recall feeling supported, inspired, and even empowered by their educators and classroom environment.

Despite the lack of representation, Tony found support from his educators. His plans for a future classroom included an environment where students feel seen, welcome, and engaged. Vee acknowledged that life seemed to "not be the best at home," but her mother strongly encouraged an education, which led Vee to find comfort and reprieve from her home life in the school environment. Vee expressed finding success in her K-12 classrooms which prompted Vee to seek to provide positive learning experiences to her students similar to those she encountered in her own schooling. Happy wrote that she also did not see much representation growing up, until college, where she had a mentor who was African American. She realized she could bring different perspectives to her role as a teacher and develop deeper connections with her students. Growing up in a single-parent household, Maxwell Steven described their home life as not always idyllic, but they exhibited neurodivergent qualities that enabled them to excel in school. Their plans for future teaching focused on student engagement and ensuring students' likes and dislikes would be accounted for and reflected in the classroom.

Negative schooling experiences and future teaching

Of the seven PTs who shared negative schooling experiences, five spoke of feeling neglected due to having needs or a background that were not like those of their peers. PTs who reported feelings of neglect in the classroom stated feeling "lost", "outcasted", "inferior", and even "belittled". They felt that their teachers "were not equipped or prepared for the students at [the] school", which resulted in PT's neurodivergent and socioemotional needs that were not properly met, were ignored, or even criticized.

While some PTs spoke of feeling neglected in their learning needs, others spoke of feeling shamed due to their learning difficulties and/or cultural differences. Phoebe Bridgers shared she once had trouble spelling the word "abuelito" (Spanish for grandfather) and was made to feel ashamed for asking and not knowing the English word for grandfather instead. Cardinal North retold a time when a teacher laughed at them for asking a question during class. This made Cardinal North feel "cheated of [their] education". Manuel positioned himself in regard to how others reacted or responded to him. For example, he reported being called "faggot" by his peers and cited harassment of "queer Black and Brown students" in his hometown but did not explicitly say he was a member of those groups. As a future educator, Manuel sought to counter "oppressive structures" and feelings of "erasure and exclusion". Soi Kat, shared that she is half Asian and half Black, but did not grow up in a marginalized community.

It was not until she moved to the U.S. that she experienced what she described as a "sharp shift in [her] education experience" and that "for the first time [she] noticed serious discrepancies within the education system." She sought to use her position of power as a teacher to serve as a mentor to students of color and transform the school system into what she referred to as "a safe space for diverse students."

These PTs were explicit in stating the importance of the classroom environment serving as a safe space and expressed their belief that student differences shape understanding. Aligned with readings such as Gutiérrez and Rogoff's (2003) work on cultural repertoires as well as a recorded talk by Tanner (2013) about deficit- and resilience-based models from course work, these PTs did not discuss differences as deficits. Instead, future students were described as multi-faceted individuals whose needs can be expected to be as unique as the students themselves. Individual differences were discussed as strengths, and student input was framed as crucial.

Comparing across positive and negative stories

Commonalities in stories

Across all statements, it was evident that PTs from marginalized groups yearned for a classroom where students from diverse backgrounds were valued, attended to, and understood as holistic individuals. They stressed the importance of having teachers from different backgrounds to develop deep relationships with students who may not always be understood. Many PTs drew explicit connections to their own identity and expressed a desire to make their classroom a place where students of all backgrounds felt welcome and secure. PT statements overwhelmingly showed an intentional effort to seek student opinion, primarily in the belief that this was central to a classroom that is sensitized and responsive to the needs of others. However, it was evident from the statements that the nature of the schooling experiences impacted the depth of exploration that PTs underwent.

Differences across PTs: Conceptualizations of equity and goals for future teaching

Our analysis showed that based on the nature of the stories retold, PTs conceptualized equity differently; PTs who told positive stories conceptualized equity-as-representation, and those who told negative stories of school neglect and harm conceptualized equity-as-transformation within their statements.

Equitable-as-representation vs. Equitable-as-transformation

PTs who cited positive experiences prioritized an equitable classroom specifically as tied to having teachers that represented the race/ethnicity of students in the school. This idea of equity-as-representation was used to argue that their presence in future classrooms, as members of marginalized communities in the US and those underrepresented in the US teaching force, would be valuable to their future students. They used their identity to recognize that the needs of students from marginalized groups may be different from those belonging to dominant groups. However, teacher representation was viewed to develop camaraderie and build community with students who may feel "othered." It may be because these PTs found overall success in the existing system that their focus was consistently to help their students find similar success.

Negative experiences drove PTs to discover deeper issues in existing systems and reject these in their own classrooms, envisioning a transformational classroom. These PTs sought to create student-dictated and student-informed classrooms, where expectations for "normalcy" were not predisposed by society. Their plans for future teaching centered around getting to know students' personal histories and identities and letting students take an active role in their learning, centering ideas from course theory readings, video, and podcasts like cultural repertoires (Gutiérrez & Rogoff, 2003), the role of teachers as serving students and the role of teachers and peers in co-constructing disability and otherness (e.g., Annamma et al., 2013; Tanner, 2013). PTs who did not have positive experiences sought to understand the "whole student" both in and outside the classroom (e.g., horizontality) perhaps in relation to Ramsey's (2004) use of Bronfenbrenner and recognized how outside realities can impact education as the classroom is not a vacuum (Emdin, 2020).

Discussion

In the statements we examined, pre-service teachers with self-named marginalized identities recognized these identities as an area of strength for teaching students from diverse backgrounds. We recognized PTs with positive schooling experiences as conceptualizing forms of equity-as-representation. We also recognized PTs with negative schooling experiences as conceptualizing equity-as-transformation with the need to disrupt "normal" (e.g., Annamma et al., 2013) in favor of centering and cultivating heterogeneity as part of a thriving classroom sensemaking community. Both forms of equity are important, though the first is likely to demand assimilation of learners from non-dominant communities which prior research shows does active harm to learners (e.g., Bang et al., 2012) while also limiting possibilities for sensemaking for students across both marginalized and dominant communities (Warren et al., 2020). Equity-as-transformation takes a more systematic approach to understanding learning in context, systems of oppression, and more accurately reflects critical, sociocultural theories of learning (e.g., Gutiérrez & Rogoff, 2003; Rogoff, 2003; Emdin, 2020). We propose both forms of equity are necessary and valuable. However, equity-as-representation does not adequately disrupt school, and societal norms. Thus, seeding the ground for all students to critically examine existing systems and work towards conceptualizations of equity-as-transformation must be a priority in DEI-informed teacher preparation programs.

Conclusions & implications

Given the divide between PTs who told stories of positive learning experiences and those who told stories of negative learning experiences, a pressing question emerged for our authorship team of how to engage those who told stories of experiencing success within existing K-12 schooling systems in imagining more transformative futures for their own students. From an inquiry perspective, it might be said that these PTs did not encounter the same "felt puzzle" (Keifert & Stevens, 2019) as those PTs who recognized significant harm caused by teachers, other adults, and peers in US K-12 schools as a result of their belonging to non-dominant communities. In this analysis we focus specifically on learners from non-dominant communities who describe positive past learning experiences, though in our broader work we are also concerned about learners from the dominant community. Thus, we wish to pursue two questions in our subsequent work. First, how can opportunities to feel, recognize, and name these problems be presented both to students from non-dominant communities and dominant communities who saw themselves as successful in schooling systems? Second, what kinds of experiences in PT courses might provoke opportunities for recognizing the need to develop a vision for transformative futures without asking for performative or harmful public re-telling of such experiences from members of the classroom community who have directly experienced this harm?

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Against “Both Sides” Argumentation: Resisting Dehumanization in Intellectual Community

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Abstract: In this paper, we respond to an argument that has circulated in the learning sciences in recent years, that it is necessarily advantageous for learners and learning scientists to engage with “both sides” of a debate. While engaging in argument and civic dialogue can be advantageous for learning, its limits must be carefully examined. Drawing on studies of fascism, ideology, and learning toward equity, we suggest that platforming both sides of debate can be a harmful strategy that creates conditions for advancing bad faith arguments, dehumanizing already minoritized communities, burdening people with the work of refutation, and compromising with immoral positions. Without care, engaging “both sides” ultimately threatens the ideals of an open, democratic learning community.

The learning sciences in this political moment

Several years ago, the Politics of Learning Writing Collective (2017) wrote a call to action warning of the rise of right-wing nationalism. In the shadow of Trump’s election to the presidency of the United States and the rise of fascist leaders internationally, they reminded the field of the long history of racist, nationalist, and settler-colonial violence. They called for the learning sciences to take a greater interest in learning as a political act, and over the five years since they published that piece, many of us have tried to heed their call. It is becoming increasingly clear, though, that the tide has not been stemmed, that democracy is in perilous danger, and that along with it attacks and forms of exclusion aimed at trans people; people with uteruses; queer people; migrants; Black people, Indigenous people, and people of color (BIPOC); Jewish people; and disabled people have worsened. Further, in fascist political strategy, agitators foment division through appeals to a mythic national past of purity and order. To secure this myth, they must destabilize collective knowledge of history and attack educational institutions (Stanley, 2018). Observers of recent developments in the U.S. may note the increasing attacks on LGBTQ2S+ educators, on the teaching of the history of racism and slavery, and on intellectual freedom and the institution of tenure in higher education. Left unchecked, these swelling movements threaten every educator and researcher.

Perhaps counterintuitively to some in our intellectual community, “balanced debate” is not an apolitical intervention that always supports productive dialogue; rather, it is one tool being mobilized to advance fascist ideas, policies, and political movements. Calls for balanced debate may be alluring. They evoke images of an even playing field for rational actors, where reasoned argumentation holds sway over ideas that are obviously wrong, or even violent in their implications. Yet, in classrooms, in broadcast media, and on the internet, fascists are working hard under the banner of “free speech” to make space for their repugnant ideas. This year, at one of our universities, known advocates of political violence were invited to speak at campus in supposed defense of free speech, and political violence predictably ensued. We also see advocacy for hearing “both sides” of a debate in some spaces within the learning sciences, including conference plenaries, manuscript reviews, and classrooms. We are concerned both with the environments we study and with our professional community. We write with examples in mind, yet we are opposed to citing specific instances, which could be seen as “calling out” individual community members—such an approach locates the problem in people rather than a system of ideas, which any one of us might invoke. Rather, we draw attention to the ideology that underpins the calls for balanced debate because we have been alarmed by the impacts it has on minoritized members of the community, and because it legitimizes fascist tactics that directly threaten minoritized people, educational systems, and democracy. Supporting heterogeneous viewpoints in learning environments is not the same as considering all perspectives as valid without regard to whether they are moral, logical, or supported by evidence (Rosebery et al., 2020).

In this paper, we make a theoretically grounded conceptual argument against carte blanche support for platforming, listening to, and engaging with “both sides” of an argument, especially as an equity intervention. We argue that the idea of listening to both sides can work against equity and justice, obscure power relations, and harm minoritized people. We look to research on authoritarianism as well as equity studies to propose a conceptual intervention in our field. Our hope is that we will collectively reconsider the perpetual calls for balanced debate, and instead center historicized, evidence-based equity and justice analyses in our calls to platform particular ideas.

Argumentation: Evidence and ideology in learning

Learning scientists have significantly studied the role of argumentation in the classroom as both a pedagogical goal and a tool. While there are many potential models, it is agreed that argumentation can productively support (especially science) learning, but that its effectiveness is highly sensitive to scaffolding and community norms (e.g., Manz, 2015; Schwarz, 2018). Some studies of democratic education have argued that engaging in civic dialogues is a core practice of democracy that should be part of schooling (Mirza & Perret-Clermont, 2009), while other learning sciences research has focused on fostering dialogue across difference (Asterhan & Schwarz, 2016). However, as Curnow (2021) demonstrated in her study of argumentation in a politically contentious space, some "neutral" approaches to argumentation in fact expect minoritized people to "engage with ideas, practices, and ways of knowing and being that fundamentally undermine and seek to degrade their humanity, their civil and human rights, and their ability to participate fully in the world" (p. 281).

Thus, in spaces of argumentation, ideology—not just evidence—is at issue. As Philip et al. (2017) explained, "all sense making that stabilizes (e.g., 'War is inevitable'), challenges (e.g., 'U.S. military action has been mostly in the interest of corporations'), and/or transforms (e.g., 'We should spend as much on a Department of Peace as we do on the Department of Defense') the distribution of material and symbolic resources in society is ideological" (p. 186). In their study of ideology in an engineering ethics classroom during a discussion of drone warfare, debate converged on ideological stances that marked some people as less worthy of moral consideration than others. In another classroom study, Vakil and McKinney de Royston (2019) explored how "politicized trust" was undermined interactionally in a computer science classroom through an absence of shared political understanding, respect, and commitment. When a white student presented on the relative lack of Black students in the school's honors track and reasoned aloud about issues in students' homes and communities, initial solidarity based on an assumption of good intent soon gave way to tension, with one student saying in a follow-up interview about the incident, "Who are you to speak on this?" (p. 562). Intellectual community can be severely undermined when participants invoke ideological stances that bring others' humanity into question.

Fascism and disinformation

The stakes of dehumanizing ideological convergences are further raised in a context where fascist movements are gaining momentum. We draw on fascism here not as an ad hominem attack, but as a political form that can be studied empirically. Stanley (2018) identifies fascism as ultranationalism that uses a common set of strategies, including "the mythic past, propaganda, anti-intellectualism, unreality, hierarchy, victimhood, law and order, sexual anxiety, appeals to the heartland, and a dismantling of public welfare and unity" (pp. xxviii-xxix). Fascists dehumanize marginalized groups to seize power and enforce extreme hierarchy. Stanley (2018) argues that fascists reject expertise and linguistic complexity to undermine the sophisticated debate democracy requires. One strategy used to expand the range of ideas people are willing to entertain in public discourse is to repeat abhorrent ideas and false claims (Arendt, 1951/1973), while framing the ideas that may have once been viewed as extreme as important to consider and debate in the interest of democratic engagement. These patterns from fascist leaders create a dangerous mix with a segment of the population, known as right-wing authoritarians, who are more likely to be submissive toward strong authority figures and act with aggression toward the people those figures target (Altemeyer, 2004). The net effect of this is to shift the range of acceptable discourse such that previously unacceptable ideas can become mainstreamed, at least in some communities.

Conceptual intervention: Against "both sides"

Calls to hear from "both sides" suggest that for analysis or argumentation to be rigorous, both sides of a debate must be thoroughly reasoned through. In the learning sciences, this often takes the shape of advocating for learners engaged in civic discourse to hear both sides of a debate, regardless of what is being debated and powered relationships between the speakers. This view presupposes that all "sides" of a debate are reasonable, put forward in good faith, and rooted in evidence. People advocating for both sides argue that listening to both sides is itself a social good that enables learners to understand the position of their opponent and move toward civil middle ground. Sometimes the "both sides" approach is framed in negative terms, as in, "Both sides (or all sides) carry some (or equal) blame for injustice or polarization." Others express the same sentiment in more subtle ways: "What is most important is to dialogue with one another," or "Valuing heterogeneity means we must weigh and consider all opinions." We presume this begins from a place of good intentions. Dialogue and discourse across differences can result in changed minds and new insights—when those discussing are doing so in good faith and on equal footing. Yet calling for learners to listen to both sides as a requisite strategy for ensuring fairness and quality evaluation of ideas is not commensurable with a justice-oriented framing of how equity is achieved. Justice-oriented scholars and activists have argued that doing so has several problems.

First, prioritizing engaging with both sides creates conditions for advancing arguments that are *not* actually reasonable, put forward in good faith, nor based in evidence. Demanding that scholarship engage with "both sides" works against historicity and evidence. Often in the context of equity debates and discussions, attention to the historical relations of power clearly demonstrates the *lack* of evidentiary basis for arguments against equity. For example, there is a clear scientific consensus that race is not a biological reality, but a social construct (Collins et al., 2003). We would not need to engage a debate about the intellectual capacity of Black people or the inherent greed of Jewish people; we can mark those as intellectually vapid arguments rooted in anti-Black racism and antisemitism without hearing both sides. Engaging both sides in such scenarios actually undermines intelligent debate by creating a sense of false equivalency (Stanley, 2018). "We should therefore claim," Karl Popper (1945/2002) wrote, "in the name of tolerance, the right not to tolerate the intolerant" (p. 668).

Second, the contours of equity and justice discourse mean that this impulse often leads to debates over the humanity of historically minoritized and disempowered groups of people. It requires that community members made marginal through racist, heteropatriarchal, colonial, ableist policies and practices once again be exposed to ideas which undermine our dignity and question our inclusion. We already know these ideas circulate. In fact, we must be aware of them for our daily safety, yet we gain nothing from hearing these ideas again and again, particularly in professional contexts. Is it "good," for example, for trans people to have to listen to and engage with arguments that question their right to exist, to access medical care, and to be safe in schools and society? Entertaining "both sides" directly creates harm for marginalized people. Yet we stress that the primary harms of these debates are not emotional or symbolic at all, but rather material (e.g., Gill-Peterson, 2022). They impact people's well-being through upholding the institutional structures, practices, and policies that threaten our right to life, safety, and full participation in our academic society and in democratic society more broadly.

Third, beyond the emotional and material damage done through the continued exposure to these ideas, marginalized people must also do more work to refute these ideas prior to being able to engage the broader community with their own theoretical and design ideas. As Toni Morrison (1975) has explained:

> [T]he very serious function of racism is distraction. It keeps you from doing your work… Somebody says you have no language and you spend twenty years proving that you do. Somebody says your head isn't shaped properly so you have scientists working on the fact that it is… There will always be one more thing.

In this way, advocating for "both sides" prevents progress on equity and justice issues by requiring a re-litigation of oppression in every meeting and discussion—arguments that disproportionately fall to BIPOC and other minoritized scholars, who must use our time to restate the basics of equity and justice rather than leveraging our expertise to actually design more equitable teaching and learning environments.

Finally, while the notion that equity can occur if we can build common ground through dialogue is an appealing sentiment, a focus on taking a middle position is a strategy that takes us far from a better world. As Tayari Jones (2018) argued, "The middle is a point equidistant from two poles. That's it. There is nothing inherently virtuous about being neither here nor there… What is halfway between moral and immoral?" Focusing on dialogue can suggest that an issue is a matter of reasonable disagreement. When it comes to some equity issues (e.g., police brutality; LGBTQ2S+ youth suicide), affected parties make clear again and again that these issues are urgent and that opposing positions (e.g., it's fine for police to kill people without a trial; LGBTQ2S+ youth are fundamentally broken and perverted) are simply not reasonable. Seeking to meet them halfway in such cases is to espouse an unproductive, and harmful, theory of change.

Conclusions

In sum, demanding we platform both sides advances fascist tactics for sowing disinformation and makes it more difficult for people to evaluate truth claims. In fact, the "both sides" approach is often intentionally deployed by fascist organizations, and taking this approach can inadvertently align with fascist political goals. Indeed, research on fascism and authoritarianism shows that fascists intentionally rely on the framing of "needing to hear from both sides" or "balanced perspectives" as a way to platform ideas which have previously been marked as fringe or extreme (Stanley, 2018). Through repetition, harmful perspectives without an evidentiary base become normalized as reasonable, which effectively shifts the range of viable political possibilities. In many cases, we see how dehumanizing and untrue discourses about queer people, for example, or the biological basis of racial difference, for another example, can become mainstream talking points, such that oppressed peoples' existence and rights become debatable and expungable. Allowing factual and moral untruths to be repeated is itself dangerous! Hannah Arendt (1951/1973) argued in *The Origins of Totalitarianism*: "What convinces masses are not facts, and not even invented facts, but only the consistency of the system of which they are presumably part.

Repetition... is only important because it convinces them of consistency in time" (p. 351). Historical and contemporary analyses show that this strategy is effective; as a field, we cannot let our good faith efforts to listen across difference and to build consensus where possible be used in service to dehumanization.

These arguments require us to take up our field's calls to value heterogeneity (e.g., Rosebery et al., 2010) with nuance and care. Bringing diverse meaning-making practices into contact in our intellectual community can expand the possibilities for human understanding, but only under certain conditions. When we allow dehumanizing positions to proliferate, or worse, when we relentlessly insist on engaging them, we poison the well of dialogue and bring harm upon everyone who drinks from it. This careful and intentional, rather than "anything goes," engagement with multiple viewpoints is what results in more equitable learning environments (Rosebery et al., 2010; Agarwal & Sengupta-Irving, 2019) and more generative moves towards equity in the field. We resonate with Vakil and McKinney de Royston's (2019) conclusion that we must remain "unsatisfied when there is a breakdown of [democratic learning] communities, even when other forms of rich learning and thinking may be taking place" (p. 564). As scholars who care about the relational outcomes of learning (Nasir & Hand, 2006), we hope our field can model these principles in our own scholarly spaces. Finally, we must remember that dialogue is not a substitute for explicitly working towards equity and justice. Such work requires materially shifting our policies and practices toward different outcomes. We have heard enough talk.

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Examining Undergraduates' Epistemic Emotions and Discourse Moves That Support Collective Knowledge Advancement in Knowledge Building

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Abstract: The purpose of this study was to investigate how undergraduates' epistemic emotions and discourse moves influence collective knowledge advancement in a knowledge-building environment, emphasizing ideation, learning journey design, and collective idea building through learning analytics. Thirty-Five undergraduates studying *Education and Modern Technology* participated. Quantitative ethnography and qualitative analysis were used to analyze student online Knowledge Forum discussions. The findings demonstrate that epistemic emotions such as *curiosity*, *challenged*, *neutral*, and *frustration* might influence collective knowledge advancement via deeper discourse moves. The qualitative analysis indicates how undergraduates engaged in these epistemic emotions to perform sustained inquiry, progressive theory building, and collective idea mapping and creating.

Introduction

Knowledge Building is a major model that intends to facilitate the transformation of education by introducing the concept of knowledge-creating communities (Scardamalia & Bereiter, 2022). Most focus of knowledge building is placed on the ideas that students discuss and the discourse moves they employ to develop those ideas (Chen & Hong, 2016). In earlier research, we utilized the learning analytics tool Knowledge Building Discourse Explorer (KBDeX, Oshima et al., 2012) to evaluate how students' in-depth discourse moves contribute to the advancement of collective knowledge. Students worked in the knowledge-building environment enhanced by their self-designed learning journey and external representations of KBDeX (Feng et al., 2020). Despite years of effort devoted to constructing and analyzing the efficiency of collective knowledge advancement, other aspects (e.g., emotion) in the complex environment may be largely overlooked.

Recent research has focused extensively on epistemic emotion to comprehend the learning process better. Zhu et al. (2021) investigated how knowledge-building practices based on students' feedback affects their emotional engagement. Teo et al. (2022) found that students' epistemic emotions varied during activities aimed at improving ideas. Based on previous investigations, the current project aims to develop a knowledge-building environment using undergraduates' self-designed learning journeys, coupled with representations of KBDeX, and to examine how students' epistemic emotions and discourse moves could support collective knowledge advancement. Seven epistemic emotions were examined: *confusion*, *challenged*, *surprise*, *curiosity*, *neutral*, *frustration*, and *enjoyment.* The research questions are: (1) What was the interplay among undergraduates' epistemic emotions, discourse moves, and collective knowledge advancement? (2) How did undergraduates engage in epistemic emotions and discourse moves towards collective knowledge advancement?

Methods

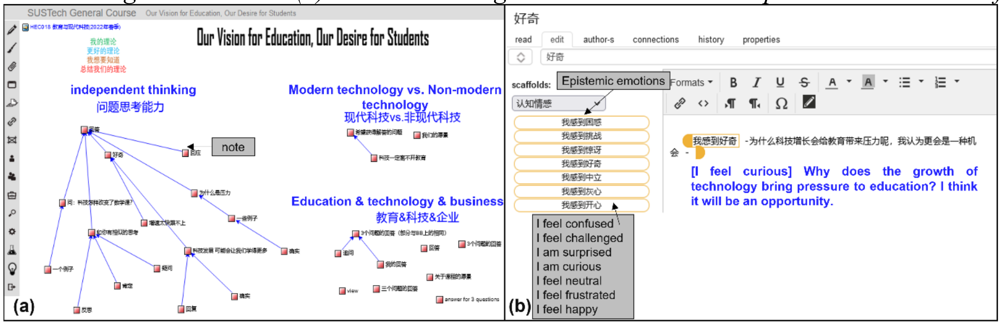
Participants

Thirty-five students across several majors and grades from a science and engineering university in Shenzhen, Mainland China, participated in this project.

Pedagogy design

The participants engaged in a ten-week inquiry on the topic of the liberal arts, *Education and Modern Technology* on Knowledge Forum. They used epistemic emotion scaffolds when writing each note (Figure 1). In the *Ideation* phase (Weeks 1-3), students initially investigated topics of education and modern technology on Knowledge Forum. In the *Learning Journey Design* phase (Weeks 4-6), each group created a model of the knowledge-building journey on Knowledge Forum for visualization and shared inquiry. In the *Collective Ideas Building* phase (Weeks 7-10), students pursued collective knowledge advancement through learning analytics and the designed journey. Figure 2 depicts how students utilized word networks exported from KBDeX, a learning analytics tool, to map and advance collective ideas. The red and yellow circles represent keywords having or having not been used by the group, respectively. Each group received weekly word networks. For example, a student in group 1 discovered that they had neglected the keyword "talent" (a yellow circle) in the previous week, so they brought it into the current week and proposed new ideas focused on the linkages between educational transformation, social development, as talent demand.

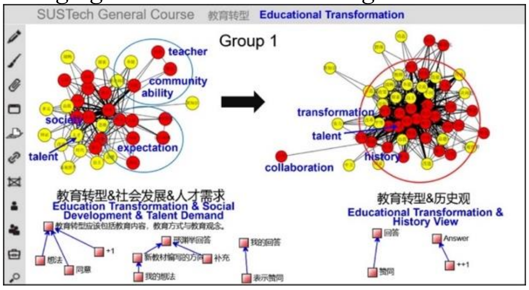
Figure 1
A Knowledge Forum View (a) and a Knowledge Forum Note with an Epistemic Emotion Scaffold (b)



我感到好奇 -为什么科技增长会给教育带来压力呢，我认为更会是一种机会 -

[I feel curious] Why does the growth of technology bring pressure to education? I think it will be an opportunity.

Figure 2
Changing Word Networks Showing Connections among Collective Ideas



Data source

328 Knowledge Forum notes were collected as the data source.

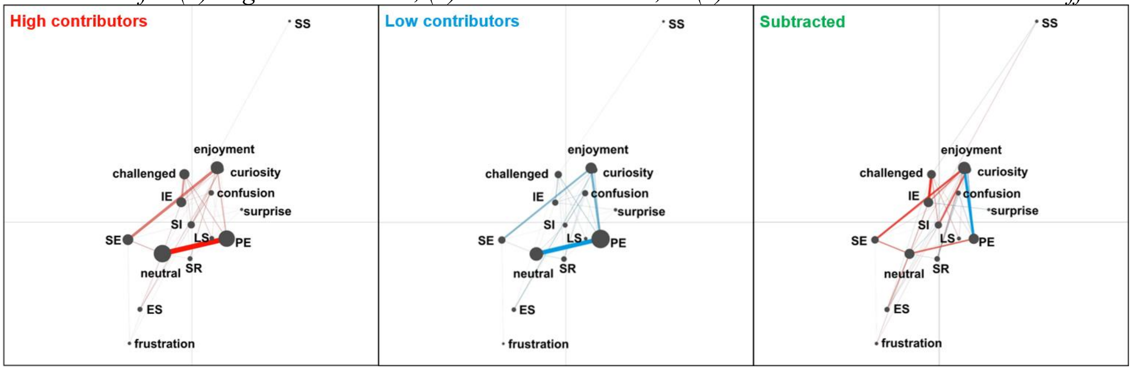
Data analysis and findings

RQ1: What was the interplay among undergraduates' epistemic emotions, discourse moves, and collective knowledge advancement?

We first adopted KBDeX to distinguish undergraduates with high and low contributions to collective knowledge advancement (Feng et al., 2020; Oshima et al., 2020), then we used Epistemic Network Analysis (ENA, Shaffer et al., 2016), an approach in quantitative ethnography, to visualize the associations between epistemic emotions and discourse moves by different contributors (Figure 3 (a) and (b)). The heavier saturation of the edges and nodes indicates that *enjoyment* and *neutral* play essential roles in both networks. However, such epistemic emotions show prominent associations with lower-level *Theorizing* (i.e., *proposing an explanation* and *supporting an explanation*). A two-sample t-test reveals a significant difference in the mean network location in the X dimension between high and low contributors ($t(32.05) = -4.00$, $p < .001$, Cohen's $d = 1.34$). In contrast, there is no significant difference in the Y dimension. The main differences between the two networks are more pronounced in the subtracted network (Figure 3c). The high contributors created a more vibrant network model for the discourse: they have stronger connections between *neutral* and higher-level discourse moves of *Theorizing* (i.e., *improving an explanation*) and *Community* (i.e., *synthesis*); they demonstrated stronger connections between *challenged* and higher-level discourse moves of *Questioning* (i.e., *sustained inquiry*), *Theorizing* (i.e., *improving an explanation*), and *Community* (i.e., *lending support*), and between *curiosity* and *Questioning-sustained inquiry*. More surprisingly, the high contributors have stronger connections between *frustration* and *Questioning-sustained inquiry* and *Theorizing-improving an explanation.* These results suggest that both high and low contributors engaged in *enjoyment* for low-level discourse moves. In contrast, those who engaged in greater *curiosity*, *challenged*, *neutral*, and *frustration* were more inclined to exert collective knowledge advancement through deeper discourse moves.

Figure 3

ENA Models for (a) High Contributors, (b) Low Contributors, & (c) Subtracted Network to Show Differences



(a) (b) (c)

Note. Questioning: ES=explanation seeking; SI=sustained inquiry. Theorizing: PE=proposing an explanation; SE=supporting an explanation; IE=improving an explanation. Community: SS=synthesis; SR=shared regulation; LS=lending support.

RQ2: How did undergraduates engage in epistemic emotions and discourse moves towards collective knowledge advancement?

The qualitative analysis of students' Knowledge Forum activities, reflecting how students advanced collective knowledge by engaging in epistemic emotions and discourse moves, involves the following three themes.

Theme 1: Curiosity, challenged, and frustration for sustained inquiry

Curiosity. When discussing *Educational Transformation*, student s01 first neutrally proposed that the formulation of education policy needs to consider ideas from the educated. Another high contributor, student s31, built on this idea using the discourse move of *Questioning-sustained inquiry* with *curiosity*, focusing on the question of to what extent the educated' ideas are taken into account.

Challenged. When discussing *The Impact of Technology on Education*, student s11 first *neutrally* proposed that technology is the application of objective laws by human beings. Then, an improved explanation of how to extract high-quality information from massive amounts of information, a new challenge for technology and individuals, was proposed by student s29 with the *challenged* emotion. After that, the high contributor student s06 adopted the discourse move of *Questioning-sustained inquiry* with *challenged*, proposing a new question of whether lowering educational thresholds would lead to a decline in the average level of teaching staff.

Frustration. When discussing *What is Education*, student s01 first neutrally proposed that education depends more on one's ownership of learning rather than the teacher's delivery, followed by an improved explanation that education should consider a person's interests and talents. Later, the high contributor student s25 expressed *frustration* that people sometimes could not fully understand themselves. In this case, this student utilized the discourse move of *Questioning-sustained inquiry* to propose a new question of how education could help people identify interests and talents. These results suggest that the high contributor could engage in epistemic emotions of curiosity, challenged, and frustration for sustained inquiry.

Theme 2: Challenged, neutral, and frustration for progressive theory building

Challenged. As noted earlier in the *challenged* case from Theme 1, student s29 adopted *Theorizing-improving an explanation* with the *challenged* emotion to build on the previous explanation and then raised another question for sustained inquiry still with the *challenged* emotion.

Neutral. When discussing *Educational Transformation*, student s27 first neutrally proposed that educational transformation should focus on cultivating talents suitable for current society. Afterward, student s32 used *Theorizing-supporting an explanation* to support this proposal with enjoyment by the example of vocational education, followed by the high contributor s01's improved explanation in neutral.

Frustration. When discussing *What is Education*, student s25 first proposed that one's ultimate ability depends on individual learning approaches. Student s35 supported this explanation that the ideas and approaches brought by education are more important than education itself. Later, the high contributor student s33 improved this explanation to the angle of how to select educational assessment, with the discourse move of *Theorizing-improving an explanation* and the *frustration* emotion. These results suggest that the high contributors could engage in epistemic emotions of challenged, neutral, and frustration for progressive theory building.

Theme 3: Challenged and neutral for collective ideas mapping and creating

Challenged. When discussing *Educational Transformation*, most students focused on the relationships between society, technology, and educators. In contrast, the high contributor student s14 built on collective ideas and pointed out a new direction that educational transformation should consider for future education, with the discourse move of *Community-lending support* and the *challenged* emotion.

Neutral. When discussing *What is Education*, the high contributor student s29 *neutrally* synthesized the group ideas of relationships among education, society, and individual with the discourse move of *Community-synthesis*. The student also summarized group members' ideas of freedom, pointing out the gap between reality and the expectation of freedom. These results suggest that the high contributors could engage in challenged and neutral for collective ideas mapping and creating.

Discussion

This study investigated how undergraduates engaged in epistemic emotions and discourse moves contribute to collective knowledge advancement, supported by a learning environment enriched with students' designed learning journeys and learning analytics in knowledge building. Results from ENA models indicated that undergraduates who engaged in greater *curiosity*, *challenged*, *neutral*, and *frustration* were more inclined to advance collective knowledge through deeper discourse moves such as *Questioning-sustained inquiry*, *Theorizing-improving an explanation*, *Community-Synthesis*, and *Community-lending support.* The qualitative findings revealed three themes about the associations between these epistemic emotions and discourse moves that supported sustained inquiry, progressive theory building, and collective idea mapping and creating. This study evaluated epistemic emotion, which has seldom been studied in the context of knowledge-building, concerning students' usage of discourse moves and collective knowledge advancement. However, more emotions should be researched, as this study only looked at seven epistemic emotions. A significant future effort is also required to explore and examine knowledge-building designs for fostering epistemic emotions and progressive knowledge-building among students.

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Decolonizing Climate Change Imagination: An “Engineering Fiction” Learning Experience

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Abstract: The inadequate societal response to the climate crisis is partly due to epistemological and ontological colonization of climate change imagination. Climate education privileges scientific knowledge (epistemological colonization), which divorces climate change from emotions that typically drive concern and action, and dominant visions of the future obscure the possibility of collective socio-political transformation (ontological colonization). This study examined the effect of a learning experience that integrated engineering systems design and speculative fiction writing to engage 48 high school science students in imagining sustainable climate futures. Students wrote three climate fiction stories: an individually-authored story and a group-authored story during the introductory session, and a final group-authored story. We performed qualitative content analysis of these stories to identify relevant themes. The findings suggest that the intervention decolonized participants’ imaginations about climate change.

Decolonization of the imagination is the most dangerous and subversive form there is: for it is where all other forms of decolonization are born (Imarisha & Brown, 2015).

Introduction

The lackluster societal response to the climate crisis has been called a double failure of imagination (Milkoreit, 2017). First is a failure to perceive the severity of climate change risks since climate change is often construed as *psychologically distant* (i.e., more likely to impact strangers in remote locations and times), which reduces connection to emotional reactions that typically drive concern and action. Second is a failure to envision pathways towards just and sustainable futures.

The first failure of imagination is partly due to epistemological colonization. According to psychologist Jerome Bruner, there are two general modes of thought for interpreting and understanding the world. The first is the logico-scientific mode, which is a rational scientific approach to explain how the physical world works (Bruner, 1986). Western science purports to be the foundation of valid knowledge claims in modern societies, and it splits cognition from emotions in the pursuit of “objectivity,” a legacy of colonial thought imposed on other cultures. Climate change education privileges the logico-scientific mode, and several studies suggest that these approaches have been ineffective in altering youth’s climate change attitudes and behaviors (Rousell et al., 2017). The second mode of thought is the narrative mode, a storytelling approach used to make sense of people and their (inter)actions (Bruner, 1986). Fiction stories are a type of narrative that facilitate cognitive and emotional immersion into an imagined world (Mar & Oatley, 2008). The emerging sub-genre of climate fiction (or cli-fi) allows readers to cognitively inhabit climate-changed worlds and to vicariously experience the emotions of characters that live there (Milkoreit, 2017). The narrative mode thus promises a decolonial epistemology in STEM learning environments (Tzou et al., 2019).

The second failure of imagination is partly due to ontological colonization. Narratives about the future (i.e., ontologies) can generally be classified into four archetypes: continue, collapse, discipline, and transform (Dator, 2009). The continue archetype corresponds to continuation of the status quo. Since fossil fuels are so deeply embedded within our infrastructure, values, and habits, we lack coherent imaginaries of alternative post-fossil futures (Hajer & Versteeg, 2019). The collapse archetype consists of system degradation or failure. Popular apocalypse narratives in cli-fi stories depict this future as a foregone conclusion (Schneider-Mayerson, 2018). In the discipline archetype, behaviors adapt to imposed limits. Environmental education typically emphasizes individual, private-sphere behavior change (e.g., use less energy), but this directs attention away from the need for collective systemic change (Chawla & Cushing, 2007). The transform archetype involves game-changing new models or factors. Transform narratives often come from utopian fiction in the form of an imagined, idealized society. These narratives offer no concrete strategies for connecting future visions to present reality, and those that do typically privilege technological innovation as the primary or only driver of transition (Jovchelovitch & Hawlina, 2018). These Western visions of the future dominate our shared climate imaginaries and shape the boundaries for what is perceived as plausible and desirable through mental colonization that obscures the possibility of collective socio-political transformation.

Intervention design

We hypothesized that it may be possible to decolonize climate change imagination through a learning experience that integrates engineering systems design and speculative fiction writing. With its basis in the narrative mode of thought, speculative fiction expresses a decolonial epistemology. Furthermore, both engineering and speculative fiction are ontological design tools concerned with imagining alternative worlds and their societal implications.

We designed an intervention that tasks students with developing solutions and stories depicting transformation of a socio-technical system (e.g., food, energy) to a future 50 years from now where catastrophic climate change has been mitigated for a vulnerable population. To mitigate techno-utopian visions of the future, the intervention employed the "Systemic Transitions Framework" (Zaidi, 2017). This framework is derived from the worldbuilding practices of science fiction authors and guides the process of constructing an imaginary world by stripping it down to its foundations: philosophical, political, economic, environmental, technological, social, and artistic. The framework involves a "backcasting" process: (1) map the current state of the world; (2) envision a preferred future state of the world; and (3) backcast from the preferred future state to the current state.

The intervention consisted of ten 80-minute sessions. In the first session, students wrote individual and group (pre-intervention) stories. Groups of students were then guided through alternating stages of the engineering design and creative writing processes: define a climate justice problem in their chosen system, build an imaginary storyworld based on their system, analyze stakeholders in their system, develop characters based on their stakeholders, backcast a solution pathway to a desired future, outline a story plot based on their solution pathway, evaluate the potential impacts of their solution, write a draft (post-intervention) story, and share and reflect.

Methodology

This study was guided by the following research question: What is the effect of the "engineering fiction" learning experience on epistemological and ontological decolonization of students' climate change imaginations?

Participants

The participants were students in an environmental science class at a public Title 1 high school in Northern California. There were a total of 48 students split into 12 groups of 3 to 5 students each. Participants self-reported their demographic information (gender: 65% female, 35% male; age: M = 17 years, SD = 0.8; race/ethnicity: 71% White, 12.5% Hispanic/Latinx, 12.5% Asian/American, 2% Native American, 14.5% did not respond).

Data collection

We analyzed participants' pre- and post-intervention stories because they are concrete externalizations of imagination. Individual (n = 43) and Group (n = 12) pre-intervention stories addressed the following prompt: "Picture a person from a group that is at high risk of being negatively impacted by climate change. Write a short story (~300 words) describing who this person is, how they are affected by their situation, and the future world of this person's group 50 years from now." Group (n = 12) post-intervention stories addressed a similar prompt: "Write a story (minimum 2,000 words) depicting the struggle of your protagonist to face a climate justice problem and bring about a desired future 50 years from now." Final stories available here: https://climateimaginaries.com/.

Data analysis

We performed qualitative content analysis (Krippendorff, 2018) to uncover themes related to epistemological and ontological colonization. We used a team-based deductive and inductive coding approach (see Table 1).

Table 1
Codes and descriptions

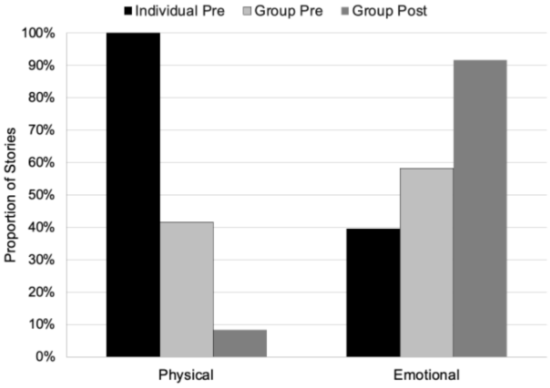
Parent Code	Unit of Analysis	Child Code	Description
Character impacts	Phrase / sentence	Physical	Describes physical impacts of climate change on a character.
		Emotional	Describes emotional impacts of climate change on a character.
Future vision	Story	Continue	Continuation of the status quo.
		Collapse	System degradation or failure.
		Discipline	Behaviors adapt to internal or external limits.
		Transform	Game-changing new models or factors.
Climate justice solutions	Phrase / sentence	Economic	Solutions related to resource management.
		Philosophical	Solutions related to beliefs, attitudes, values, ethics.
		Political	Solutions related to governance, laws, policies.
		Social	Solutions related to behaviors, norms, social institutions.
		Technological	Solutions related to scientific and technological innovation.

Results

The proportions of stories depicting physical or emotional impacts of climate change on characters are plotted in Figure 1. Depiction of physical impacts was common in the pre-intervention stories (42-100%) and decreased significantly in post (8%). As a character in one pre-intervention story states: “When the temperature exceeds 75 degrees…my body reacts in bizarre ways.” Depiction of emotional impacts increased significantly from pre (40-58%) to post (92%). A character in a post-intervention story describes their reaction to being forced away from her family farm due to drought: “I screamed, my world was falling apart, all I have ever known was crumbling in such a short amount of time. I was scared, scared for what’s going to happen to my family, what I’m going to have to do.”

Figure 1

Proportion of stories depicting physical or emotional impacts on characters

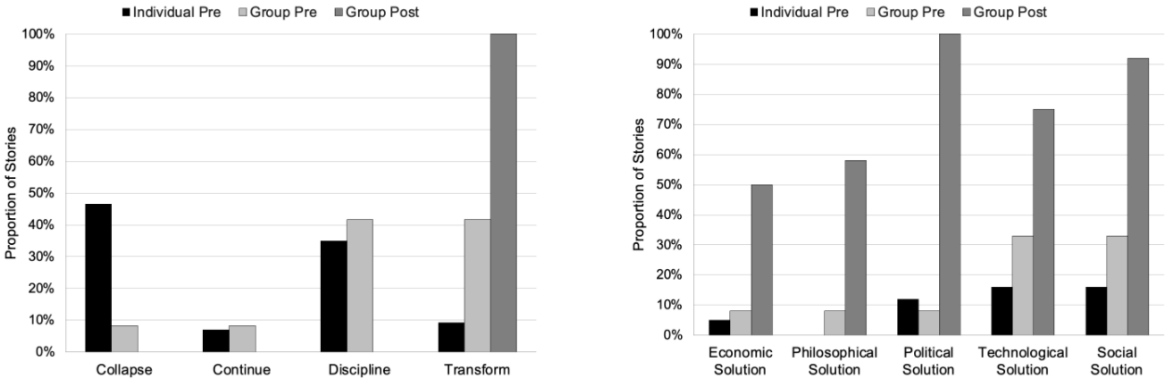


The proportions of stories depicting the various future vision archetypes are plotted in the left-hand side of Figure 2. Individual pre-intervention visions of the future were mostly collapse (47%) and discipline (35%). An example from a collapse story depicts system degradation: “We are left in a world where anyone who cannot afford food simply dies.” An excerpt from a discipline story highlights the need for characters to adapt: “...they would need to find a new environment to live in with less harsh conditions.” The group post-intervention stories were all transform. One narrative describes how: “The people have overpowered the government's will to pump oil for money and went full electric.”

The proportions of stories depicting various climate justice solutions are plotted in the right-hand side of Figure 2. Few pre-intervention stories depicted solutions, and those that did tended to emphasize technological (16-33%) or social (16-33%) solutions. In one pre-intervention story, a character: “...had to adapt to wearing thermal gear that completely protected him from the sun, he looked like an astronaut.” In the group post-intervention stories, there was much greater depiction of climate justice solutions, particularly political solutions (100%). For example, in one post-intervention story: “people took to the streets, all across the nation people were outraged…The capital saw the biggest protest since the beginning of the nation.”

Figure 2

Proportion of stories depicting various future visions (left) and climate justice solutions (right)



Discussion

A large proportion of pre-intervention stories depicted physical mechanisms of climate change impacts on characters, which aligns with the logico-scientific mode of thought (Bruner, 1986). The post-intervention stories primarily centered around emotional impacts of climate change, suggesting that the students demonstrated deeper empathy for the impacted people by imagining their feelings to a greater extent. These results support theoretical arguments that the narrative mode of thought can facilitate emotional immersion into a storyworld and empathy for the characters (Mar & Oatley, 2008), specifically those impacted by climate change (Milkoreit, 2016). Greater emotional connection to climate change may in turn spark greater concern and action (Rousell et al., 2017). This finding suggests that the intervention fostered epistemological decolonization of climate change imagination.

Future visions depicted in the individual pre-intervention stories were mostly collapse or discipline archetypes, which aligns with dominant visions in cli-fi stories (Schneider-Mayerson, 2018) and climate change education (Chawla & Cushing, 2007), while the group post-intervention stories were all transform archetype. Furthermore, most pre-intervention stories lacked details of transitions connecting future visions to the present, which is a common limitation of utopian fiction (Jovchelovitch & Hawlina, 2018). The few solutions depicted in pre-intervention stories were mainly technological, which aligns with dominant Western images of the future (Angheloiu et al., 2020; Jovchelovitch & Hawlina, 2018). In contrast, the group post-intervention stories largely emphasized collective socio-political transformation. These results suggest that the use of worldbuilding techniques that encouraged transformation of multiple dimensions of human culture was successful in mitigating techno-solutionism (Zaidi, 2017). The findings also support the intervention design rationale of engaging participants in "backcasting" and writing "transtopias"—stories depicting transitions between our world and those in fictional futures (Zaidi, 2017). Overall, the learning experience appeared to foster ontological decolonization of climate change imagination, which supports findings from other studies of how writing cli-fi can be an ontological tool for imagining new possible worlds through resistance to the present (Rousell et al., 2017).

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Science and Engineering for What? A Large-Scale Analysis of Students' Projects in Science Fairs

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Abstract: Science and Engineering fairs offer K-12 students opportunities to engage with authentic STEM practices. Particularly, students are given the chance to experience authentic and open inquiry processes, by defining which themes, questions and approaches will guide their scientific endeavors. In this study, we analyzed data from over 5,000 projects presented at a nationwide science fair in Brazil over the past 20 years using topic modeling to identify the main topics that have driven students' inquiry and design. Our analysis identified a broad range of topics being explored, with significant variations over time, region, and school setting. We argue those results and proposed methodology can not only support further research in the context of science fairs, but also inform instruction and design of contexts-specific resources to support students in open inquiry experiences in different settings.

Introduction

Participating in Science and Engineering Fairs (SEFs) provide students with an opportunity to showcase the outcomes of inquiry processes, developing a better understanding of science and an increased interest in STEM fields. (e.g., Grinnell et al., 2020). SEFs also offer students a space for authentic participation in "doing science," by engaging with science and engineering practices, as well as taking a sense of commitment and ownership over their projects (e.g., Koomen et al., 2018). Similarly, SEFs are often used to illustrate how students can experience open inquiry, since they can define themes, questions, and approaches in a continuous decision-making process (Zion & Mendelovici, 2012). In particular, while students are able to bring their passions and interests into the scientific inquiry process (Adler et al., 2018), with limited research on how such agency in problem finding manifests in SEFs (LaBanca, 2012). To help address this gap, we propose the following research questions:

1. What are the main topics students participating in SEF choose to explore in their projects?
2. How do those topics vary in time, school settings, and region where they come from?

In this study, we employed topic modeling, a machine learning technique, to analyze data from over 5,000 projects presented in a nationwide science and engineering fair in Brazil. Our analysis revealed the main themes driving students' investigation and design in their projects, and how they are responsive to their context, illustrating how students' interests manifest in their work. We argue these findings can inform designers and teachers on what kind of resources would be most relevant to support students in open inquiry processes.

Methods

Setting: The Brazilian Science and Engineering Fair (FEBRACE)

FEBRACE is a major outreach program of the Universidade de São Paulo launched in 2003 that annually holds the largest nationwide SEF in Brazil, where students from all states showcase hundreds of projects after being selected from over 2,000 submissions per year. To join FEBRACE, teams up to three students from public and private schools submit their projects for evaluation by a jury or are selected by one of the associated regional fairs. The submission materials include a paper/report and a five-minute video presenting their project. Selected students present their project in a synchronous event and undergo a further round of evaluation and feedback. FEBRACE publishes information about the projects selected (e.g., title, authors, institution, abstract and keywords) in annual proceedings available on their website. Outstanding projects are then selected for the International Science and Engineering Fair (ISEF), to which FEBRACE is affiliated.

Data collection and analysis

In this study, we collected information from 5,296 projects accepted and presented at FEBRACE, from 2003 to 2022. Information of each projected included title, keywords, abstract, year presented, school setting, and state/region of origin. FEBRACE proceedings were the main data sources for the dataset (additional information was provided by the organizing committee), which is available upon request.

We used topic modeling to identify major topics among students' projects. Topic modeling is a statistical model that consists in extracting topical patterns within a collection of documents (Egger & Yu, 2022). It has been widely applied to educational research, such as identifying the relationship between the topic relevance of pre-service teachers' journals and their grades (Chen et al., 2016), and identifying major topic from students' essay to support the design of culturally adaptive learning experiences (Coelho & McCollum, 2021).

More specifically, we used the BERTopic (Grootendorst, 2022), which is a deep learning-based model that takes a set of documents, clusters it into topics, and generates representative words for each topic. Before using the BERTopic, we employed text pre-processing techniques, namely *Stopword Removal* (cutting non-significant parts of the vocabulary) and *Lemmatization* (converting nouns and adjectives to their masculine and singular form, and verbs to their infinitive form) (Ferraz et al., 2021).

Two automatic metrics guided the BERTopic: *coherence* (measures an average of the degree of semantic similarity between the words that represent each topic) and *diversity* (measures the percentage of unique words that represents the topics, which means how varied the whole set of topics is) (Dieng et al., 2020). BERTopic managed to assign 58% of the projects in 72 topics with at least 10 projects, which is a reasonable performance given the challenges of automatic categorization (Alcoforado et al., 2022). We manually proposed shorter terms based on the representative words of each topic and reviewed them with external professionals from the FEBRACE organizing committee.

We compared the distribution of topics across three variables: year (grouped into 4-year intervals), region (corresponding to Brazil's 5 macro regions) and school setting (categorized as public or private, which were the most prevalent in our sample). We used the Chi-square statistical test of independence to determine if there were statistically significant differences between groups for each variable. Finally, we identified topics with the highest values of dispersion and described top-5 lists for each variable to expand the findings from the statistical test.

Findings

Using topic modeling, we classified 3,087 projects from our sample into 72 topics (42.9 projects per topic, SD=36.9). Topic coherence was 0.62, which aligns with typical results in the literature (Röder et al., 2015), and topic diversity was 0.72, indicating that the topics are distinguishable from each other (Dieng et al., 2020). Figure 1 shows the distribution of projects across the topics, with the top 10 topics (colored in yellow) containing 1,188 or 38.5% of the projects, while the bottom half of topics (colored in dark gray, each with 30 or fewer projects) represent 765 or 24.8% of the projects. A complete list of topics is available at bit.ly/isls-2023-sef-topics.

Figure 1

Number of occurrences for each topic identified in the model, together with a general top-10 list of topics.

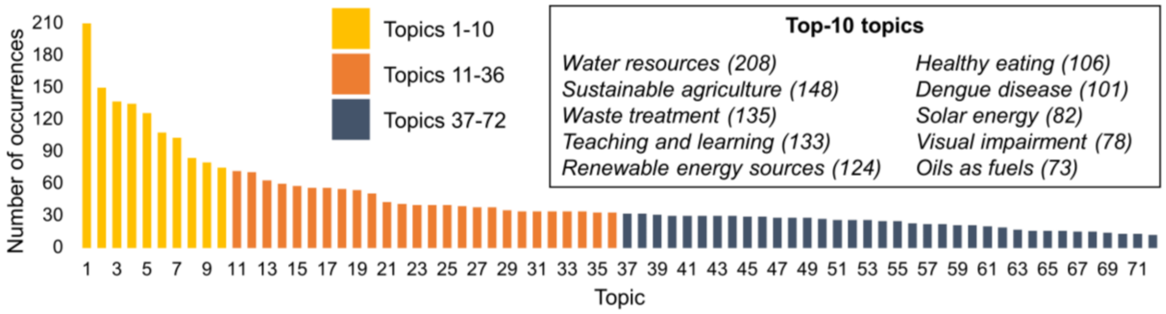

Table 1 presents results from the Chi-square Test of Independence on the topics across three variables: *year* (grouped in 5 four-year ranges, from 2003-2006 to 2019-2022), *region* (corresponding to Brazil's 5 macro regions), and *school setting* (public or private schools). Degrees of freedom (DoF) were adjusted for variables with 5 categories due to the requirement of at least 5 projects in each category, resulting in fewer topics (N_topics). Despite this, p-values ($p<0.05$) and strength of association ($0.1<\omega< 0.3$) indicated the difference between groups are statistically significant with a small relationship between topic proportion and each variable, respectively.

Table 1

Results for the Chi-square Test of Independence with three different variables

Variable	Categories	Dof	N_topics	Chi-square	P-value	Cohen's omega (ω)
year	5	60	16	97.3	0.0017	0.255
region	5	36	10	55.6	0.0195	0.216
school setting	2	42	43	81.0	0.0003	0.179

In addition, we identified the 5 most frequent topics for each variable in their respective categories to help illustrate the relationship between topics and variables. Due to space constraints, we only present the results for the “year” (Table 2) and “region” (Table 3) variables; we used a color scheme to help identify the “intruders”, i.e., topics present only in one or two intervals.

Table 2
Top-5 topics for each year-interval explored in the study.

Rank	2003-2006	2007-2010	2011-2014	2015-2018	2019-2022
#1	Water resources	Water resources	Waste treatment	Water resources	Sustainable agriculture
#2	Robotics	Sustainable agriculture	Water resources	Waste treatment	Teaching and learning
#3	Renewable energy sources	Renewable energy sources	Dengue disease	Sustainable agriculture	Water resources
#4	Teaching and learning	Heritage languages	Sustainable agriculture	Dengue disease	Covid-19
#5	Oils as fuels	Learning of sustainability	Teaching and learning	Renewable energy sources	Healthy eating

Table 3
Top-5 topics for each region explored in the study.

Rank	Southeast	Northeast	South	Central West	North
#1	Water resources	Water resources	Sustainable agriculture	Sustainable agriculture	Water resources
#2	Sustainable agriculture	Dengue disease	Waste treatment	Renewable energy sources	Waste treatment
#3	Teaching and learning	Waste treatment	Teaching and learning	Water resources	Sustainable agriculture
#4	Renewable energy sources	Teaching and learning	Water resources	Waste treatment	Teaching and learning
#5	Visual impairment	Sustainable agriculture	Renewable energy sources	Dengue disease	Traffic accidents

Some "intruders" in Table 2 demonstrate how topics are influenced by the year in which projects were designed. For example, "dengue disease" is the seventh most common topic among all projects but became significantly more frequent in the 2010s due to an increase in cases in Brazil (Nunes et al., 2019). "Covid-19", which became relevant globally, was the fourth most common topic in 2019-2022. Similarly, in Table 3, "dengue disease", is more relevant to students from two regions (Northeast and Central West), which historically have had the highest incidence *per capita* of the disease (Catão & Guimarães, 2011).

Discussion and future work

Our findings illustrate the diverse range of topics that students have explored in their science and engineering projects at FEBRACE (RQ1). Some of the most frequent topics relate to environmental studies (e.g., “water resources”, “sustainable agriculture”, “renewable energy sources”) and indicate some responsiveness to the Brazil’s natural resources and economy; at the same time, they support a more traditional view of scientific inquiry, associated to the Natural Sciences. On the other hand, the list of topics also provides examples from the Social Sciences, such as “teaching and learning”, violence against women” and “heritage languages”. Further in-depth analysis of sample projects focusing on specific topics can provide valuable insights into their relevance and potential impact on students' understanding of science inquiry and the broader scientific field. In addition, the results from statistical tests suggest the topics identified in this study are responsive to their context (RQ2), supporting their description as open inquiry processes (LaBlanca, 2012). Including additional variables, such as city size and HDI, together with the analysis of actual projects from those topics can provide a more nuanced understanding of the relationship between context and scientific inquiry.

This study has limitations stemming from the data sources used. The topic modeling analysis was based solely on projects presented at FEBRACE, as they are publicly available. Including data from all submissions could have led to different results but would still have been limited in terms of representativeness, as we cannot affirm students have equal access to the fair. Additionally, the list of topics is specific to the context of this study and may vary in other contexts. Rather than generalizing our results to any SEFs, we propose that our methodology can support the design of similar studies in different SEFs and open inquiry processes, both within and beyond Brazil. Most importantly, those findings point to the opportunity of providing students with adequate resources to support their inquiry. Open inquiry processes can be mistakenly perceived as independent of teacher guidance and support, whereas teachers play an important role in scaffolding students' inquiry (e.g., Hmelo-Silver et al., 2007). That means, for example, making sure students have access to resources that will enable their inquiry (Zion & Mendelovici, 2012), taking into account context-specific opportunities and constraints. Our results can thus inform both instruction and the design of meaningful resources that support teachers and students' inquiry not only in SEF projects, but in general open inquiry experiences.

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Designing for Feelings: Disruptive Beginnings in Youths' Designs of Mixed Reality Activities for Sustainability

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Abstract: Dominant approaches to increasing environmental sustainability emphasize anthropocentric, technocentric solutions and definitions of progress, often failing to recognize humans' entanglement with the rest of the world. This study explores how youth conceptualized sustainability when they were positioned as designers of mixed reality activities about environmental issues for younger students. Specifically, we analyze the emotional configurations (Vea, 2020) youth designed for and explore how their designs reached toward posthumanist approaches to science education for sustainability (Jeong et al., 2021).

Introduction

Our current environmental precarity generates several pressing needs for education to foster more sustainable human-nature relations. First, to counter the burden of environmental anxiety that people, particularly youth, feel, we need *forms* of participation that will build hope and agency (Ojala, 2012) and fuel continued participation rather than despair and apathy. Second, to sustain reciprocal rather than exploitative human-nature relations, we need to shift away from didactic science instruction *about* the natural world, which objectifies nonhuman beings, upholds human supremacy, and backgrounds sociocultural and ethical issues behind the veil of objectivity (Gilbert, 2016); toward a recognition of humans' entanglement *with* the natural world (Jeong et al., 2021). And third, recognizing the undue burden on youth to 'fix' environmental problems that they did not create and power hierarchies that often strip youth of environmental agency (Kouppanou, 2020), we need to center youth voices as we fashion collective actions that can express new human-nature relations. New representational media such as mixed reality (MR) offer opportunities to engage in alternate realities and develop new orientations toward action, but their promise to support collective action for environmental good is still unknown. Thus, we asked: *When given the opportunity to design MR learning experiences about environmental sustainability, how do students conceptualize sustainability and their role within it?* In this paper we share findings from a workshop in which 9th graders designed MR activities for middle schoolers on a topic that the 9th graders chose: sustainability.

Design rationale and analytic framework

Participatory simulations have enabled learners to explore the impact of individual (agent-based) actions on the behavior of social-biological systems (Kumar & Tissenbaum, 2019), and contributed to students' empathy toward nonhuman beings and disruption of human-centric relations with nature (Jen et al., 2021). In this study we leveraged MR technologies to facilitate perspective taking to create space for youth to explore relational understandings of and disrupt the anthropocentrism that pervades typical science classrooms. Moreover, we positioned youth as designers of participatory simulations for younger learners which pressed them to elucidate their understandings of sustainability phenomena for others. Our prior experiences with students' emotional engagement in participatory simulations (Jen et al., 2021), recognition of feelings as inherent in science (Pierson et al., in revision; Jaber & Hammer, 2016), and desire to position youth as change agents, led us to center three guiding questions throughout youths' design process: *How do you want participants to feel? What do you want them to think about? How do you want them to act or change their behavior?* When analyzing students' design responses, we realized these questions aligned with Vea's (2020) concept of *emotional configurations,* which refer to interrelationships between emotions, sense-making, and practice in social activity. More specifically, we saw his concept of *guided emotion participation* as one way that youth designed to cultivate emotional configurations for others. Their designs and design process suggest potential *generative* and *exploratory* roles that activities might play in *identifying* emotional configurations, which could complement the *normative* role of guided emotional participation in producing participant alignment to a *fixed* configuration.

We saw students' nascent articulations of emotional configurations as reaching toward an image of social-ecological relations that could move beyond anthropocentrism. Though they had no explicit guidance in this respect, we saw alignment with Jeong and colleagues' (2021) *posthumanist* framework intended to guide science education towards cultivating more sustainable human-nature relationships. Their emphasis on favoring relational rather than humanist ethics, balance instead of progress, and entanglements over "neutral" objectivism aligned with students' emergent conceptualizations about sustainability learning.

Context & methods

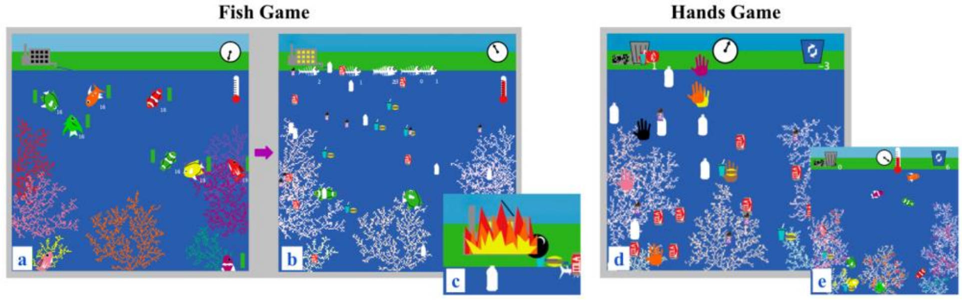
Our data come from a six-session workshop in a STEM program that is a joint venture between a private university and an urban public school district in a southeastern U.S. city. The four-year program brings a racially and economically diverse cohort of high school students to the university one day per week throughout their high school career to engage in research-centered science learning. All of the 9th graders (28) participated in our workshop, working in groups to design and then facilitate sustainability-themed MR activities for middle school participants in another university program. Each author guided one group of students throughout the workshop; this paper focuses on Jen's group. Each of the six sessions lasted 1.5–3 hours. (For session details, see Brady et al., 2022.) Since design, rather than programming, was the focus of the workshop, the research team converted groups' designs into MR using NetLogo (Wilensky, 1999) and a NetLogo language extension (Brady, 2022). This paired NetLogo's visualization capacity with a tag-based tracking technology called Pozyx, which enabled participants' movements around the room to control digital agents in a projected NetLogo model (Figure 1).

Figure 1
The MR environment

While we were initially interested in differences between groups' approaches to design (see Brady et al., 2022), the complexity of each group's work led us to narrow our focus to Jen's group of seven students, because of the nuanced ways they took up guidance to design for participants to feel, think, and act. Jen content logged all video recordings of her group, then transcribed select episodes to explore students' conceptions of sustainability in their initial brainstorming and later reflections on the workshop, as well as the motivation behind their designs and their facilitation with middle school students. Interaction analysis (Jordan & Henderson, 1995) of students' brainstorming led to a focus on students' ideas about agency (who does or doesn't have it) and the emotional configurations at play in their designs and design process. This led Jen to code transcripts from focal episodes as well as students' written reflections with a priori codes informed by emotional configurations (Vea, 2020) and posthumanist science education (Jeong et al., 2021). She reviewed coded excerpts to synthesize understandings of students' conceptions of sustainability and refined these findings through conversations with the other authors.

Findings

Figure 2
Students' MR activities



The focal group designed activities that highlighted impacts of pollution and climate change on ocean ecosystems (Figure 2). They created two games: Fish Game and Hands Game. In Fish Game, participants played as fish trying to survive in a coral reef ecosystem by eating coral (Figure 2a). After ten seconds, a factory turned on and polluted the water with a steady stream of trash, on which fish got caught. The factory also polluted the air (gradually darkening the sky) and emitted greenhouse gases, which raised the temperature of the water (represented by a thermometer). This in turn caused the coral to bleach. It became nearly impossible for fish to survive, so most of the fish died (see fish skeletons in Figure 2b). After Fish Game, the students facilitated a discussion about what happened, how it felt, and what should change, and then played an animation where a wrecking ball destroyed the factory (Figure 2c). Then, in Hands Game, participants played as hands to clean up the ecosystem, picking up trash and sorting it into trash and recycling bins (Figure 2d). Finally, a second animation showed the temperature gradually decreasing, coral regrowing, and fish eventually returning to the ecosystem (Figure 2e).

In brainstorming Fish Game, students developed a core idea of having participants feel and make sense of human impacts from the perspective of a different species. For example, one student shared, “I feel like I would want them to think like about being in… the shoes of the life in the ecosystem. And like seeing, like thinking about that and then seeing the effects [of changes to the ecosystem].” As students grappled with design specifications, such as how much trash the factory should emit, they emphasized making the game feel “overwhelming,” and spurring participants to feel “upset” and “regret for knowing humans contribute to the problem.” Students thus designed for an emotional configuration that linked feelings of stress, anger, and regret to the practice of polluting, and sense-making about the accumulative impact of pollution.

Students’ emphasis on feeling as and for fish demonstrates an expansive ethics of the sort Jeong and colleagues (2021) advocate, recognizing fish as worthy of care. By centering fish’s perspectives, students also decentered humans. Furthermore, they centered entanglement (Jeong et al., 2021) in their facilitation of Fish Game. Though they did not incorporate how humans were affected by the interactions in their game, they touched on this while facilitating a debrief with middle school participants, framing humans as entwined in a larger system. They asked how the death of fish indirectly affected humans and a participant shared how people rely on fish and the ocean for food, concluding, “Basically if you destroy it [the ocean] you’re also kind of destroying yourself.”

At first glance, students’ Hands Game may seem to forward an anthropocentric narrative of humans as saviors. However, the arc of their entire activity sequence, and the emotional configuration they designed for complicates this assumption. While leading a debrief of the two games with middle school students, Uma, described, “I feel like they’re like two contrasts almost like, it like really, makes you think about, wow what are these humans doing to the Earth? And it like makes you think about what you can do to fix it.” Uma’s distinction between “these humans” and “you” distances her from polluting industries and aligns her and her peers with those working to ameliorate environmental degradation. Notably, this frames Fish Game as a critique of capitalist industries. While youth’s ability to ‘fix’ the economic and political systems that cause environmental degradation is limited in the real world, within the imagined space of MR, youth can tear these systems down. The wrecking ball that concludes Fish Game does just this and seems to signify a transition from a scenario modeling the real world to an imagined alternative. In this context, Hands Game can be interpreted as a speculative design of an alternate future, where the factory’s absence enables collective, restorative action. Importantly, rather than a linear narrative of cleaning up the trash to solve the pollution problem, students discussed Hands Game in terms of a *cyclical* relationship between practice, feeling, and sense-making. Xavier reflected, “When [participants] help clean up and see all the good effects they feel excited to help make a difference. We want our audience to think about if someone individually can really make a difference.” He described an interrelationship between the practice of cleaning up, a feeling of excitement, and sense-making about the cumulative impact of individual positive actions. He and his peers saw this emotional configuration as impetus for further environmental practices, and they were adamant about *not* representing a full return to a pre-pollution state. For example, they said coral ought to regrow *on top of* the bleached coral rather than *replace* the bleached coral in the final animation (Figure 2e). Xavier explained, “that shows like this is still here, this is still a problem. You didn’t fix everything. Instead of, ‘Oh it’s all gone, it’s all better now,’ cause once you pollute, it’s not gonna be all better again.” Retaining representations of pollution, students did not simply view humans as saviors. Furthermore, rather than the linear logic that is traditionally emphasized in science education, the emotional configuration students designed for in Hands Game represents a virtuous cycle towards a more harmonious ecosystem (Jeong et al., 2021).

At another level, the sequence of activities students designed suggests the emotional configurations that stabilized for the youth *designers*. A student in one of the other groups reflected, “I always felt like there was pressure towards people our age to fix environmental problems and face the consequences of human activity… I wanted [participants] to not feel this huge amount of pressure… to show them that they aren’t alone.” The weight of environmental problems, frustration with inheriting them, and desire to feel a sense of community was evident in the focal group’s work as well. This feeling was entwined in their representation of negative human impact as a polluting factory, which served as an indictment of power-holding older generations. The practice of designing thus served as a release of their frustration, however it also offered a way to make sense of their agency to sustain Earth and to counter negative emotions with a sense of hope. Students stressed the importance of awareness in efforts toward sustainability. For example, Kareem explained that their activity would make “participants feel surprised for how small impacts can build up to a larger problem… because I don’t believe they have realized visually what impacts that pollution leads to… participants will maybe even be determined to pick up after themselves if they already don’t and even after others that leave their trash behind.” They viewed awareness as potentially spreading beyond their middle school audience as that audience could share with others, who might share with others, and so on and so forth. The importance of working together also came up in their reflections on the process of design. For example, Niles reflected, “Working alone is not easy and having the support and contribution of others can be a great thing.” Thus mirroring the emotional configuration they designed for in Hands Game, the practice of working together to spread awareness was linked to feelings of fellowship and hope, and to a notion of individual actions accumulating to make a difference. In summary, collectively designing for a hopeful emotional configuration generated a hopeful emotional configuration.

Conclusion

Designing for MR encouraged students to consider the interconnections between different elements in a system and to view the system from a nonhuman perspective. In combination with a focus on emotions, it allowed them to gain a felt embodied sense of environmental degradation. It also created opportunities to imagine alternative futures, which in turn created space for hope. Given the importance of cultivating hope to counteract youth’s anxiety around environmental issues (Ojala, 2012), the significance of this should not be understated. Moreover, our study also suggests that designing MR activities for younger peers may offer a compelling setting for exploring and recognizing the importance of emotional configurations. If so, it would offer a *generative* activity structure for *constructing* new emotional configurations, thus complementing the *normative* activity structure of guided emotion participation (Vea, 2020), which aims to *disseminate* existing emotional configurations.

On the other hand, we do not want to overstate the outcomes of the workshop. Undoubtedly, aspects of students’ designs and interactions throughout the workshop demonstrated posthumanist notions of sustainability (Jeong et al., 2021), extending care to nonhuman beings, decentering humans, centering entanglement, and forefronting cycles towards harmony over linear progress. However, notions of human control over nature were also persistent throughout the workshop. So, we do not mean to suggest that the posthumanist conceptions that emerged were necessarily enduring. Nonetheless, the construction of emotional configurations seems to have spurred disruptive beginnings towards recognizing human entanglement with the rest of the world.

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Developing Teachers' Contingent Responsiveness in Science Discussions With Mixed-Reality Simulation: A Design-Based Study

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Abstract: Orchestrating productive science discussions is challenging for teachers. Little is known about how to support teachers to develop contingent responsiveness (CR), the adaptive expertise in responding to student ideas in the moment to improve the collective dialogue. Using a design-based research method, a professional development (PD) programme that incorporates mixed-reality simulation (Mursion) was co-designed remotely by researchers and practitioners in Pakistan during the pandemic over four iterations. This study found that the PD is effective in supporting teachers to develop CR, which was evident in the shift of teachers' response patterns shown by epistemic network analysis (ENA). Furthermore, conjecture mapping shed light on how the PD works and how teachers learn. It was found that 1) adopting dialogic framings, 2) developing fluency with talk moves, 3) deploying flexible attention, 4) engaging in knowledge-based reasoning, and 5) experiencing metaphoric resonance could lead to CR.

Introduction

The role of talk in science education has long been established – an essential part of learning science is for students to learn to engage in scientific discourse (Lemke, 1990). There is increasing empirical evidence for the role of talk in student learning, including evidence from large-scale randomised control trials (Alexander, 2018; Howe et al., 2019). Nonetheless, productive talk is still rare in the classroom. The rarity of productive talk can be partly attributed to the complexity of dialogic teaching. So far, little is known about how teachers manage the demanding work of moment-to-moment interaction and decision-making in classroom and how to prepare teachers for such a challenge (Lefstein, 2008; Sedova et al., 2014). This study attempted to shed light on how we could support teachers to think and act in the moment and respond to student ideas during science discussions.

What is contingent responsiveness (CR)?

Studies have found that the teacher's response in classroom discourse, plays a vital role in determining opportunities for student sense-making and the quality of classroom discourse (Park et al., 2017). For example, Boyd and Rubin (2006) found that the contingency of teachers' questions mattered more than the nature of the question itself (e.g., open or closed) in terms of extending student talk. However, most of the classroom discourse is characterised by the IRE (Initiation-Response-Evaluation) or IRF (Initiation -Response-Feedback) patterns (Mehan, 1979; Park et al., 2017; Sinclair & Coulthard, 1975) Usually teacher initiate a question, which is responded by student's reponse, followed by teacher's evaluation or feedback. The IRE/IRF pattern of discourse is highly controlled by teachers and limit students' opportunities to engage in sense-making (Howe et al., 2019). In this study, *contingent responsiveness* (CR) is defined as a teacher's adaptive expertise in responding to the dynamic flow of student talk in the moment, with the goal to improve the collective dialogue.

Operationalization of contingent responsiveness

Previous research often focus on the *form* of the teacher's talk rather than its *function* in the dialogue (e.g., Jacobs & Empson, 2016). For instance, often researchers define responsiveness in advance and look for it in teachers' discourse using a predetermined observational rubric (e.g., Lineback, 2015; Pierson, 2008). Indicators of responsiveness include the use of talk moves, such as eliciting a student's ideas and pressing students to elaborate. Boyd and Markarian (2011) noticed that talk could appear dialogic in form, but not dialogic in spirit. O'Connor and Michaels (2019) also found that sometimes talk moves were used in a robotic and perfunctory manner without necessarily advancing the discussion and student thinking. Thus, a teacher's moves should not be predetermined, but rather selected and invented in response to the situation at hand (Chazan & Ball, 1999).

Shifting away from decontextualised indicators of responsiveness, we draw on Bakhtin's (1986) dialogism and view dialogue as relation of voices rather than a tool of mediation (Wegerif, 2008). This shift implies an ontological change from seeing student ideas as individual "things" to mediate to seeing them in relation with each other. Engaging with others in dialogue thus means to de-identify from the individual ideas and instead identify with the whole dialogue to improve the collective dialogue. Wegerif (2010, p. 66) used the metaphor of a space to convey dialogism. Class discussion thus can be conceptualised as a dialogic space where different lived experiences, perspectives, and ways of knowing and understanding are not only acknowledged and respected, but also resonate, merge, clash, to generate new ideas and perspectives. From a dialogic perspective, teacher's role is not to mediate various student ideas, but rather to facilitate the collective dialogue, i.e., to widen, deepen, maintain, or shape the dialogic space.

This operationalisation of CR emphasises the role that the teacher's response plays in the discussion rather than the form of talk. *Widening* dialogic space is defined as increasing the degree of difference between perspectives in dialogue (Wegerif, 2010). In a classroom, the widening of a dialogic space can be enacted by soliciting different student ideas, encouraging students to elaborate, introducing new ideas, embracing a diversity of intellectual resources and multiple ways of knowing, and incorporating students' language and experience into the classroom discourse. *Deepening* was defined as increasing the degree of reflection on assumptions and grounds (Wegerif, 2010). The deepening of a dialogic space in a science classroom often looks like moving from surface observation to underpinning features of the phenomenon, examining evidence, constructing scientific reasoning, questioning the ontological and epistemological assumptions. *Maintaining* is to signal the ongoing nature of dialogic space. In contrast to the conventional practice of wrapping up a lesson or a unit neatly and reaching a conclusion or agreement, dialogic education reveals the messiness and ongoing nature of learning and thinking. Finally, *shaping* a dialogic space is to make visible the expectations and ground rules of the particular kind of dialogue that students engage in and practice of a discipline according to the standard of the community and the disciplinary ways to share their thinking.

Research questions

The goal of this study is to design a professional development programme (PD) that allows teachers to develop CR . The research questions are formulated as the following:

1. To what extent were teachers contingently responsive to students before and after the PD?
2. What are the mechanisms that support teachers in developing contingent responsiveness?

Methodology

This study used a design-based research method to answer both whether the PD works and to understand how it works. Researchers co-designed a PD programme remotely with practitioners in a democratic school in Pakistan during the pandemic. Thirteen teachers initially participated in this study. Four teacher coordinators participated in the co-design and refinement of the workshops throughout four iterations. The PD programme had two components: 1) Four collaborative workshops, where teachers engaged in collaborative and guided inquiry (i.e., asynchronous interactive learning module), collective reflections to develop a conceptual understanding of dialogic science teaching; 2) Four simulation sessions, in which teachers put into practice their learning from the workshops by orchestrating a science discussion in a virtual classroom with avatar students (controlled by a simulation specialist behind the scene), just as a pilot learns to fly a plane in a simulator.

Data sources and analysis

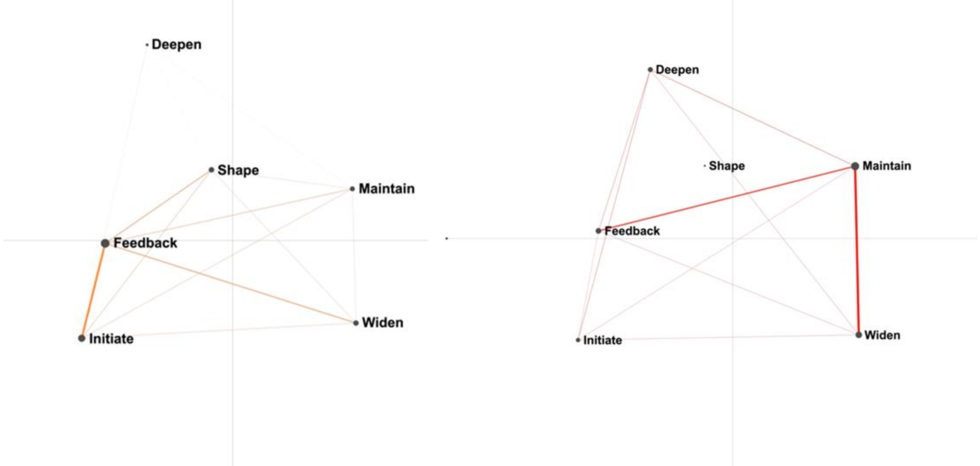
Teachers were asked to record their science classroom discussion for approximately 20 minutes both before and after the PD. There was no specific framing or topic given to teachers. The open-ended nature of the task allowed researchers to capture teachers' practice in an authentic manner when in-person observation was not possible. Thirteen teachers initially participated in the study, but due to pandemic-related attrition and administrative reshuffling at the school level, seven teachers left the school, and four teachers participated in all four iterations. Three teachers provided both pre- and post-PD video recordings of their real-world classroom discussions, which the analysis was based. To measure the extent to which teachers were contingently responsive to students before and after the PD, teachers' pre- and post- PD classroom discussion recordings were transcribed, systematically coded using the dialogic function coding scheme developed for the purpose of this study, and analysed using epistemic network analysis (ENA). An ethnographic method for quantifying, visualising, and interpreting thematic connections across datasets (Shaffer et al., 2016). To understand how the PD works, Sandoval's (2014) conjecture mapping was used. The relations between each mediating process to CR (theoretical conjectures) and the connections to design features (design conjectures) were established based on empirical observation from a variety of data sources, such as video recordings of the simulation session, retrospective interviews, artefacts teachers produced during the workshop, (e.g., note catcher, collective reflections), post-workshop feedback, and post-simulation feedback, and teacher reflections during the simulation. 10% of the dataset was randomly selected and coded by two researchers independently for inter-rater reliability check, which reached substantial or near-perfect agreements.

Findings

RQ1: Assessing changes in teachers' response pattern

ENA showed a significant difference in the response patterns of the three teachers before and after the PD, both visually and statistically. Due to the length of this paper, one teacher's data was presented in Figure 1 as an example. Before the PD, Minahil's classroom discourse was primarily monologic, characterised by IRE/IRF, evident in her response pattern, with the strongest connection being between initiate and feedback (M=0.23). There was also a relatively strong connection between widen and feedback (M=0.13). Minahil's post-PD discussion took place after a field trip, during which students visited a local lake and observed the pollution in the lake. Her post -PD response showed the strongest connections between maintain-widen (M=0.46), and relatively strong connections between maintain-feedback (0.17), shifting towards a more dialogic pattern to improve the collective dialogue.

Figure 1
Minahil's response pattern before the PD (left), after the PD (right)



RQ2: Unpacking the mechanism of the PD

Due to the limited space in this paper, we focused on the emergence of the mediating processes. As a result, we did not elaborate on the relationship between mediating processes and design features (i.e., design conjecture) and or the outcome (i.e., theoretical conjecture). **Adopting dialogic framings:** Teachers shifted from a monologic framing (e.g., interactive lecture) before the PD to dialogic framings of science discussions (e.g., consolidation discussion) after the PD. These findings provided further evidence to support the coherence between framing and response (e.g., Richards et al., 2020; Russ & Luna, 2013), i.e., the teacher's response is coherent with their framings of the situation. Such findings highlight the importance of supporting teachers to recognise their own framings and adopt a variety of dialogic framings in fostering CR. **Developing fluency with talk moves:** Teachers demonstrated fluency with talk moves over time (Michaels & O'Connor, 2012), evident in their increased use of productive talk moves – both in frequency and diversity – in the simulations and pre- and post-PD discussions. **Deploying flexible attention:** All three teachers demonstrated an increase in the frequency of noticing and the diversity of what they noticed in the classroom. What was noticed by teachers include classroom climate, pedagogy, student characteristics, student lived experience, and classroom equity (Luna & Sherin, 2017; Thompson et al., 2016). Overall, the findings suggest that the teachers' attention were flexible and able to encompass a broad range of important features in a multifaceted classroom. **Engaging in knowledge-based reasoning** (van Es & Sherin, 2002): How teachers interpret what they notice is defined by van Es and Sherin as (2002, p. 573) as a form of knowledge-based reasoning: 1) Use one's knowledge and experiences to make sense of what is observed; 2) Make connections between what is noticed and broader principles of teaching and learning. All three teachers demonstrated an increase in the frequency of knowledge-based reasoning during the post-PD interview and diversity of knowledge they deployed, especially in their knowledge about students and pedagogical knowledge. **Experiencing metaphoric resonance**: Metaphoric resonance concerns the recognition of structural resemblances that lead to analogical thinking and reasoning (Mason & Davis, 2013). According to Mason (2002), elements in the structure of the current situation can resonate with a metaphor or structure of previous experience, bringing associated thoughts and awareness to mind. Teachers' experience of metaphoric resonance is evident in their retrospective accounts of their thinking in the moment during the post-PD interview. Metaphoric resonance supported teachers to recognise alternative possibilities in the moment, leading them to diverge from their usual discourse pattern to take up a more dialogic response.

Conclusion

This study illustrated the affordances of a DBR approach to simultaneously produce usable knowledge for practice and advance learning theory. This study also showed the affordance of DBR to move beyond testing 'what works', and understand 'how it works', enhancing the adaptability, sustainability, and potential of scalability of the PD programme. This work highlighted the importance of co-designing with practitioners and leveraging their ground-level wisdom, opening a dialogic space for the emergence of new ideas. It is important to highlight that the result about the effectiveness of the PD in this study is limited by its small sample size in a specific context and thus not immediately generalisable. However, the mechanisms underlying the PD and promising learning pathways were identified, which could be studied, tested, and refined in other educational and cultural contexts. Because traveling was restricted during the pandemic, findings in this study were based on one pre-PD and one post-PD discussion from each teacher. Nonetheless, teachers' consistent tendency towards dialogic practice in the simulations provided some evidence for the sustainability of change. Future studies should therefore further develop and test this preliminary theory of CR in other educational settings and cultural contexts.

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“I Will Be Your Informant”: Observing Young People’s Emergent Critical Platform Literacy Development

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Abstract: Platforms mediate much of modern life. To assist young people in making sense of platforms’ power, researchers have shared different literacy frameworks. In this paper, we build on existing frameworks to outline critical platform literacy. We observe how young people practiced critical platform literacy through engaging platforms’ political-economic model of data capitalism and platforms’ technical surveillance capabilities. Practicing critical platform literacy by making platforms’ visible and hidden dimensions more transparent provides youth with one more way of understanding and responding to platforms’ increasing–and often harmful–influence.

Introduction

Platforms pose a threat to our collective and individual well-being. Through their gathering and use of personal data, platforms entrench historical inequalities, further concentrating power in the hands of a few to the detriment of the many. Responding to platforms’ power is thus increasingly essential.

Platforms are both the hardware and software infrastructures upon which applications are constructed as well as digital spaces where people socialize and conduct economic exchange (Nichols et al., 2022). The urgency to better attend to platforms occurs at a time when education scholars continue to share literacy frameworks, such as critical computational literacy (Lee & Soep, 2016) and personal data literacies (Selwyn & Pangrazio, 2019), as means for helping youth make sense of technology’s potential harms. With so much of modern life mediated by platforms, a pressing need exists for deeper theorizing on the attributes of a literacy framework that specifically engages platforms and their multiple dimensions.

In this paper, we examine how three participants in the Young People’s Race, Power, and Technology Project (YPRPT) demonstrated their emergent critical platform literacy (CPL). YPRPT is a National Science Foundation-funded, out-of-school initiative in a Midwestern metro area in the United States of America that provides a research-based curriculum for high school-aged youth to explore, critique, and reimagine technology. We present evidence of the ways three youth responded to platforms’ political-economic business model of data capitalism, an “economic model built on the extraction and commodification of data and the use of big data and algorithms as tools to concentrate and consolidate power” (Milner & Traub, 2021, p. 4), as well as platforms’ technical surveillance capabilities.

We begin our paper with a genealogy of CPL. We then elaborate our theoretical framework, describe our methods, and share preliminary findings. We argue that observing how young people engage with platforms’ dimensions nuances our understanding of how youth practice CPL and points to potential ways to support their CPL development. We end our paper with future research suggestions.

Literature review

We assemble critical platform literacy from critical literacy, digital literacies, critical digital literacy, and hacker literacies.

We use critical literacy in the tradition of Freire and Macedo (1987), with an emphasis on analyzing the ways power operates through words and in the world. Developing a CPL means engaging visible texts posted on a platform and invisible technical and political-economic systems undergirding platforms’ social functions.

Because platforms include digital spaces, we draw upon digital literacies when constructing CPL. Scholars examine digital literacies in the plural, highlighting social aspects of using technology to connect with others and produce content (Ito et al., 2013). Nichols and Stornaiuolo (2019) advocate for an approach to digital literacies that focuses explicitly on sociotechnical and socioeconomic concerns. We take up these ethical and political dimensions as part of CPL.

Critical digital literacy merges critical literacy’s critique of power with digital literacies’ interest in how people consume and produce media (Ávila & Pandya, 2013). Recently, critical digital literacy scholars have emphasized the need for students to analyze the ways technology is encoded with its creators’ biases (Bacalja et al., 2022). However, conventional critical digital literacy practices may be insufficient for examining platforms’ complexities (Nichols & LeBlanc, 2021). For instance, critical digital literacy practices concentrate on representational forms, yet a technology company’s black box algorithm defies representation.

Finally, CPL grows from hacker literacies. Rooted in critical mindsets, hacker literacies are "empowered participatory practices…that aim to resist, reconfigure, and/or reformulate the sociotechnical digital spaces and tools that mediate social, cultural, and political participation" (Santo, 2013, p. 21). CPL shares hacker literacies' emphasis on empowering young people by making platforms' dimensions more transparent in order to understand and respond to platforms' effects on individuals and societies.

Theoretical framework

We use *critical platform literacy* to denote a singular focus on platforms, while still acknowledging the lingering limitations of a traditional literacy framework for analyzing platforms. We view CPL practices as building upon a platform orientation to critical digital literacy (Nichols et al. 2022) and embedded in a stance of civic media ecology (Nichols & LeBlanc, 2021). If platforms are complex ecologies, then CPL practices are the tools used to navigate and map those ecologies while also charting new courses. Students can develop CPL by studying and responding to a platform's social, technical, and political-economic relations (Nichols & Garcia, 2022). For example, students can strengthen their CPL by analyzing how a platform user's social experience is related to a platform company's political-economic model that relies on content moderators and their labor that is often underpaid and traumatizing (McNeil, 2022).

Our following analysis addresses the research question: How did young people demonstrate their emergent CPL? By addressing our question, we seek to bring into greater focus the characteristics of CPL and possible design considerations to support its development.

Research context and methods

Context

The Young People's Race, Power, and Technology Project (YPRPT) is a community-based social design experiment (Gutiérrez & Jurow, 2016). Our study focuses on data collected during the fully virtual second iteration of YPRPT that occurred during the 2020-2021 school year. The 12 participating groups–from local high schools, community-based organizations, and faith-based groups–completed an application to be considered for the program. Participants completed a 19-week curriculum designed by the research team.

Methods

We first analyzed the Week 3 activity titled "How Do Platforms See Us, and Why?" Each of the 12 groups produced a reaction video in Zoom documenting their responses to viewing and discussing data that Google, Facebook, Instagram, and/or Twitter had gathered about them. We transcribed the Week 3 collective reaction videos by rewatching each until we had accurate transcripts. Next, we began our analysis with deductive coding. We identified instances when a participant demonstrated CPL by articulating and critiquing a platform's social, technical, or political-economic dimension. See Table 1 for more on our coding decision-making process.

Table 1
Operationalizing critical platform literacy using a platform's three dimensions

Dimension of platform	**Example from data**	**Is the example critical platform literacy?**
Social	"Bruh, my former usernames were CurlyHeadedLisa, Flamin_Lisa, PrincessLisa." (Note: usernames are pseudonyms.)	No, because the young person doesn't reflect on a component of the asymmetrical power relationship between herself and the company.
Technical	"Yeah, it's kind of weird that [Google is] tracking such young kids."	Yes, because the young person names and critiques Google's technical capacity to surveil children's behavior online.
Political-economic	"[T]he problem is what the data can do in the future. It can classify certain people in groups, right? It can make them eligible for a loan or not."	Yes, because the young person critiques a key component of data capitalism: companies' use of a person's data to increase inequality.

After deductively coding the Week 3 reaction videos, we used successive rounds of inductive coding (Miles, Huberman, & Saldaña, 2020) followed by writing an analytic memo (Saldaña, 2016) for each reaction video.

At this point, we centered our study on one community-based organization. We call this group Amplify; we refer to the youth participants with the pseudonyms Vicki (Grade 11), Ife (Grade 11), and Sandra (Grade 12). We selected this group for three reasons. First, Amplify members were unique in their collective sensemaking about platforms' technical and political-economic dimensions. Second, Amplify members mostly kept their cameras on throughout the Week 3 recording. Third, of all the YPRPT participants, only Vicki uploaded her Week 4 reaction video. While a limitation to the study, the small sample size also indicates the ongoing challenges of asking youth to complete assignments in addition to their academic and personal responsibilities. As with our other data sources, we completed the same process of deductive coding, inductive coding, and memo-writing to analyze Vicki's Week 4 video.

Findings

Below we share examples from our data that we're examining to understand how youth practice CPL. The data demonstrate how the girls of Amplify engaged two dimensions of platforms: the political-economic dimension of data capitalism and the technical dimension of surveillance.

Platforms' political-economic dimension: Data capitalism

The youth engaged platforms' economic-political dimension in their collective Week 3 reaction video by exploring their ad settings on Instagram and Google. Vicki rephrases a research-team provided question, asking why platforms want to know how many times they open an app or what they search for on Google.

> Ife: I heard that they sell our data to people. [*Vicki raises her eyebrows*.] I don't know why anyone would want to know about me. I'm not important, you know? So why would they sell data? Well, apparently you can use it for different things. I don't know what things, but it's useful.
>
> Sandra: I know a lot of people take data for ads. Basically that they try to, that's the main thing they do. They try to freakin see what we're doing and see what we're looking at and searching up, so they can incorporate ads that they think we might like.

Sandra helps Vicki and Ife fill the gaps in their knowledge by making more transparent platforms' technical capabilities of surveillance and how they reinforce an economic-political model of data capitalism. In this exchange, Sandra uses her more advanced CPL to strengthen her group mates' understanding of why platforms collect and sell data.

Platforms' technical dimension: Surveillance

Vicki begins her Week 4 individual reaction video by saying hello. Then she says, "I will be your informant for some information that I just learned about." Vicki positions herself as an "informant," a whistleblower with explosive news about Google's data-gathering and surveillance.

Vicki's emergent CPL is apparent when she cuts to a screenshot of a map from her Google profile to make concrete the experience of being surveilled. She says, "If you don't have your location turned off, they know every single point that you were at." Unsatisfied by only advocating people turn off their location tracking in Google, Vicki next shows her audience how to do so in the form of an instructional video. She has embraced her role as informant, realizing her agency to push back, even a little, against Google's surveillance.

Discussion

The three girls of Amplify demonstrate their emerging CPL through a process of collective and individual sensemaking. They notice how Instagram and Google gather personal data on their behavior, ask probing questions of the platforms and each other, and share their existing knowledge in order to deepen their CPL. They appear to have a more nuanced understanding of how technology companies use surveillance for profit. This more nuanced understanding isn't neutral, either. As Sandra says, the companies "try to freakin see what we're doing," and in her disgust one can hear a critique that may open opportunities to act and transform if not the platforms then perhaps our relationships with the platforms. In Vicki's case, her individual reaction video illustrates how her growing CPL helped her to develop an identity as a self-determined informant with a need to tell her audience how we too can assert our agency and become more difficult to track and monetize.

Notably, the girls' emergent CPL occurred in the context of making reaction videos. A playful genre, reaction videos evoke a person's surprise, an emotional state repeatedly expressed by the girls as they discover and name the extent to which the platforms extract their data and monitor their movements. Future research can build on existing literature on learning environments that use technology-mediated play to support development (e.g.: Gutiérrez et al., 2019), with a specific focus on reaction videos, to better understand how creating the feeling of surprise might be integral to developing CPL.

Conclusion

The "platformization of education" has arrived (Nichols & Garcia, 2022), and with it, the urgency to work with young people to better understand and respond to platforms' visible and invisible elements. While existing literacy frameworks attend to issues at the intersection of technology and power, CPL centers platforms' social, technical, and political-economic dimensions. Achieving a more nuanced view of CPL and its attending practices is essential if we are to better support young people as they resist, refuse, and reimagine platforms.

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Barriers to Reflective Learning: Perspectives of University Students and Instructors

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Abstract: Studies have outlined postsecondary students' lack engagement in reflective learning. However, factors affecting students' engagement has not been studied from the perspective of students. This study examined barriers of reflective learning as perceived by students and instructors in a large university in Western Canada. Data were collected from 32 instructors and 161 students through interview and open-ended questionnaire respectively. A qualitative analysis of the data showed four main categories of barriers: emotional, instructional, personal, and structural and contextual barriers. Although instructors and students perceived some common barriers in each category, the findings also showed important differences in the type of instructional and personal barriers.

Introduction

Recognizing the benefits of reflective learning for professional development and everyday life, educators have used various strategies to cultivate and develop post-secondary students' reflective capacity. However, research shows that students' engagement in reflective learning is unsatisfactory (Power, 2016).

Despite instructors' awareness of the benefits of reflective learning and their commitment to incorporate it in their courses, the actual process of engaging with reflective learning could be hindered due to several factors. The literature discusses potential barriers ranging from misconceptions about the nature and process of reflective learning to institutional factors that impact instructors' and students' activities (e.g., Boud & Walker, 1998; Finlay, 2008). For instance, Finlay (2008) expressed concerns that instructors embrace conceptualizations of reflection in uncritical, piecemeal, and reductionist ways. Other explanations of potential barriers focus on instructors' expertise which include poor facilitation skills and lack of knowledge (Platzer et al., 2000) and recipe following (Boud & Walker, 1998). At a more systemic level, efforts to foster reflective learning can be inhibited by factors such as the culture of performativity (Harford & MacRuairc, 2008) and disciplinary framings within which instructors and students operate (Boud & Walker, 1998).

Existing studies on barriers to reflective engagement and learning are limited in their scope and perspective. Both theoretical framings and empirical studies largely focused on the perspectives of practicing educators (Butani et al., 2017). We believe that understanding students' perceived barriers to their engagement in reflective learning is crucial. This study therefore aimed to examine the barriers to reflective learning from the perspectives of both instructors and students at a Canadian university. The research question that guided the study is: *What are barriers to reflective learning as perceived by instructors and students?*

Reflective learning in post-secondary education: A brief overview

There has been a growing interest in fostering reflective learning in post-secondary education because it helps students to develop effective learning strategies (Ertmer & Newby, 1996) and skills and habits of mind essential for living in the contemporary world (Rose, 2013).

Although its benefits are well established in the extant literature, reflective learning is "a complex construct to define, scaffold and develop in the arena of higher education" (Roberts, 2016, p.32). Dewey (1933) defined it as: "active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusion to which it tends" (p.9). Dewey's conceptualization emphasized thought processes involved in examining experiences based on evidence and rationality. Since then, the concept has evolved to embrace more critical and transformative frameworks (Brookfield, 2017).

The diverse interpretations of the construct itself are considered main constraints on its implementation in higher education. That is, the prevalence of often elusive and vague descriptions of reflective learning may limit the opportunities for practitioners and researchers to foster it adequately. Thompson (2022) discussed internal and external barriers to reflection. Internal barriers are related to the person's experience and beliefs; external barriers come from others or the environment. Notwithstanding the theoretical discussions on potential barriers, however, there is paucity of empirical research regarding instructors' and students' perceived barriers to reflective learning.

Method

Data were collected from instructors and students in the Faculty of Education at a university in western Canada. Education courses that were scheduled to be offered during the time of the study (2020) were first identified. Courses that included reflection in the course descriptions, learning outcomes, or assessment strategies were selected as potential sources of data. We then invited the instructors of the identified courses to participate in the study. As a result, data were collected from 32 instructors who agreed to participate. Instructors announced our study in their respective classes with a link to our survey. A total of 274 students completed the survey. Participants include students from undergraduate, graduate and teacher education programs.

Data collection and analysis

We used semi-structured interviews with instructors and open form survey with students. The general purpose of instructors' interview was to examine their understanding of reflective learning, related instructional strategies they use to foster reflective learning and their perceptions of barriers to students' engagement in reflective learning processes. However, the data used for this study focus specifically on barriers to reflective learning. Interview questions that helped to elicit instructors' perceptions of barriers include: "What things did you find easy or difficult in helping students develop reflective learning?" "What do you think are enabling/ hindering factors for students to engage in reflective learning?" Interviews were conducted both in-person and virtually. Since most of the data were collected during the Coronavirus pandemic, phone and zoom interviews were used depending on the participants' preferences. Interviews were audio-recorded and transcribed verbatim. The length of instructors' interviews ranged from 27 to 56 minutes each. Data from students were collected through survey. The survey included several questions in different forms that were intended to answer the research questions we formulated in the larger project. However, in this paper we used responses to one open form item, i.e., "What were the barriers or challenges to engage in reflective learning in this course?" Among the 274 students who completed the general survey, 161 students responded to this question. Of these, 39.6% were taking preservice teacher education courses, 41.8% undergraduate courses, and 18.6% graduate courses. Data analysis was an iterative process of reading through transcripts, segmenting data relevant to the research question, examining underlying meanings, and comparing and contrasting responses across transcripts. Accordingly, we employed open coding to understand instructors' and students' perspectives of barrier to reflective learning.

Results

Results indicated that both instructors' and students' perceived barriers to reflective learning can be grouped into emotional, instructional, personal, and structural and contextual barriers (See Table 1). It is noteworthy that although both instructors and students' perspectives belong to these four focus areas, specific barriers in each category showed both similarities and differences.

Emotional barriers

Instructors' and students' views indicated that concerns with safety and vulnerability preclude students' reflective engagement. When asked about barriers to reflective learning, many instructors responded using terms such as trauma, safety, being uncomfortable, vulnerability, and fear. One instructor stated, "there's a fear of vulnerability in doing this kind of work and a lot of the topics that we take up evoke a lot of emotion in our students" (PDt24).

Participants pinpointed that creating a safe space is crucial for facilitating reflection since it involves a lot of personal and emotional engagement that may be traumatizing and leading to a crisis. Like instructors, students expressed issues of safety and vulnerability as a main barrier to their reflective engagement. The following excerpt from a student illustrates this point: "there are a lot of sticky topics that can be hard to talk about and see within oneself, like white privilege" (GDs16).

Instructional barriers

Instructional barriers focus on the design and facilitation of instruction. Both instructors and students reported a variety of barriers related to the instructional process. However, the elements of instruction that they emphasize showed some differences. Instructors emphasized the inhibiting roles of assessment and feedback practices, cognitive load, objects of reflection, and remote teaching. GTt16 expressed how course readings inhibit reflection:

> I think too much reading and writing is a hindrance. Obviously, there needs to be a demonstration of understanding and, you know, academic writing. But if there is too much of that I think it hinders engagement. Because there needs to be a balance.

On the other hand, students' views of instructional barriers focus on instructor guidance, language, and nature of reflective tasks. For example, a student illustrated: "Reflective learning is not reinforced in most course activities. Directions are often 'you may reflect on anything that speaks to you', for example. Effective reflection is prompted, not asked for" (UGs13).

Table 1
Instructors' and students' perceived barriers to reflective learning in post-secondary education

Category	Description	Example excerpts
Emotional Barriers	Students' emotions and feelings such as concerns with safety and vulnerability, feeling of shame, trauma etc.	***PDt34 (Instructor):*** "I think one thing that I worry about is that if we're asking people to get personal, but it is also important to understand that people have past traumas that this type of information could be triggering." ***UGs01 (Student):*** "It is emotionally draining. Students who have not done this type of work can default to text-book answers to protect themselves from feeling; most students expect to learn, not to be asked to examine their emotions, thoughts and needs in learning."
Instructional Barriers	Teaching-learning processes which include the nature of learning activities, content of reflection, assessment, grading and feedback.	***UGs10 (Student):*** "Many disparate focuses in the course detracted from extended concentration on reflection. I was too distracted by all a complex syllabus and different criteria to let myself fall into a comfortable reflective state." ***GTt21 (Instructor):*** "they're worried about the grades. And that really gets in the way, worrying about grades really is a problem for students and I do everything I can to discourage them from focusing on the grade."
Personal Barriers	Students' background (e.g., cultural, age, educational background) and prior experience (e.g., limited experience with reflection; life experience)	**UGs09 (Student):** "my own lack of motivation and just do the assignment for a good mark rather than actual learning" ***UTt14 (Instructor):*** "some students are just more naturally inclined with this kind of work than others, right, people who tend to be very concrete thinkers who find such reflexivity difficult might just not be able to do this very well."
Structural and Contextual Barriers	Institutional norms and practices, time, and related contexts.	***GDs06 (Student):*** "Reflective learning requires time and space to marinate on new ideas, merge them with existing ideas and refine understanding . . . but with working full time on top of school it can be difficult to find the time or space to work through ideas." ***GTt02 (Instructor):*** "So a large part of what I'm noticing more is that graduate students and even undergraduate students are having to work more and so the material aspects of their lives leave them less time."

Personal barriers

Participants reported personal background as barriers for reflection although these may be interpreted differently by instructors and students. For example, an undergraduate student explained the role of experience as a factor:

> I am older than those who typically go to university. I have ample life experience and I am not afraid to engage in dialogue. However, my classmates are only able to connect with the readings and dialogues on a surface level. I believe much more reflection and life experience is necessary for those who aspire to become teachers. (UGs15)

In addition to prior experiences, students reported the impact of their lack of motivation including the propensity to complete assignments for grades than actual learning and the lack of honesty and openness to change one's views. On the other hand, instructors emphasized factors related to intellectual capacity and cultural background. For instance, GDt02 claimed that "some students have a greater intellectual capacity than others and thus they are able to ask more in-depth questions." This participant further posited that only some students can pick up on questions, no matter how hard s/he try to get everyone aboard.

Structural and contextual barriers

Most participants, instructors, and students alike, considered time as the main barrier to reflective learning. Lack of having time for reflection was described in relation to students' busy life due to learning, work, and family commitments. Besides time, instructors also reported differences in structure between programs as potential barriers. PDt24, for example, illustrated:

> I think a significant piece of it is the way we've structured school. It's quite jarring for some of them to come into a program where we make reflection so central … And a lot of them have been programmed to not trust that process, not see it as a valid form of personal research and inquiry… It works against our school, or the way we structure schooling and learning.

Although students focus mainly on time, instructors also mentioned barriers such as large class size and expectations of success that focuses merely on acquisition of content knowledge.

Discussion

The results of our preliminary analysis indicated both groups emphasized emotional issues, time, and limited experience as key barriers to students' reflective engagement. On the other hand, differences are observed in instructional and personal barriers. These perceived barriers have implications for designing learning activities. If we aim to foster critical reflection and thereby develop students' agency to make informed decisions, it is important that reflective learning activities are designed as integral parts of education. Doing so would help to overcome the barriers and allow space for its practice. For instance, the perception of time as a barrier implies that participants' understanding focused on retrospective reflection, i.e., reflection taking place after the event. However, designing reflective tasks that can be done during instructional time would help to address time-related challenges. Also, the nature of assessment and grading practices encourage formulaic and superficial approaches to learning thereby inhibiting reflection (Brookfiled, 2017). This can be counteracted by developing assessment criteria inherent to the purposes of reflective tasks.

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Theorizing Mathematical Unitizing Through Fiber Crafts

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Abstract: This article examines how fiber crafting can develop mathematics learning and learners. Extending the constructionist paradigm with relational materialist principles, this paper advances the notion of "materialized action," which describes the natural inquiry process that results through emergent patterns between learners and the materialized traces of their actions. This paper takes a qualitative approach, combining a design and intervention phase examine fiber crafts (here knitting) and engagement in a "powerful idea" (i.e., unitizing in multiplicative proportional reasoning) as an illustration of how we can better understand micro-developmental learning processes, and advance constructionist theory.

Introduction

Identifying relatable contexts to practice challenging mathematics topics, such as multiplicative proportional reasoning, remain a challenge in mathematics learning. In this study, we build on fiber crafts a rich context of mathematics learning and examine how fiber crafting can develop mathematics learning and learners. Toward this end, we asked: How does knitting develop mathematics learning and learners and under which conditions? In the context of an out-of-school workshop developed by crafting professionals and mathematics educators, this qualitative study examines knitting as process of creating units and engagement in multiplicative proportional reasoning. This effort combines research on the use of textile crafts for learning advanced mathematics (e.g., Greenfield & Childs, 1977; Peppler et al., 2020) with a relational materialist lens on learning (Hultman & Lenz-Taguchi, 2010) to capture, analyze, and theorize how materials prompt human development and learning. As part of a longer-term qualitative study that focused on capturing evidence of learning via fiber crafts (e.g., Keune et al., 2021), this paper presents a close analysis of the micro-developmental engagement of knitting with youths to show how material changes led to engagement in powerful mathematical ideas of unitizing and proportional relationships. While the full study shows these ideas unfold in three fiber crafts (i.e., knitting, crochet, and pleating) we focus on presenting findings on knitting in this paper. Through this examination, we advance the notion of materialized action as a micro-developmental condition under which epistemic understanding emerges. At its core, materialized action can be conceptualized as the patterns of action in the construction of an artifact. Materialized action allows for the reformulation of ideas (if the physical outcome was not intended) and the co-construction between learner and materials. It has the potential to disrupt in mathematics education.

Proportional reasoning and unitizing in mathematics

This study takes as a starting point the theory of constructionism, which posits that learning occurs best when individuals design physical (or digital) constructions that can be shared, representing cognitive transformations that happen as learners actively engage with domain concepts. Working out reasons for why designs fail and adjusting designs is one important way to deepen understanding of mental models and concepts (Papert, 1980; Kafai, 2006). The types of materials used for learning are not without consequence, as materials, and the relative marginalization of other materials, shape domains in formative ways. Friedman (2018) details how compass and straight-edge produced a range of mathematical techniques and practices that subverted and marginalized other mathematical principles based on paper folding. In a recent workshop organized at the Technical University of Munich and Deutsches Museum, Friedman and Zetti (2023) trouble the immateriality of mathematics by highlighting the distinct role paper played in knowledge production within mathematics and computing contexts. This has manifold consequences for how we conceive of mathematics learning. Additionally, while math learning and fiber craft learning were historically placed in opposition to each other in European and American schools (Harris, 1997), researchers have observed ample connections between textile crafts and math that belie this separation, such as in knitting, crochet, cross-stitch, quilting, needlepoint, and tatting, among others (e.g., Belcastro & Yackel, 2011). Other work demonstrated mathematical learning through textile craft engagement, such as sewing of tents and costumes, knitting, crochet, and weaving (Peppler et al., 2022).

In the constructionist tradition, researchers look for powerful ideas that are persistently difficult as taught using traditional approaches. One such powerful idea, which we examine in this study, is unitizing in multiplicative proportional reasoning (PR). PR is the understanding of the multiplicative part-whole relations between rational quantities and is a predictor of future mathematics achievement (de la Torre et al., 2013; Boyer & Levine, 2015). Persistently, PR has been challenging to learn (Lobato & Thanheiser, 2002); often, young learners try to use additive instead of multiplicative strategies (e.g., incorrectly solving 2/3 = x/6 by adding 3 to both numerator and denominator instead of multiplying both numerator and denominator by 2; e.g., Dooren et al., 2010). Unitizing, the partitioning into composite units, is a foundational concept for multiplicative and proportional reasoning and is difficult for children to develop (Lamon, 1992). There is a powerful possibility in feeling and practicing units across multiple materialities as to "disturb narrow (and perhaps white, western, male) images of mathematics—and to open up opportunities for a more pluralist school mathematics," that draws on different cultural experiences, materialities, and abilities (de Freitas & Sinclair, 2020, p.2). Missing from this prior work is how units can be dynamic and tangibly produced (rather pre-formed) as well as how units build over time.

Methods

This qualitative study explored what features of activities could lead to exploration of proportional reasoning by analyzing data from a three-day fiber crafts camp in which youth performed the craft activities to understand how the crafts supported engagement with PR. The camp took place over the course of three consecutive days (4 hours each). Each day youth learned a new craft and created a project with the craft: 1) Crochet a bag, 2) knit a bag o, and 3) sew a pleated bag. 17 middle-school-aged youths (9-12 years old) participated in the craft camp (16 female, 1 male). This is an age at which PR is typically taught (Common Core State Standards Initiative, n.d.) as well as the age at which girls—and other underrepresented youth—begin to wind down on interest with STEM (Corbett & Hill, 2015). Two participants were joined by their parents to support language translation. For analytical purposes, we focused on three focal youth based on active participation.

The data sources included projects created by the research team. Wideo recording of the youth camp observed the youth-produced proportional reasoning across projects through material unitizing and shaping (40 hours). The video showed youths' hands and faces as they worked on their projects. Data sources also included 231 photographs of youth projects that showed detail of the projects. We first analyzed the projects by the research team through 1) verbal descriptions of the step-by-step craft process, 2) visual representations that showed the emergent material and craft patterns, and 3) corresponding mathematical notation of the RP in the crafts that represented the rules that governed the patterns. As per constructionist philosophy, the abstractions into mathematical notation were not a part of the camp. The analysis of the video recordings of the youth camp focused on how youth produce PR across fiber crafts through material unitizing (i.e., how crafters produced units in the materials). Our analysis of the photographs of youth projects closely observed stitches to reconstruct the mathematical doing that occurred to produce the project. We focused on the differences between planned and implemented projects (e.g., in relation to stitch size) as reference for mathematical processes.

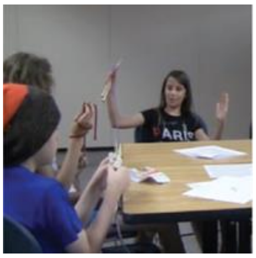
Findings

In contrast to the use of established units as the basis for ratios and proportional relationships, fiber crafting begins with an initial stitch unit that users define through their choice of materials and their body's relationship to their manipulation. Crafters reason with multiplicative part-whole relations as rhythmic and repeated movements of people and materials arrange and multiply stitch units into pattern units, which are multiplied again into a project unit. In this study, we identified three levels of unitizing: *Stitch units* form the basis of proportional relationships when considering the number of stitches per row. *Pattern units* emerge by bringing stitch units in relation. We define a pattern as a form or model used for imitation. *Project units* from through the combination of completed patterns. The project unit shows the mathematical connections even more clearly.

How knitting develops mathematics learning and learners

Katie, a 10-year-old knitter, produced stitch units only to unravel them and to restart 12 times, working to establish a consistent feel for her stitch units. Where initial stitch units were loose and irregularly shaped, as Katie got into a routine, her stitch units became tighter and more uniform. Katie and a neighboring youth also explored stitch units through a conversation about arm knitting, a knitting technique that uses the arms of the crafter in place of knitting needles (see Table 1). Together, the youth determined that the stitches would be gathered on one arm and picked up by the other arm (see Table 1, panel 1 and 2). Through gestures, the youth compared the effects of using different materials (i.e., wooden needles vs. arms as needles) on one's personal stitch unit (see Table 2, panel 3 to 5). Through her body posture and arm gestures, Katie expressed how the size of a needle affected the amount of yarn needed for a stitch as well as the size of a stitch unit (see Table 1, panel 6).

Table 1
Transcript of a conversation about arm knitting that involves stitch units and pattern units.

 1) Katie: "Your arms are like needles." Katie turns to Sarah and lifts her arms. Katie's arms become needles.	 2) Sarah: "Like this?" Sarah lifts her project. Katie drops her arms and nods. Sarah introduces her project as a comparison.	 3) Katie: "I don't know how exactly." Katie lifts her arms and twists them. With arms as needles, Katie explores how arm knitting would work.	 4) Katie: "Now that I think about it, it's like the needles." Katie lifts her project and points at the needles. Katie suggests that arm-needles act similar to wooden needles.
 5) Sarah: "Ah." Katie: "Yes." Sarah lifts her left arm and grabs it with her right hand at three places. Katie nods. Both knit on. Sarah's arm becomes a needle and the grabbing motion becomes stitches on the needle.	 6) Katie: "If you used this arm, it'd be stitches that big." Katie holds her hands one foot apart. Katie shows how the size of the project becomes larger with arms as needles.	 7) Katie: "Lalala" Singing, Katie waves her arms. The waves become stitches and Katie adds a few stitches to her imaginary project.	 8) Katie: "Then you have that much." Katie holds her arm two feet apart. The imaginary project grew over twice in size and, thus, at a faster rate compared to using wooden needles.

Starting over allowed Katie to practice a sense of her personal gauge, reflective of pattern units. With an increasing number of unraveled projects, Katie considered how the number of stitches she cast on would relate to the size she produced, counting the stitches as she cast on her needle. Katie also compared knitting as getting a physical sense of the size of a stitch in relation to the created pattern unit in space, and, more specifically, the length of a row of stitches (see Table 2, panel 7 and 8). This is relevant because needle size is one aspect of how knitters conceive of their personal pattern unit, which shapes the look and size of a stitch unit (i.e., how big or how loose it is). As she worked, each stitch reconstructed the rectangular stitch unit that became the basis for a proportional relationship while this reconstruction was a part of forming the pattern unit. Each pattern of stitches thus formed another unit of the mathematical materialized action. The project unit showed the mathematical connections even more clearly. A knitted stitch unit is rectangular in shape and, thus, the stitch height is unequal to (shorter than) stitch length. This produces a proportional relationship, which in knitting looks like a performance centered on the gauge of a knit. As she worked, Katie noticed the proportional relationship at the site of the project unit, when she realized her project unit did not match the drawn pattern unit and that her stitch unit was not square.

Moving across three units provided space for iterative material exploration (i.e., through the undoing and redoing of stitch units) and drawing relationships across units, which brought about the implementation of proportional reasoning, but in greater complexity than what we would find in traditional classroom exercises. Learning about the epistemic idea is moving between units and is building toward larger constructions. This performative comparison of knitting with needles and knitting with arms was indicative of Katie's developing sense the craft material that affected the production of a stitch unit, the basic element for PR within knitting. Yet, when moving from stitch unit to pattern unit, we start to see intersections and moving back and forth across units.

Discussion and implications

Through our analysis of knitting across units, we can see how learners engage epistemically in mathematical ideas across different levels and complexities. The personalized stitch unit becomes a materialized action that crafters can recognize with hands and eyes. Beyond building units, crafters can zoom in on the combination of units into pattern units as a way to think about what the combination of units can produce that is larger than the unit itself. Taken together, this advances a notion of materialized action, resituating the "doing of" mathematics as a natural inquiry process that results through emergent patterns between learners and the materialized traces of their actions. Types of units can be simultaneously and separately engaged. By working across units, crafters engage materialized actions that provide opportunities for proportional reasoning. Materialized actions integrate (rather than exclude) worldly concreteness into mathematics, promising another way to relate to math. Units do not have to stay the same within a mathematical activity. Materialized actions as a theoretical idea can guide the design of mathematics learning that is embracing (rather than reducing) complex concreteness as part of learning. This holds the promise to engage people with diverse interests in mathematics learning and unsettle what has previously been conceptualized as a canonical source of mathematics activity.

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After-School Programs During the COVID-19 Pandemic: Shifting Figured Worlds

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Abstract: This study focuses on the identity work of after-school service providers within one large state-wide after-school network after the onset of the COVID-19 pandemic. Through the lens of Holland et al.'s figured worlds and self-authoring, we explore after-school service providers' experiences as they made meaning of and negotiated identities within shifting figured worlds of after-school and school because of the pandemic. Findings indicate that after-school service providers engaged in reauthoring within the figured world of the pandemic.

Purpose

The COVID-19 pandemic forced the closure of schools, resulting in unprecedented challenges for students, families, teachers, and staff (Munir, 2021; Lewnard & Lo, 2020). Existing literature suggests that the COVID-19 pandemic has had a profound impact on the identities of educators (Kim & Asbury, 2020), medical students (Byram et al., 2022), and fitness instructors (Andersson & Andreasson, 2021). As a result, many professionals experience pressure to reinvent themselves and find their place in the new pandemic reality (Andersson & Andreasson, 2021; Byram et al., 2022; Kim & Asbury, 2020), including after-school service providers. However, there is a gap in research on after-school service providers' experiences and challenges during the COVID-19 pandemic. In the United States, after-school programs are tasked with keeping students safe, promoting positive social and personal behaviors, and enhancing school attachment and academic achievement (Durlark et al., 2010); thus, after-school providers play a crucial role in delivering high-quality after-school services to students and their families and fostering positive youth development (Durlark et al., 2010; Payne & Eckert, 2010). Viewing after-school service providers' COVID-19-related challenges through the lens of figured worlds aids us in making sense of how the pandemic affected after-school service providers' normacy and the avenues of education access they make through reinforcing learning and socialization for children.

Framework

Figured worlds

Figured worlds are socially and culturally constructed worlds in which people "figure" their identities through social relationships and activities within the world (Holland et al., 1998; Urrieta, 2007). In figured worlds, individuals share reasonably stable understandings, values, and expectations of a certain phenomenon. However, because figured worlds are socially organized, they also produce a web of meaning that divides and distributes people's sense of self across multiple realms (e.g., after-school provider, parent, community member) (Holland et al., 1998).

Within education, figured worlds have served as a tool for studying learning contexts and the identities that are formed within those contexts (Urrieta, 2007). Rubin (2007), for example, explored the figured world of learning and identified the figured world of "smartness" at an urban high school, which involves students studying hard, getting good grades, and completing their assigned tasks diligently. According to Holland et al. (1998), figured worlds are made up of an imagined world in which actors (i.e., members, nonmembers, or a certain kind of members) hold a set of assumptions, beliefs, and norms and act with agency as they author themselves and position their identities. Actors within figured worlds make improvisations strategically through activities using tools of change, such as teachers and utilizing virtual meeting platforms to meet with students.

Hybrid figured worlds of the after-school program during COVID-19

Urrietta et al. (2011) puts forward the idea of "hybrid" figured worlds, in which individuals have to reauthor their identities as they try to make sense of new realms of interpretation, reorganize their roles, and adapt to unexplored performance expectations. For example, hybrid figured worlds in the context of education have explored the worlds of African American males who are in prison and simultaneously attending college (Urrieta et al., 2011); and a the worlds and professional identity of an elementary teacher when their inclusion class was moved online (Naraian, 2009). Furthermore, youth participation in science learning can be understood through hybrid figured worlds as they move across various learning spaces of the science class and out-of-school-time space (Gonsalves et al., 2013).

In this paper, we focus on a hybrid figured world concept, in which multiple figured worlds are integrated jointly, and there are no clear boundaries between figured worlds (Urrieta, 2007). We examine the COVID-19 pandemic's influence on after-school service providers' space and the hybrid space of virtual after-school programming.

Methods

In the current study, we present findings from a qualitative study with providers of an after-school network in California, United States (NSF DRL #1906490). Our analysis includes interview data with eleven after-school service providers. Interviews were conducted virtually from Summer 2020-Spring 2021 and were recorded and transcribed. Interviews lasted roughly one hour. Questions focused on continuous quality improvement (CQI) practices within after-school programming, experiences during the COVID-19 pandemic, the after-school system of support, and Science, Technology, Engineering, and Mathematics (STEM) offerings within the program. Initially, we conducted an inductive thematic analysis of transcribed data and found the emerging themes of service provider identity and changing contexts. In a second-level analysis, we identified figured worlds themes as the providers described their changing identities to accommodate the circumstances of the COVID-19 pandemic shut-down while continuing to provide after-school services through various online platforms.

Findings

The emerging themes in our analysis illustrated after-school service providers' making meaning of and negotiation of new roles in shifting schooling contexts. We find that the after-school network's community formed hybrid figured worlds from their pre-existing after-school figured world pre-COVID and a new figured world of the new normalcy during the COVID-19 pandemic. Negotiating new roles included reauthoring selves through improvisations while expressing hopefulness to return to the before-the-pandemic after-school figured world they previously knew so well.

Reauthoring selves as after-school service providers during the pandemic

Our findings reflect the improvisations many schools and after-school programs made during the pandemic shut-down period to meet their students' physical, social, and academic needs. After-school service providers continued to offer after-school activities virtually and provided the supplies needed to complete the projects at home. Improvisations were made within the after-school network programs by service providers during the shut-down period of the COVID-19 pandemic. These improvisations included: (1) learning new technologies (e.g., Google Classroom, Zoom) to maintain continuity with communication with students during the pandemic, (2) preparing and delivering supplies for learning activities, and (3) maintaining their after-school staff and redefining roles.

Learning new technologies during the COVID-19 pandemic was one of the major themes that emerged from conversations with after-school service providers. Initially, many service providers were unfamiliar with new technologies and the social expectations of delivering services virtually. However, with increased exposure to a new world of technologies, these service providers learned to use new tools (e.g., Google Classroom, Zoom), adjust their practice to align with their professional identities, and meet the expectations of the hybrid figured world of after-school during the COVID-19 pandemic. In the hybrid figured world of virtual after-school programs, these service providers have learned to make sense of and incorporate their work identities as after-school service providers in a casual home environment. Slowly, service providers came to share a stable understanding and ways of operating. As a result, after-school providers could assist students virtually through improvised tutoring through "Pods" in Google Classrooms, Zoom sessions, and virtual field trips. Kim and Sam shared their experience with navigating and delivering after-school services online:

> Also because this virtual world was so new to us, we started doing trainings even a Zoom tutorial training where what's the basics of Zoom? […] and we said, we need to do a Zoom etiquette. [...] Then we also did building rapport with students online because that was something that our staff could definitely benefit from that training (Kim_092420_CA).
>
> Then we have a whole another set of staff that are working in the day; working with Pods of kids in the Internet rooms so that they can access Internet and get assistance during the day (Sam_082120_CA).

Additionally, many after-school services providers recognized that not all students and staff members have access to the devices and supplies they would need to conduct the activities virtually. To make the program more accessible and equitable for their students, these service providers improvise their roles and responsibilities corresponding to the current climate to continue providing support and meeting their students' needs. In short, these providers also became a resource hub for students and their families. Specifically, service providers went beyond their role to assess students' needs, looked for ways to address those needs, and met students where they were at:

> This year, we're also providing them supplies to do the activities. Through the lunch pick-up, they're gonna pick up supplies for their Google Classroom (Sam_082120_CA).
>
> We survey students and staff and see do they even have devices? The after-school team really engaged in supporting with distributions, whether it was food or devices. […] The kids and the staff had all the supplies needed. That was a lot of work. […] We just created assembly lines of work and packages. We had distributions at every site. Every kid that was participating in summer, they got a bag and it was labeled for day 1, day 2. […] They had the tools that they needed, staff and students (Kim _092420_CA).

Our findings indicated that after-school service providers strongly identified with their roles as educators and support staff in supporting students' positive development regardless of the current pandemic situation. They are appreciative and take pride in their work with students. However, these providers also expressed frustrations with the lack of support and recognition for after-school programs and staff members. Some after-school service providers anticipated that their full-time staff would not return due to several factors, including the inability to work with the students in person and difficulties making meaningful connections with students virtually. Moreover, many service providers shared how their work in the after-school program is a huge part of their identities as they hope to continue their work in the future. As Leslie stated: "I live and breathe after-school. I hashtag my life after-school forever and ever." In sum, as multiple figured worlds of home and service became tangled during the COVID-19 pandemic, after-school service providers had to reauthor through repositioning and reorganizing their roles to adjust to the changes. By doing so, service providers can maintain the figured world of after-school programs amid the pandemic.

Significance

Considering a hybrid context of a pre-COVID figured world and reconciling it with the figured world of the pandemic is an important undertaking in this study because it informs the current educational contexts. Our findings suggest that educators and service providers experience tensions in maintaining an identity in one (pre-COVID) world while reauthoring an identity in a figured world of a pandemic. Findings from this study have important implications for policy-making and evidence-based program design to support educators and service providers. These findings are valuable for schools, institutions, and organizations as they consider and develop current programming, type of services, and approaches that can benefit educators' and service providers' overall well-being, growth, and development. Furthermore, educators and service providers can also benefit from the information as they make meaning of and negotiate their identities in the figured words of after-school after the COVID-19 pandemic. Finally, students' education progress and whole-child development are deeply intertwined with educators' and service providers' overall well-being. Thus, support programs that target students' education success and positive development may find this information useful as they provide services for students.

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Preparing Teachers to Teach Artificial Intelligence in Classrooms: An Exploratory Study

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Abstract: The rapid expansion of Artificial Intelligence (AI) necessitates educating all students about AI. This, however, poses great challenges because most K-12 teachers have limited prior knowledge or experience of teaching AI. This exploratory study reports the design of an online professional development program aimed at preparing teachers for teaching AI in classrooms. The program includes a book club where teachers read a book about AI and learned key activities of an AI curriculum developed for middle schoolers, and a 2-week practicum where teachers co-taught the curriculum in a summer camp. The participants were 17 teachers from three school districts across the United States. Analysis of their surveys revealed an increase in teachers' content knowledge and self-efficacy in teaching AI. Teachers reported that the book club taught them AI concepts and the practicum sharpened their teaching practices. Our findings reveal valuable insights on teacher training for the AI education field.

Introduction

From manufacturing to household automation, Artificial Intelligence (AI) is transforming almost every corner of our lives. This transformation presents a need for developing a generation of citizens who are AI literate so that they can partner with AI technologies in future workplaces and make informed decisions about AI-related civic issues. Meanwhile, youth and adolescents interact with AI-enabled tools in social media on a daily basis without realizing it. They may be targeted by AI-moderated and generated media such as Deepfakes and become persuaded to think that a fake event, image, or text is real, and act accordingly. Thus, teaching K-12 students how AI is used to generate misinformation and how to view information from online sources with essential skepticism is crucial to protecting them from being manipulated by AI-moderated media tools and AI-generated content.

While the need for AI education at the K-12 level is evident and urgent, the field of AI education is in its infancy. Little is known about how to prepare teachers to adopt and offer AI education in regular school day classrooms. This paper helps address this gap by reporting the design and findings of an online professional development (PD) program called Everyday AI (EdAI) PD, which includes two major components to prepare teachers to teach AI: (1) a 20-hour (two hours per week, over 10 weeks) AI Book Club (ABC), and (2) a 30-hour summer practicum. The ABC engaged teachers in reading a book and materials on AI and reviewing and discussing the Developing AI Literacy (DAILy) curriculum, which aimed to develop AI literacy among middle school students through interweaving AI technical concepts, related ethics issues, and the impact of AI on future jobs (Zhang et al, 2022). The practicum engaged teachers in co-planning and co-teaching the curriculum to youth enrolled in summer camps so that teachers can develop pedagogical knowledge and practices. In an earlier study we reported teachers' experiences of participating in the EdAI PD program (e.g., their engagement and attendance) (Lee et al., 2022). This study focused on evaluating the efficacy of the two PD components, with the following research questions: (1) How does the EdAI PD program influence teachers' attitudes toward AI and self-efficacy around teaching AI?, and (2) What do teachers' perceive as the affordances and constraints of the EdAI PD program components?

Rationale

A wealth of research has suggested that the success of educational initiatives and innovations in school depends strongly upon the support and attitudes of teachers involved (McNeill et al., 2016). If teachers believe or perceive an educational initiative as fulfilling neither their own or their students' needs, they are not likely to attempt to introduce it into their teaching and learning. Since AI is new to most K-12 teachers, PD programs offering AI education must take into consideration that teachers may hold mixed feelings and varied views of AI. Thus motivating teachers' interest in AI is of paramount importance. Further, in contrast to many PD programs where teachers possess content knowledge from prior training or education, teachers typically join AI PD programs with limited understanding of AI or experience teaching AI. It is therefore critical that PD programs in AI education develop teachers' content and pedagogical knowledge of AI and foster their self-efficacy beliefs. To address these needs, the design of the EdAI PD program was informed by literature on effective PD components and combined the experience of learning AI literacy as students with experiential learning as teachers.

Characteristics of effective professional development program

Teacher PD programs are crucial to ensuring in-service teachers learn new strategies for teaching and keep up with advances in their fields. Researchers have identified features of high-quality and effective PD programs including: collaborative learning (McNeill et al., 2016); establishment of professional learning communities (DuFour, 2004); adequate time for implementation practice; emphasis on pedagogical content knowledge; and follow-up support for teachers (Garet et al., 2001). In particular, the literature calls for sustained systematic PD programs that unfold as processes over time because they are often more effective than one-time PD events (Harwell, 2003). Yoon et al. (2007) reviewed more than 1,300 studies and found that PD programs lasting 49 hours or more showed a positive and significant effect on teachers and ultimately boosted students' achievement by about 21 percentile points. Informed by these essential findings on PD effectiveness, the EdAI PD program was designed to span approximately five months (over 50 hours) and focus on creating a collaborative environment for teachers to learn AI, become familiar with the DAILy curriculum, and develop implementation strategies and teaching practices.

Experiential professional development

As more and more research started questioning traditional teacher PD models that focus on the transmission of information to teachers through direct instruction (Guskey, 2002), many researchers called for incorporating and extending experiential learning in teacher PD (Marlow & McLain, 2011). Experiential PD engages teachers as active participants in a lived experience upon which they can reflect, think and act (Clarke & Hollingsworth, 2002). Such experience allows for an ongoing process that attends to the personal nature of PD wherein teachers draw upon their own past experiences and what they learn from the PD as a foundation to engage and experiment with the new experience. Experiential PD can be particularly successful in motivating teachers to try new practices and making desired changes to realize the curriculum in their classrooms (Darling-Hammond et al., 2017).

One key component of experiential PD is reflection on action and experience. Teachers who reflect more often were more likely to make changes to their teaching practices than those who reflect less often (Camburn & Han, 2015). Rooted in conceptual models of professional learning which posit that learning begins with a dilemma or problem that one encounters in the workplace (Marsick et al., 2009), reflection should be structured to enable teachers to recognize dilemmas in teaching and should also engage them in attempting to resolve the dilemmas. In the EdAI PD program, teachers were engaged in a daily reflection as a group at the end of every day during the summer practicum. They reflected on the experience of teaching AI, observed student reactions, challenges, and potential solutions. By reflecting and sharing thoughts with peer teachers who have similar experiences of teaching AI, EdAI teachers are expected to identify problems or difficulties and collaboratively develop solutions to better meet the needs of supporting middle school students in learning AI, which is necessary for the adoption of new initiatives and changes in teaching (Van Driel & Berry, 2012).

EdAI PD: AI book club and summer practicum

The EdAI PD program includes a 20-hour AI Book Club (ABC) and a 30-hour summer practicum. The ABC included synchronous online meeting for 1.5 hours and asynchronous "homework" assignment of approximately 0.5 hour every week. Each week featured an AI related topic, such as *What is AI?, Algorithms as Opinions, Ethics in AI, Logic Systems, Perceptions and Machine Learning, Neural Networks and Deep Learning,* and *Generative AI.* The weekly assignment consists of (1) 15 minutes of readings or watching videos that exposed teachers to new AI topic of the week. The readings were chapters from Mitchell's "*Artificial Intelligence: A Guide for Thinking Humans*", a book that interweaves AI concepts, examinations of AI hype versus reality, and ethical concerns about AI. The videos included presentations on how algorithms could be biased, how facial recognition systems failed to recognize darker-skinned females, and a collection of videos about the application of AI in various industries; and (2) 15 minutes of reviewing activities and learning materials from the DAILy curriculum that aligned with the topic of the week. Teachers also participated in an online Slack channel to share their thoughts and impressions of the readings and videos. During the synchronous online ABC meetings, teachers first reviewed what they learned from the assignment and then experienced the AI curriculum activities as learners where the PD instructors and facilitators provided teaching demonstrations and pedagogical tips. They also reviewed student work from previous implementations of the DAILy curriculum and discussed key points, common misconceptions, and how to assess student understanding.

In the summer practicum, teachers formed co-teaching teams to teach the DAILy curriculum in 2-week camps. Each co-teaching team was composed of three or four teachers from the same school district who attended the ABC together. The summer camps were organized by partnering youth-serving organizations that focus on engaging middle school aged youth from underrepresented and underserved groups in STEM. The teachers worked together to apportion the teaching load (each teacher needed to lead eight or nine hours of activities).

When not leading an activity, teachers observed the instruction, supported individual students, and helped lead small group activities. At the end of camp every day, teachers, led by a researcher from the project team, reflected on their experience and discussed how to improve instruction to better meet students' needs and how they will approach teaching these activities in their own classrooms.

Methods

In total, 17 in-service teachers from three US school districts completed the EdAI PD program. The teachers taught a variety of disciplines: 52% Computer Science/Technology, 12% Library/Media Literacy, 12% English Language Arts, and 24% Science. Their school districts serve student populations that are largely from underrepresented groups in STEM and Computing (59%, 90% and 85% respectively). Eighty-eight percent of the participants (n=15) were from groups underrepresented in STEM and Computing education: 82% (n=14) being female, 18% (n=3) male; 35% being African American (n=5), and 12% being Hispanic/Latino (n=2).

Data collected in this study included responses to a survey administered three times among EdAI teachers: before ABC, after ABC (before the practicum), and after the practicum. The survey included 5-point Likert scale questions assessing teachers' (1) attitudes toward AI (Cronbach's alpha=.85) which consisted of 25 questions examining teacher's interest in AI, anxiety toward AI, awareness of AI's impact on future jobs, and perceived relevance of AI to their lives; and (2) self-efficacy of teaching AI (Cronbach's alpha=.85) which included 19 items evaluating teacher's beliefs in middle school students' competency of learning AI, confidence of teaching AI, and community support of teaching AI. The qualitative data collected included teachers' daily reflections and exit interviews upon the completion of their summer practicum. The interview questions asked teachers' experiences during the ABC and the practicum and their views of the benefits and drawbacks of the two components as PD. In this paper we focused on the analysis of teacher interviews.

The data analysis started with a one-way repeated measures ANOVA analysis of teacher survey. We are cognizant that the sample size was not sufficient to reach statistical significance, and therefore the results were used to provide a holistic view of changes in teachers' attitudes and self-efficacy observed between the three measurement waves and to suggest initial codes for the subsequence analysis of the exit interviews. In this paper we reported findings from the analysis of nine teacher interviews. The teacher interviews were purposefully selected to be representative of EdAI participating teachers, which included teachers from the three school districts, taught in different subject content areas, and with mixed demographics (gender, race and ethnicity). The interviews were analyzed using grounded theory. Final themes were emergent based on multiple rounds of coding around teachers' self-described experience and their perceived affordances and opportunities of each PD component.

Findings

The ANOVA analysis showed continued increase in teachers' mean scores of attitudes toward AI (F(2, 20) = 11.32, $p < 0.001$) and in teachers' self-efficacy of teaching AI (F(2, 20) = 12.00, $p < 0.001$) over its time course. Teachers' mean attitude score started with 3.70 (SD=.35, maximum score=5) before ABC, increased to 3.94 (SD=.27) after ABC, and further increased to 4.11 (standard deviation=.37) after the practicum. A similar trend was observed in teachers' self-efficacy score (before ABC: Mean=3.45 (SD=.42); after ABC: Mean=3.83 (SD=.40); after practicum: Mean=4.09 (SD=.39)). This suggests that the ABC and practicum led to continued teacher growth in preparation to offer AI education in middle school classrooms. A closer examination showed that after the ABC, teachers achieved the biggest learning gains in their knowledge around AI's impact on jobs, views of community support in teaching AI, and confidence of teaching AI. After the practicum, teachers became more confident about teaching AI and having community support when teaching AI. They also became more interested in AI and believed more firmly that middle school students are capable of learning AI.

Several themes emerged from the analysis of teacher interviews. For instance, teachers thought that the ABC enabled them to engage with peer teachers from various disciplines across the country teaching AI, e.g., "*I like the idea of getting together with other teachers, especially from different parts of the country. I liked that a lot. I liked the team building"* (teacher FD). They also perceived the experience of learning AI as a student was valuable and helped them gain knowledge about AI, e.g., "*as an adult, I don't want to be embarrassed, but I don't understand it, it [ABC] was like a no pressure zone. The way that you all handle it that those who didn't know participated. So, I can just sit back and listen, but eventually, I was able to participate, that was a bonus"* (teacher RH). For the practicum experience, all the teacher interviewees appreciated the opportunity of teaching and reflecting on their teaching experience as it helped them become more familiar with the curriculum, deepen their understanding of AI, and develop pedagogy, e.g., "*Just like how the lessons work, like being actually asked to teach, it forces you to like, prepare for it and learn from it. And also, the reflections at the end of the debrief, like forces you to think about, how would I do in my classroom? I think that's the biggest thing I learned"* (teacher

HW). Four teachers highly valued the experience of co-teaching with other teachers, e.g., "*You always pick up wonderful tips when you're just in the presence of the teaching of a great teacher... So doing it with other teachers from my district, which would have never happened if it weren't for the practicum, it was great"* (teacher JM). Teachers felt the practicum built their belief that the topic of AI is age-appropriate for their students and motivated them to think about classroom implementations, e.g., "*For me, so coming into this not knowing much, I learned that this is doable with middle school students. Definitely"* (teacher RB). With regard to the constraints of the PD program, three teachers hoped to engage in richer discussions of the readings during the synchronous ABC meetings and felt the online asynchronous discussion was not sufficient. All teachers explained that the practicum required more time and energy to become prepared. On average they spent at least an hour on preparing for the teaching and another half an hour on coordinating with other teachers every day during the practicum.

Conclusions

Bringing AI into classrooms is not easy. This paper reports the design and findings of a PD model that extends learning over time and incorporates an experiential learning component. Our results suggest the PD model was effective in engaging and sustaining teachers' interest in AI and preparing them for offering AI education in classrooms. Learning AI as learners together with peer teachers proved to be a valuable opportunity for teachers; not only did they experience the struggle of learning challenging concepts, they also shared frustrations and started to build a sense of community. The practicum experience sharpened teachers' practices of teaching AI and helped confirm teachers' belief that middle school students are capable of learning AI. The daily reflections prompted teachers to recognize difficulties or problems in their teaching of AI and devise solutions, and motivated them to actively plan for the implementation of AI education in their own classrooms. It was noteworthy that EdAI teachers all voluntarily spent additional time preparing for the teaching during practicum. This expending of time and effort, while demonstrating teachers' enthusiasm, would present a barrier to participation for many teachers.

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Treading Lightly With Computing Education: Politicized Care as an Intervention of Black Life

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Abstract: This paper arises out of a need to take seriously interventions on anti-Black racism in the computing education space. We extend the framework of *Politicized Care* to an out of school space to explore how Black femme mentors' pedagogy opens up alternative experiences of computing education. We offer another frame for computing teaching and learning that develops protection and care as a part of deep intellectual work. This necessitates our attention to relationships within moment to moment teaching and learning alongside youth. We offer a vignette from a summer STEAM program that highlight aspects of *Politicized Care*. This paper offers a domain specific example of politicized care that may inform future research design.

Introduction

We urge you to tread lightly. To take care, to proceed with caution, to remember, as we journey towards cultivating more space for Black life. This urgency comes from a tradition of Black school teachers who found moments outside of the gaze of white supremacy to provide their Black students with material no textbook would offer (Givens, 2021). To affirm for children's spirits that there are spaces "they are wanted, where they [can feel] happy and inspired" (DuBois, 1935, p. 5). This work offers an example of how we might tread more lightly with the spirit of Black students within computing. Through the framework of *politicized care* (McKinney De Royston et al., 2017), we offer another frame for computing teaching and learning that develops protection and care as a part of deep intellectual work and as an intervention on anti-Blackness within computing education. This necessitates our attention to relationships within moment to moment teaching and learning alongside youth (McKinney De Royston et al., 2017). McKinney de Royston et. al. (2020, pp. 6-7) define politicized care as a framework that allows us to "further understand how Black educators who work outside of white supremacist and assimilationist frameworks conceptualize the notion of protection to enact it to protect Black children from racialized harm."

This is decidedly relevant within computing where the same techniques that students are taught can be applied to systems that further criminalize their existence (Benjamin, 2019; Browne, 2015; Jones & melo, 2021). Centering technological innovation solely as progress, neglects the reality that youth are being asked and invited into developing algorithms that further oppression (Noble, 2018) and creating large scale surveillance networks that ultimately restrict mobility for their communities (Browne, 2015; Benjamin, 2019). When students' physical, emotional, and psychic safety is taken seriously the educational space is transformed to allow them to expand their imagination around new subject matters. In this paper, we extend the politicized care framework to examine a STEAM summer enrichment program called HubSpace, where the programming activities were led by Black femme mentors. We ask: 1) How does Politicized Care help illuminate ways learners and educators can work together within out of school computing spaces? 2) How does Politicized Care shape how computer science is experienced by learners?

Background

Anti-Black racism (anti-Blackness) is the mechanism through which "Black humanity and human possibility are threatened and disdained "by a racial calculus and a political arithmetic that were entrenched centuries ago."" (Dumas & ross, 2016, p. 6) Anti-Black racism suggests that Black experiences are reducible rather than different and interdependent (Dumas & ross, 2016). Anti-Blackness also operates within the Libidinal Economy "i.e. systems of desire and instincts and fantasies and repulsion around skin tone, hair types, and bodies"(Crockett, 2014). This libidinal economy shapes other aspects of anti-Blackness such as experiences of colorism (Crockett, 2014), and the adultification of young Black people (Nxumalo & ross, 2019). The presence of anti-Black racism in the past replicates itself in the present, and cycles within education. This is demonstrated by a "legacy of federal state and district policies and practices designed to deprive black communities and children of educational resources" (Dumas & ross, 2016, p. 418).

We situate the pedagogies within the HubSpace programming group as demonstrating acts of protection and affirmation for young people through the lens of politicized care. Caring becomes political work due to the stakes teachers understand for their students as adults who have previously experienced the racialized harms of schooling. This framework consists of four main pedagogical themes: Political clarity (Beauboeuf-Lafontant, 2005), Communal Bonds (Morris, 1999), Potential Affirming, and Developmentally Appropriate (McKinney De Royston et al., 2017). These pedagogical themes build upon Culturally Relevant Pedagogies (Ladson-Billings, 1992) to attend to layered educational racialized and gendered values (Apple, 2011) within schools. The pedagogical themes are interrelated due to the way they are co-constructed by one another (McKinney De Royston et al., 2017). For example, data that highlights potential affirming pedagogy may also illustrate developmentally appropriate pedagogy.

This is important in contesting a norm of anti-Blackness within computing, where explicitly denouncing racism is met with a denial of its relevance to a "neutral" field like computing (Jones and melo, 2021). Further, this framework emphasizes acts of care as also political and necessary for rigorous intellectual engagement. Knowing the harms that Black professionals experience in the workplace (Jones and melo, 2021) leads to hesitation in emphasizing career or innovation as a primary goal for these pedagogical interventions. Rather the primary goals are 1) to build up educators to be able to adequately care for and love the students that they work with through addressing anti-Black racism and 2) to create computing education spaces that envision Black life. Educators who might take up politicized care within computing help broaden ways of measuring learning within computing in developmentally appropriate ways as evidenced by learner shifts in political clarity, communal bonds, and self-view.

Research design

Context

The data we analyze in this paper is from a 2019, six-week summer STEAM program called HubSpace where 25 rising sixth-grade Black and Latinx learners from a suburb of a major midwestern city worked in groups to develop apps. Many learners in this program were referred by the district as those who may need additional preparation for the transition between elementary and middle school. The curriculum was developed by the mentors in the space who focused on integrating reading and writing into a creative STEAM summer program. Some of the mentors' goals were for the youth to experience being makers, to offer compliments on learners thinking and participation, to care for the community, and prepare to be in sixth grade while having fun.

The seven mentors within HubSpace were people of white and Black backgrounds. The research team consisted of three people of respectively Iranian, Black, and Latinx backgrounds. Many youths viewed the research team as another set of mentors, as we were readily available as support for facilitating groups and answering questions from the curriculum. Similarly, the mentors were also invited to co-create field notes and participate in the ethnography as a part of a research practice partnership (RPP) (Coburn & Penuel, 2016). The primary mentor was Shai, and the secondary mentor was Stephanie. Both are Black femmes and participated in the research and teaching processes consistent with the team's approach RPP. An important detail about the program is that small teams of learners elected to take on the roles of designer, marketer, and programmer while designing apps. Our analysis focuses on the learners that occupied programmer roles.

Data and methodologies

The vignette is composed of a variety of data and experiences. We received IRB paperwork from 13 learners and 5 staff. We collected 6 weeks of audio, video in addition to images, and final artifacts such as project websites. We also explained to all participants that they could ask us to stop recording at any moment. After the summer we highlighted moments of interest within the data and content logged the co-constructed field notes, expanding their level of detail. The final set of field notes (Emerson et al., 2011) consisted of 24 summaries, 3 specific interactions, and 2 content logged programming sessions. We narrowed this data set to follow the trajectory of the programming group as the primary focus of this analysis. We also completed exit interviews with 11 participants which informed the vignette. In this paper, we highlight a vignette that was created from selected field notes. Pseudonyms were picked by participants and the research team. From the larger data set, we narrowed in on specific interactions that highlighted participants of the programming group who had a variety of experiences. To create this vignette we followed a mixed qualitative approach including content logging and ethnography. This vignette and analysis were member checked (Lincoln & Guba, 1985).

Vignette: Black Beauty

This vignette is an example of how within a research practice partnership a mentor's political clarity was supported. Shai's ability to note colorism supported a brief but intentional moment at the group level and acted as an intervention on a sometimes more subtle anti-Black ideology. The primary mentor Shai, identified as a maker for over 7 years at the time, worked for HubSpace and coded and tinkered in her spare time. She is originally from a nearby midwestern city, and an alum of the city's underfunded public school system. Shai worked with these young girls to identify a pattern of colorism, a prejudice towards preferring lighter skin tones. This form of prejudice can not only shape who is visually incorporated into an app design, but into decision making around who is worthy of friendship, who is beautiful, and who is intelligent. Through this example, we illustrate how the young people's shifts in ideology showed up in their app design.

A group of girls created an app, Black Beauty, that allowed Black folks to see different images of their hair and clothing in a gallery style. They recognized that the media rarely showed images of Black folks and wanted to offer examples of their beauty, and how to take care of it (haircare, skincare, etc). While their intention was to show the diversity of Black Beauty, they initially were more narrow in their selections of images of "Black Beauty." The marketers and designers in the group often stepped into the coding space to gather opinions on what images would be essential to the app.

During debriefs, mentors and researchers would exchange information on how learners might need more support. After observing Black Beauty's progress more closely, Shai said "I am noticing a lot of their images of blackness represent uh lighter skin people." This was echoed by research team member Layla who had noticed similar patterns among other girls in the program. Layla asked "Do you think you want to talk to them about that?" to which Shai replied, "Yeah, I am just now seeing it." This delved into a moment where Layla and Shai discussed a pattern of colorism in an existing beauty app that many of the girls in the program liked to use. Black Beauty's app could be seen as in conversation with this more popular app, filling a need that the girls may have noticed but not yet articulated.

Following the debrief, Shai asked Black Beauty's programmers "Where does your app start? What's the first thing you see?" and a student responded "African Americans." This comment and the earlier debrief affirmed Shai's choice to have a conversation around the topic of colorism, asking them to consider the diversity of Black folks in their app. This is a move that disrupted harm within a societal narrative of what beauty can be for Black folks and resulted in shifts in imagery and language on their final website. By the end of their time, they had created a draft of an app portraying Black folks of all different hues and hair textures.

On their app's website, the "about" section said: "Black Beauty inspires Black people to bring out their inner Black beauty. It starts working once you go to our home page. From there, there will be different categories. You press one of the categories and it'll lead you to different videos and images on that category. Black Beauty inspires black." They included an audio clip of them saying their slogan "Black Beauty inspires Black… period!" In their final presentation, they extended their purpose to say that their app also aims to offer comfort to Black people.

Discussion

This vignette offers insight on how the mentors' political clarity around colorism was able to help the Black Beauty group shift in consciousness around colorism. As a part of a research practice partnership, Shai was affirmed in noticing this form of anti-Blackness and supported in her further explorations with learners. These conversations cannot be held in accusatory ways, but rather in ways that help open learners' perspectives to what they may not have noticed they were participating in. The learners, whose political clarity was sharpened, shifted their app to highlight a variety of skin complexions and hair patterns. Additionally, Shai cultivated space for the learners to utilize African American Vernacular English (AAVE) as they described the work of their app, "Black Beauty inspires Black… period!" The youth's description also highlights how computing has the potential to be transformative of peoples' world views.

In part, Shai's interaction with this group was successful due to the prior communal bonds she had earlier established with the youth in this group. We see how established relationships supported youths' engagement with mentors, as well as mentors' intentions to understand and support these young people. One challenge, therefore, is negotiating between the availability of support for youth, and the need for mentors' rest to be able to sustain healthy relationships with youth. Having ready and available support and community is essential to these young people's learning experiences. Communal bonds are not structured unidirectionally from mentor to learners', rather they are co-created by youth and mentors engaging together.

Shai believed in these young people's desire to represent Black Beauty, and engaged them in potential affirming ways by pushing them appropriately towards disrupting internalized anti-Black racism by interrupting colorism based logic. They detailed that their app intervention "starts working once you go to the home page," and that they hoped it would offer comfort, showing their belief that they could also help others shift and explore differences in Black Beauty. While not placing ceilings on what youth might do for their apps, mentors also needed to discern when it was developmentally appropriate to offer comfort or to step in more technically. These decisions demonstrate care for the learners' spirits and potential.

Conclusion

Through this analysis, we have offered examples of how viewing interactions through the lens of politicized care opens up alternative models for teaching and learning. Models that are focused on treating young Black people as whole individuals, requiring care as a part of their education. We shift the emphasis from app design, in favor of emphasizing the relevance of communal bonds, political clarity, developmentally appropriate pedagogy, and potential affirmation as opening up an alternative experience for computing education. With this, young people were able to wrestle with subject matters that were meaningful to them, while knowing that the mentors were actively wanting to support their thinking.

This paper offers a domain specific example of politicized care that may inform future research design. Through looking at these examples educators might begin to reflect on their own political clarity and the ways they speak about the potential of their learners. As computing educators shape perceptions of future computer scientists, it is important that we begin to hold discussions around ethical computing and open up moments to interrogate anti-Black logics. Through communal bonds, we see how programming is developed relationally, which led to narratives from Black youth around joy, laughter, and realness in computing. In these moments where we center care and tread lightly, we see how Black Life appears.

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Detection of Goal Setting and Planning in Self-regulated Learning Using Machine Learning and Think-aloud Protocols

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Abstract: In this study, we used machine learning models to detect the goal setting and planning activities in self-regulated learning (SRL) based on the linguistic features of think-aloud transcripts. Specifically, we trained six types of machine learning models (i.e., decision tree, Gradient boosted decision tree, random forest, logistic regression, support vector machine, and neural network) on 2,792 think-aloud segments of medical students, who were asked to think out loud as they diagnosed virtual patients in a computer-simulated environment. The results suggested that machine learning models, especially Gradient boosted decision tree and neural network, could make accurate predictions. This study shows the possibility of using machine learning to free researchers from the labor-intensive work of coding think-aloud transcripts. This study also informs practitioners about automatically detecting students' SRL activities in real-time as they think aloud in learning, making the provision of timely feedback possible.

Introduction

Self-regulated learning (SRL) is a core competency for students' learning with technologies such as intelligent tutoring system, serious games, and immersive learning environments. The research on SRL over the past 30 years revealed that SRL is a determining factor of student performance across disciplines. To study SRL, researchers have developed a variety of instruments and techniques, among which think-aloud protocols (TAPs) gained a lot of attention. TAPs can concurrently capture the dynamics of students' SRL processes since TAPs involve asking students to verbalize their thinking as they learn (Greene et al., 2011). However, TAPs suffer from the shortcoming of being time-consuming and labor-intensive (Hu & Gao, 2017). There is also a concern about the involvement of subjective judgments when evaluating students' cognitive and metacognitive activities. In this study, we explored the possibility of predicting students' SRL activities in an automated fashion, using machine learning and TAPs. Specifically, we aimed to examine whether machine learning models can predict the occurrences of goal setting and planning activities in SRL based on the linguistic features of think-aloud transcripts. We focused on the goal setting and planning activities since they represented the largest proportion of SRL activities in our research context, which we will describe in the following sections.

Methods

Participant

The participants comprised 34 undergraduate medical students (67.6% females) from a large North American University. The average age of the participants was 23.3 (*SD* = 2.96).

Learning environment and task

In this study, students were asked to diagnose two virtual patients in an intelligent tutoring system (hereafter the system) designed for medical students to practice clinical reasoning skills. Specifically, the system first presents a case scenario, including patient description and symptoms, to the participants. The participants collect and store useful evidence items in an observation list within the system. They can also order medical lab tests to gain more information about the virtual patient. Moreover, the participants can search an embedded library when encountering unfamiliar medical terms, tests, and procedures. They propose one or more diagnostic hypotheses based on the collected information. Students finalize their solutions with a range of scaffoldings, such as ranking, organization, prioritization, and summarization.

Procedure and measures

We trained the participants on how to use the system before the study. The participants were also instructed to conduct think-aloud as they diagnosed two virtual patients. The think-aloud of each participant was recorded in real-time. Students were reminded to think out loud when there was a long silence. It is noteworthy that the order of patient cases was randomized to counterbalance its effect on the participants' problem-solving processes.

Analysis

We used two strategies (i.e., topic representations and verbs) to segment the think-aloud transcripts into units appropriate to our research context. Specifically, the think-aloud transcripts were coded into 2,792 meaningful units. Each unit generally addressed a particular instance of thought, intention, or action. Three researchers performed the segmentation independently, whereby they could ask for help from the group when encountering difficulties. We then coded whether or not each unit involved the goal setting and planning activities. The coding scheme is shown in Table 1. A unit would be coded as one if it involves such activities and otherwise it would be coded as zero. In total, there were 760 units coded as involving goal setting and planning activities. The inter-rater reliability was .813, which was acceptable (Syed & Nelson, 2015). Moreover, we used a text mining tool, LIWC (Linguistic Inquiry and Word Count) (Pennebaker et al., 2015), to analyze the linguistic features of each think-aloud unit. We deliberately chose the most informative features that correlate with the outcome (see Table 2). In doing so, we reduced the computational complexity of building predictive models, and reduced data storage and collection requirements (Brooks & Thompson, 2022).

Table 1
The scheme for coding SRL behaviors of goal setting and planning in clinical reasoning

Sub-Code	Definition
Goal setting	Formulating a superordinate goal
Sub-goaling/planning: Ordering lab tests/	Forming a plan to order lab tests/identify symptoms
Sub-goaling/planning: Searching for information	Forming a plan to search for information in the library
Sub-goaling/planning: Using an external source to get explanations	Forming a plan to request a consult from the system
Sub-goaling/planning: Organizing thoughts about the action plan by self-questioning	Asking questions to oneself in reference to the action plan being formulated

Table 2
The selected linguistic features

Category (words)	Subcategory (words)	Example words
Function words	Pronouns (74)	I, my, myself, we, lets, us, he, she, that, this, it
	Prepositions (83)	to, of, in, for
	Conjunctions (49)	and, but, so, as
	Negations (8)	no, not, never, nothing
Cognitive words	Insight (383)	know, how, think, feel
	Causation (169)	how, because, make, why
	Discrepancy (108)	would, can, want, could
	Tentative (230)	if, any, something, or
	Certitude (131)	really, actually, of course, real
	Differentiation (325)	didn't, although, another, except
Memory words	- (26)	remember, forget, remind, forgot
Conversational words	Assent (50)	yeah, yes, okay, ok
	Non-fluencies (21)	oh, um, uh, ii
	Filters (24)	wow, so, you know

Afterward, we trained six types of machine learning models (i.e., decision tree, Gradient boosted decision tree, random forest, logistic regression, support vector machine, and neural network) to predict the occurrences of goal setting and planning activities, using the selected linguistic features of think aloud transcripts. We chose the six models based on the nature of the problem (i.e., a binary classification problem) and the size of our data. For instance, decision tree and random forest are generally better for smaller data sets. We used the 10-fold cross validation to assess the model performance. The performance metrics included classification accuracy, precision, recall, F1 score, and the value of Area Under Curve (AUC). Classification accuracy is the proportion of correctly classified examples. Precision is the proportion of true positives among instances predicted as positive. Recall is the proportion of true positives among all actual positives. F1 is also an important evaluation metric in machine learning, and F1 score is the weighted average of precision and recall. The formulas were shown in Table 3. Moreover, we evaluated the models' overall capacity for distinguishing between classes by checking the ROC (Receiver Operating Characteristic) curve and the AUC results (Mandrekar, 2010).

Table 3
Performance metrics for evaluating machine learning models

	Actually positive	**Actually negative**	**Performance metrics**	
Predicted positive	True positive (TP)	False positive (FP)	(1) Accuracy = $\frac{TP+TN}{TP+TN+FP+FN}$	(2) Precision = $\frac{TP}{TP+FP}$
Predicted negative	False negative (FN)	True negative (TN)	(3) Recall = $\frac{TP}{TP+FN}$	(4) F1 = 2 $\frac{precision \cdot recall}{precision+recall}$

Results

The performance metrics of the six types of machine learning models are shown in Table 4. The results indicated that the Gradient boosted decision tree (GBDT) is superior to others given that it has the highest values of classification accuracy (.752), F1 score (.718), precision (.726), and recall (.752). Although neural network presents the highest value of AUC (.733), the AUC result of GBDT is acceptable (>.70) (Mandrekar, 2010). Taken together, GBDT is deemed best in predictive modeling, and its performance metrics indicate the feasibility of detecting goal setting and planning activities from think-aloud protocols in general.

Moreover, we compared the performance of the machine learning models when they targeted specifically at think-aloud protocols coded as either involving no goal setting and planning activities (i.e., class 0) or having goal setting and planning activities (i.e., class 1). The evaluation results are shown in Table 5. Considering the uneven class distribution (i.e., a large number of actual negatives), we relied on the F1 score to seek a balance between Precision and Recall. The results showed that logistic regression performed best among the models when class 0 was entered as the target class (F1 = .846). When taking class 1 as the target class, neural network performed best, with F1 = .401 (see Table 5 and Figure 1). The precision and recall metrics suggested that neural network was better than randomly guessing (probability = 760/2,792 = .272).

Table 4
The average performance of machine learning models over classes

Model	**AUC**	**CA**	**F1**	**Precision**	**Recall**
Decision tree	.594	.681	.675	.671	.681
Gradient boosted decision tree	.723	**.752**	**.718**	**.726**	**.752**
Random forest	.690	.729	.702	.698	.729
Logistic regression	.703	.746	.693	.718	.746
Support vector machine	.526	.519	.546	.617	.519
Neural network	**.733**	.743	.718	.716	.743

Note: AUC = Area under curve, CA = classification accuracy.

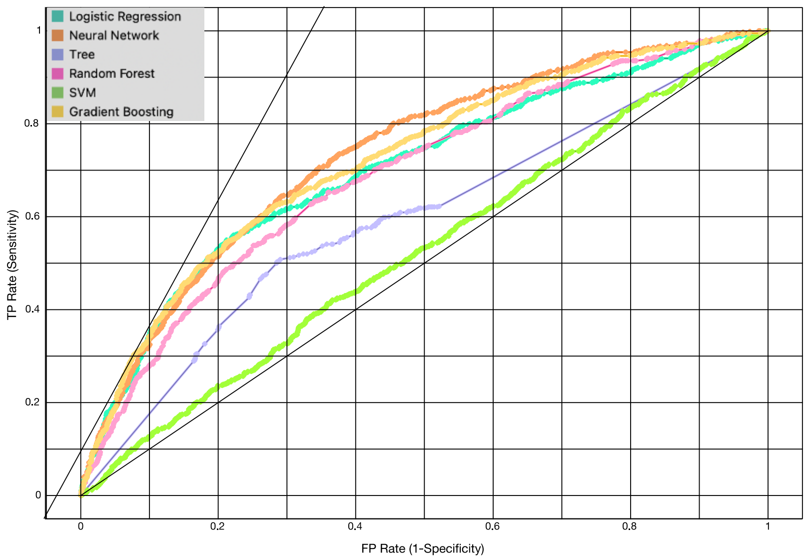
Table 5
The performance of machine learning models of each target class

Model	**Class 0 – No target action**			**Class 1 – Goal setting/planning**		
	F1	Precision	Recall	F1	Precision	Recall
Decision tree	.784	.771	.799	.383	.404	.364
Gradient boosted decision tree	.845	.775	.930	.378	.597	.276
Random forest	.828	.771	.894	.367	.505	.288
Logistic regression	**.846**	.758	.956	.283	.611	.184
Support vector machine	.613	.741	.522	.367	.286	.512
Neural network	.836	.779	.903	**.401**	.548	.316

Note: Target 0 refers to the think-aloud protocols coded as involving no goal setting and planning activities, and target 1 refers to those coded as involving goal setting and planning activities. The scores are computed separately for class 0 as a target class (the middle three columns), and class 1 as a target class (the right three columns).

Figure 1

The ROC of different machine learning models for detecting goal setting/planning



Discussion and conclusion

This study explored the feasibility of detecting the occurrences of goal setting and planning activities in self-regulated learning, leveraging machine learning models and think-aloud protocols. The results suggested that we could accurately predict whether students were engaged in goal setting and planning activities or not since all the performance metrics of Gradient boosted decision tree (GBDT) were larger than .70. Since the primary objective of this study was to detect instances of SRL behaviors related to goal setting and planning activities, we evaluated the performance metrics of machine learning models that aimed to predict the targeted state. We found that machine learning models, especially neural network, performed better than randomly guessing the occurrences of goal setting and planning activities. This study has significant methodological implications. Specifically, this study showed the possibility of using machine learning models to free researchers from the labor-intensive work of coding think-aloud transcripts. Moreover, this study informs instructors and practitioners about the automatic detection of students' SRL activities in real-time as they think aloud in learning, making the provision of timely feedback possible.

This study lays the foundation for future studies. First, it is crucial to explore the relations between SRL activities and the linguistic features of think-aloud transcripts from a psychological perspective. It would also be interesting to expand the features of think-aloud data for predicting SRL activities with machine learning models, such as acoustic characteristics of students' think-aloud. Moreover, the methodology used in this study can be applied to the investigation of other SRL activities such as monitoring and self-reflection.

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A Test of Learning Progress Models Using an AI-Enabled Knowledge Representation System

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Abstract: This study tested two competing learning progress models - the three-stage and two-stage models - based on an AI-enabled formative assessment tool. Additionally, human-rated scores were used to further validate the models. The data for this investigation consisted of expository essays about a complex problem scenario written by 116 students and 6 experts. The validation analyses, including descriptive statistics, C-LCDM, and group-mean difference tests, demonstrated that the two-stage model was a better framework given the technology. The findings showed the potential of the model to determine learners' conceptual change over time.

Introduction

From an expertise development standpoint, learning is a developmental process toward expert-like problem-solving knowledge and skills (Alexander, 2004; Chi, 2006). Kim (2012, 2015) built on expertise development theories to conceptualize and test learning progress models, shifting the focus of development from long-term change to short-term change in task-level problem-solving in the classroom context. Kim (2012) theorized that learner mental models could represent different levels of understanding of a problem situation, and thus tracking mental model changes could explain how learners develop expertise. A subsequent study proposed computational techniques to extract a knowledge structure from a student's expository essay and leveraged a specific technique, the Continuous Log-Linear Cognitive Diagnostic Model (C-LCDM) method (Bozard, 2010), to test levels of mental models (Kim, 2015).

In this study, we use an AI-based assessment system called SMART (Student Mental Model Analyzer for Research and Teaching) to extract mental models from students' essays and test two competing learning progress models. Since different modeling techniques can produce varying concept maps, it is important to validate relevant diagnostic models. SMART's diagnostic model can monitor students' learning growth over time. The study aims to answer the following questions:

- How do the models explain the stages of learning progress?
- How closely do the computerized diagnostic results align with human judgments?

Learning progress models

Learners' problem-solving abilities can be reflected in their knowledge structure, which is necessary for solving complex problems. Assessing students' problem-solving skills requires examining their knowledge base, which includes ideas and concepts learned from the problem situation (Gijbel et al., 2005). Scholars have introduced three dimensions to understand knowledge structure, known as the 3S dimensions (Kim, 2012): (a) the surface dimension, which concerns the number of constituents of a mental model (e.g., concepts and their relations), (b) the structural dimension, which describes how those components are connected and organized in the knowledge structure (e.g., size and cohesion), and (c) the semantic dimension, which reflects the extent to which students include underlying ideas and concepts used by experts. We use the 3S dimensions to characterize stages of two competing models (i.e., three-stage and two-stage models) as detailed in Table 1. The three-stage learning progress model is based on the Model of Domain Learning (Alexander, 2004) and conceptualizes three stages: acclimation (the initial stage in which most learners experience a lack of pre-structural knowledge), competent (in which learners reconsider and repair their irrelevant preconceptions through teaching and learning), and proficiency-expertise (in which proficient learners construct a sufficient knowledge structure reflecting the problem situation). The two-stage model, called conceptual change, explains that for complex problems, conceptual change from a naïve knowledge model to an informed problem space often requires a shift in fundamental knowledge structure, especially (Chi, 2008).

Methods

Research context and data source

This study collected data from 116 undergraduate students and six professors in the field of instructional sciences. The students were asked to provide their evaluation on the potential factors and variables that led to the failure of a technology innovation project: the implementation of tablet PCs in high-school classrooms that did not result in significant improvements in classroom practices and student performance. The six professors collaborated to develop a reference response using a Delphi research process. To analyze the written essays, the researchers utilized a knowledge-based AI system called SMART. The SMART system performs various core analytics tasks, such as extracting text variables from the essay, eliciting a concept map, abstracting the key knowledge structure from the concept map, comparing the student's concept map to an expert's concept map, and generating multidimensional similarity measures.

Table 1
Competing Learning Progress Models

Three Stage Model	Description	Two Stage Model	Description
Acclimation	(a) All dimensions (surface, structural, and semantic) are quite dissimilar to expert models; or (b) knowledge structures have similar surface dimension to expert models but are missing some structural and semantic dimensions.	Misconception (Novice)	(a) All dimensions (surface, structural, and semantic) are quite dissimilar to expert models; (b) knowledge structures have similar surface dimension to expert models but are missing some structural and semantic dimensions; or (c) Structural dimension might appear to be mastered because mental models, which consist of a small amount of contextual and abstract knowledge, are likely to look cohesive and connected.
Competence	(a) Structural dimension might appear to be mastered because mental models, which consist of a small amount of contextual and abstract knowledge, are likely to look cohesive and connected; or (b) student and expert models are highly similar in semantic dimension but dissimilar in surface and structural dimensions.	Conception (Expert)	(a) Structural dimension shows sufficient complexity while surface dimension is adequate, but not enough to guarantee a semantic fit; (b) knowledge structures are well-featured in all dimensions (surface, structure, and semantic); (c) a significant number of principles (semantic) create a cohesive structure (structural) but with a small number of concepts (surface); or (d) student and expert models are highly similar in semantic dimension but dissimilar in surface and structural dimensions.
Proficiency-Expertise	(a) Structural dimension shows sufficient complexity while surface dimension is adequate, but not enough to guarantee a semantic fit; (b) knowledge structures are well-featured in all dimensions (surface, structure, and semantic); or (c) a significant number of principles (semantic) create a cohesive structure (structural) but with a small number of concepts (surface).		

Data preparation

The SMART analytics system generates concept map indices and knowledge components. Model comparisons result in similarity measures (ranging from 0 to 1) that fall under one of the 3S dimensions, as outlined in Table 2. These hypothetical relationships between the similarity measures and the 3S dimensions were validated by Kim (2015). To further validate the results, two human evaluators used a rubric (Gao et al., 2019) to score the learner responses on four dimensions: content quality, content coverage, content coherence, and argument quality, each of which was rated on a six-point scale. The interrater reliability scores ranged from 0.87 to 0.91 (acceptable ICCs > 0.80; Graham et al., 2012).

Data analysis

We utilized the Continuous Log-Linear Cognitive Diagnostic Model (C-LCDM) method (Bozard, 2010) to identify the stages of mental models and compare the two competing learning progress models. The 3S dimensions are attribute variables in C-LCDM, and each dimension can be considered mastered when its probability is above 0.5 (Rupp et al., 2010). Therefore, the three dimensions ($k = 3$) create eight classes (2^k classes). The mastery profiles of attributes for individuals determine their latent class membership.

Table 2
Model-Based Similarity Measures

Similarity Measure	Definition	3S structure
Number of concepts	Compare the number of concepts (nodes) in two models	Surface
Number of relations	Compare the number of links (edges) in two models	Surface
Density of graphs	Compare the density of two models	Surface
Mean Distance	Compare the mean distances in two models	Structure
Diameter	Compare the largest geodesics in two models	Structure
Concept Matching	Compare semantically identical concepts	Semantic
Propositional Matching	Compare fully identical propositions (edges) between two concept maps	Semantic
Recall-C	The proportion of key concepts that appear in a student summary	Semantic
Recall-P	The proportion of key relations that appear in a student summary	Semantic

Findings

The results revealed the presence of four latent classes: classes 1, 3, 5, and 7, which represented 17%, 31%, 12%, and 40% of the total latent classes, respectively. According to the two learning progress models, these classes exhibited acclimation (29%), competence (31%), and proficiency (41%) in the three-stage model, and misconception (60%) and conception (40%) in the two-stage model (as shown in Table 3). However, contrary to its theoretical assumption, the stages were arranged in descending order, with the second stage of the three-stage model exhibiting lower values in most similarity measures than the first stage. In contrast, the two-stage model displayed an increase in all similarity measures from the misconception to the conception stage.

Table 3
The Estimated Final Class Counts and Proportions

Latent Class	3S Attribute			Three Stages	Two Stage	Estimated Classification (Count)
	S1	S2	S3			
Class 1 (C_1)	0	0	0	Acclimation	Misconception	0.171 (19)
Class 2 (C_2)	0	0	1	Competence	Conception	-
Class 3 (C_3)	0	1	0	Competence	Misconception	0.308 (36)
Class 4 (C_4)	0	1	1	Proficiency	Conception	-
Class 5 (C_5)	1	0	0	Acclimation	Misconception	0.120 (14)
Class 6 (C_6)	1	0	1	-	-	-
Class 7 (C_7)	1	1	0	Proficiency	Conception	0.402 (47)
Class 8 (C_8)	1	1	1	Proficiency	Conception	-

Note. $N = 116$. 3S attributes involve the three dimensions of knowledge structure: Surface (S1), Structural (S2), and Semantic (S3). 0 = absent/non-mastered and 1 = present/mastered.

We conducted an analysis to determine if the two learning progress models could differentiate human-rated scores across the four criteria outlined in Table 4. The results of all group-mean difference tests indicated significant differences between the stages in terms of rubric scores. Consistent with our previous findings, the second stage of the three-stage model received lower scores compared to the first stage. In contrast, the two-stage model aligns with the theoretical assumption, as evidenced by increasing rubric scores from the misconception to the conception stage.

Discussion

An AI-enabled knowledge representation technology can directly influence the way knowledge structures are modeled from students' textual explanations. In this study, the AI-enabled assessment setting demonstrated the potential of the two-stage learning progress model (conceptual change) to characterize the stages of mental models regarding complex problem situations. For example, some students rely on deeply entrenched naive knowledge that is incorrect (misconception), while others leverage sufficient prior knowledge connected to a given problem situation (conception). Pedagogically, the two-stage model, along with the proposed technology-based measurement, can detect students' conceptual change when conceptualizing complex problems. Instructors can use this model to monitor individual students' learning progress and determine when and how to provide instructional remedies, or when to move on to the next assignment. This initial work opens pathways to future studies, and the suggested models and methods should be tested in various technology-based knowledge assessment environments with problems. For example, well-structured problems in closed-world domains or source-based writing tasks (summarization) may produce a new dynamic in the 3S dimensions and a learning progress model.

Table 4
Means, Standard Deviations, Spearman's rho, and Group Difference Statistics for Rubric Criteria

	Three-Stage Model			*F*	Sig.	Two-Stage Model		*F*	Sig.
	Stage1	Stage2	Stage3			Stage1	Stage2		
Content	2.338	1.861	3.152	21.79	.00	2.093	3.152	37.35	.00
Quality	(1.133)	(.743)	(.809)			(.975)	(.809)		
Content	2.132	1.931	2.663	7.61	.00	2.029	2.663	14.32	.00
Coverage	(.956)	(.767)	(.913)			(.863)	(.913)		
Content	2.241	2.056	2.913	12.44	.00	2.243	2.913	20.01	.00
Coherence	(.903)	(.780)	(.652)			(.867)	(.652)		
Argument	2.221	1.875	3.054	19.82	.00	2.043	3.054	31.37	.00
Quality	(1.053)	(.721)	(.845)			(.908)	(.845)		

Note. $**p \leq .01$.

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Tortuga: Building Interactive Scaffolds for Agent-based Modeling and Programming in NetLogo

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Abstract: Agent-based Modeling and Programming (ABM & P) is widely used in educational settings to promote computational thinking and complex systems thinking. In this paper, we introduce Tortuga, a novel technical system for building interactive scaffolds for ABM & P. Tortuga lowers the threshold and raises the ceiling for constructionist curricular designers. It allows designers to build interactive scaffolds with simple NetLogo commands. These scaffolds can be aware of computational models' emergent behaviors and can react to learners' interactions in modeling spaces. We introduce its technical structure and start to explore how that structure supports learning designs. To understand Tortuga's design affordances, we implemented three types of interactive scaffolds for eight NetLogo models in out-of-school, online learning contexts. Our preliminary quantitative analysis points to potential benefits of content-specific and programming-oriented scaffolds to engage learners with ABM & P.

Introduction

Agent-based Modeling (ABM) investigates scientific phenomena by computationally modeling the behavior of individual autonomous computational agents. This approach is particularly valuable for learners as a way to investigate and understand complex phenomena (Wilensky & Resnick, 1999). Building agent-based models necessitates the learning of agent-based programming (ABP), wherein learners need to program rules for individual agents.

With many studies of ABM & P in classroom environments, less work examined learners' use of ABM & P in informal contexts. In such environments, there is a greater need for technology-enabled scaffolds to support students in engaging with ABM & P. Yet the design of such scaffolds can take significant expertise and effort to implement. The desire to engage learners in online, informal contexts brings opportunities for engaging diverse learners from different socio-economic-cultural backgrounds and further challenges for designers.

To address the challenges, we introduce the design of the first technical platform, Tortuga, that 1) focuses on the learning of ABM & P; 2) lowers the threshold and amount of effort of designing and implementing cross-platform interactive scaffolds; and 3) flexibly supports multiple paradigms of design and diverse learning needs. Through enabling scaffolds to react to the modeling space (i.e., what is happening in the model) and learner interaction, Tortuga naturally invites both learner-adaptable and learner-adaptive scaffolds.

Due to page constraints, we could only briefly explore the affordances of Tortuga. Turtle Universe (TU, Chen & Wilensky, 2020) was launched as a ubiquitous, mobile-first incarnation of NetLogo that aims to engage online, out-of-school learners. On this platform, we implemented sample learning designs on 8 models with 3 paradigms: **content-agnostic**; **content-specific**; and **programming-oriented**. Our preliminary analysis mainly explored: 1) *Were our interactive scaffolds helpful for learners' meaningful engagement with ABM or P?* 2) *Were the impacts of the three paradigms of interactive scaffolds different?*

Related Work

For the past decades, NetLogo has helped educators and learners understand topics of complex systems, such as feedback, emergence, critical parameters, and sensitive dependence (Tisue & Wilensky, 2014). One of the main goals of the NetLogo ecology is to bring ABM & P to a broader audience. The widespread availability of mobile devices for youth brings opportunities for engaging young learners in out-of-school, informal learning contexts (Chen & Wilensky, 2020). Reciprocally, it brings new challenges to scaffold engagement and learning for diverse audiences and generates fresh and urgent needs for technology-enabled scaffolds: learners' time could be more fragmented, their engagement could be more interest-driven, and instructors could be less available.

In this paper, we adopt Collins et al. (1991)'s definition of scaffolding which revolves around experts' support for novices to carry out tasks. The scaffolds will eventually be ***faded***, and learners could carry out similar tasks without them. Extending the notion of scaffolding to support from software, Jackson et al. (1998) discussed two strategies of technology-enabled scaffolds: ***learner-adaptive***, where the design will automatically change to respond to learners' needs; and ***learner-adaptable***, where the design enables learners to initiate the ***fading*** of scaffolds. The scaffolding analysis framework (Sherin et al., 2004) stresses the necessity to compare learning performance between unscaffolded and scaffolded situations. Scaffolds are also relative: while ABM & P are frequently regarded as an approach to scaffolding learning of domain knowledge (e.g., Basu et al., 2015), the learning of ABM & P needs its own scaffolds as well (Sengupta et al., 2013).

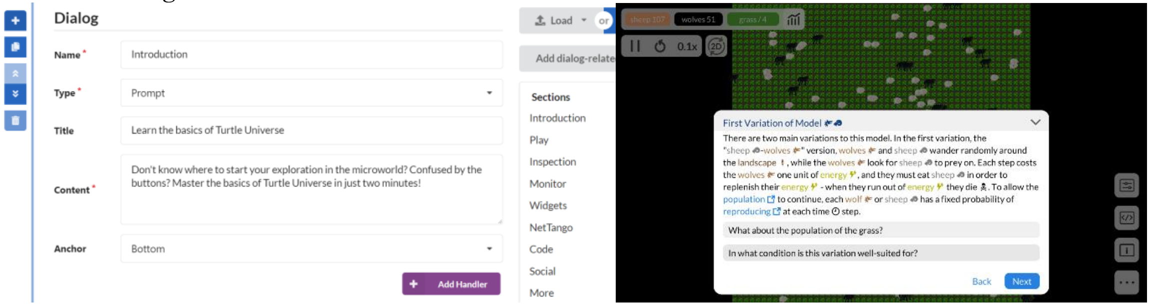
NetLogo provides several built-in features for designing scaffolds, but there are also tradeoffs in using them. For example, the scaffolding interfaces of BEAGLE curriculum (Novak & Wilensky, 2007) leads to much more complicated code, limiting learners' capability to understand or build on that model. Introducing the NetLogo language to novice learners is also difficult. Blocks-based interfaces for ABM & P, such as NetTango Web (Horn, Baker & Wilensky, 2021), or CTSiM (Sengupta et al., 2013) were launched to provide a "code-first" or "quickstart" environment to lower the threshold further. However, building those modeling interfaces requires significant technical expertise, and they often come with their own needs for scaffolding as well.

In this section, we briefly presented some related work that discusses the importance of ABM & P and the efforts to broaden its access; that defines the design goals and strategies of technology-enabled scaffolds; and that attempts to scaffold ABM & P through technology design. We believe it is necessary to further lower the threshold for designers to create technology scaffolds that are learner-adaptive and learner-adaptable.

Technological System Design

Figure 1

(a) The Visual Editor of the Tortuga System and (b) Screenshot of Wolf Sheep Predation's Interactive Tutorial, built with Tortuga.



Name* Introduction

Type* Prompt

Title Learn the basics of Turtle Universe

Content* Don't know where to start your exploration in the microworld? Confused by the buttons? Master the basics of Turtle Universe in just two minutes!

Anchor Bottom

First Variation of Model

There are two main variations to this model. In the first variation, the "sheep -wolves " version, wolves and sheep wander randomly around the landscape , while the wolves look for sheep to prey on. Each step costs the wolves one unit of energy , and they must eat sheep in order to replenish their energy - when they run out of energy they die . To allow the population to continue, each wolf or sheep has a fixed probability of reproducing at each time step.

What about the population of the grass?

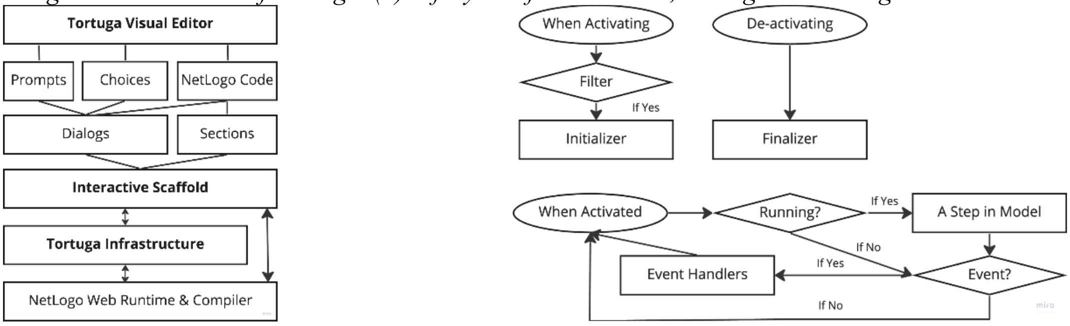
In what condition is this variation well-suited for?

(a) (b)

The technical design of Tortuga aims to bring a low-threshold, high-flexibility way of designing, developing, and implementing technology-enabled interactive scaffolds for ABM & P. Using the NetLogo language and a visual editor (Fig 1a), Tortuga eliminates the need for designers to learn complicated web-based technology for creating scaffolds. The deep integration between Tortuga and NetLogo allows designers to build scaffolds that could capture learners' emergent interactions and the models' emergent behaviors (see the example in Fig 1b). Tortuga is built on the infrastructure of NetLogo Web and works in parallel with NetTango Web (Horn, Baker & Wilensky, 2021), the domain-specific block-based programming interface maintained by the NetLogo team.

Figure 2

(a) The Technological Architecture of Tortuga. (b) Lifecycle of a "Section", the logical building block



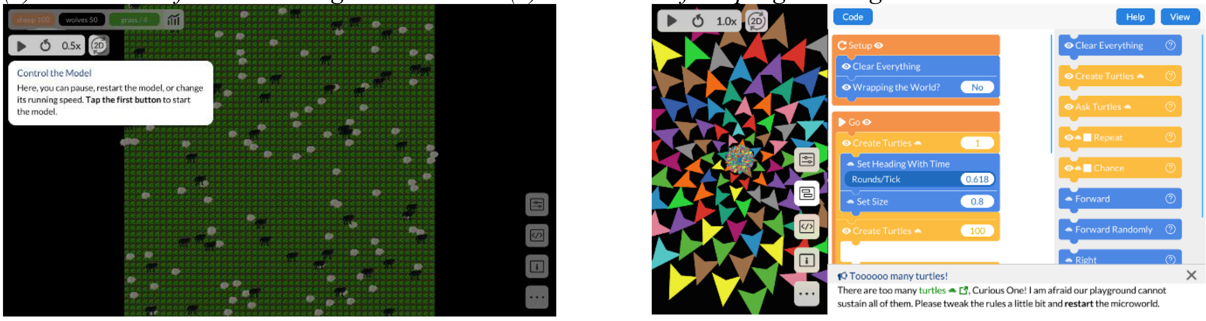
Interactive scaffolds built with Tortuga are capable of interacting with both its own infrastructure and NetLogo Web's runtime and compiler (Fig 2a). By keeping the interactive scaffolds separate from, but running in the same context as the model code, the designers gain access to 1) new customizable and programmable interface widgets such as dialogs and stencils (Kelleher & Pausch, 2005); 2) new capabilities to operate on and take input from most of NetLogo's interface widgets; and 3) new affordances to react to the learner interaction (e.g. changing a certain parameter, or clicking somewhere) and the modeling space (e.g. when the status of agents changes). Fig 2a and 2b demonstrate its main building blocks: 1) Section, similar to a unit or sub-unit in a curriculum; and 2) Dialog, similar to a page or paragraph. The main difference between a traditional curriculum and Tortuga Interactive Scaffolds (TIS) is that while the former is designed linearly, the latter can be designed with a network of triggers.

Sample Learning Design

We designed and implemented 9 sets of TIS. One of them is a content-agnostic interface tutorial. The other 8 sets cover diverse scientific topics, such as biology (Wolf Sheep Predation) or physics and chemistry (GasLab Gas in a Box). Finally, we created a new model (Pocketworld Playground) to introduce ABP through a block-based programming space. All the scaffolds and the Tortuga system are open-sourced.

Figure 3

(a) Screenshot of the content-agnostic tutorial. (b) Screenshot of the programming tutorial.



Control the Model

Here, you can pause, restart the model, or change its running speed. **Tap the first button** to start the model.

Toooooo many turtles!

There are too many turtles, Curious One! I am afraid our playground cannot sustain all of them. Please tweak the rules a little bit and **restart** the microworld.

Fig 3a demonstrates the first paradigm of sample learning design that is **content-agnostic**, mainly to introduce the usage of the software. Here, the stencil-based design asks learners to carry out a specific task and is conceptually similar to Kelleher and Pausch's (2005). The second **content-specific** paradigm comprises 7 tutorials that aim to support first-time learners' exploration at their own pace. Designed with existing learning materials accompanying the models with slight changes of texts, we conducted another embedded experiment: for learners to opt out of the scaffolds, similar texts are still available. Fig 3b shows some design highlights: 1) learners can choose to "learn more" of concepts; 2) learners can choose to "ask questions"; 3) learners can choose to interact with the world instead. In addition, each interface widget receives a question mark that will trigger more information. The third paradigm, the **programming-oriented** tutorial, extends the previous one with several major differences. As the introductory model for ABP, the Pocketworld Playground is designed for learners to explore the space of creativity through programming. Instead of a mostly linear task structure, this tutorial was designed as a network, with 6 major pathways and many branches that fit different levels of prior knowledge and types of personal interest. It also comes with learner-adaptive scaffolds that react to learners' modeling decisions, such as when a learner creates too many turtles in the modeling world (Fig 3b).

Preliminary Study

We implemented all scaffolds in Turtle Universe since early 2021. Then, we collected and analyzed anonymized log data from consented learners during a 14-month period. The timing of user interaction suggests that most were K-12 age learners in out-of-school contexts. Our observation and informal conversations show that most learners had little knowledge of ABM & P before. By filtering the dataset to only include first-time users' first visit to any project, we excluded the effect of learners' prior exposure to Turtle Universe. Learners who spent less than 10 seconds in any model are also excluded. A total of 7,256 learners were left in our study.

Three quasi-experimental conditions were created through TU's design, each with two groups. Each first-time user is presented with two options: "*Free Exploration*", leading to the content-agnostic scaffolds for all but one model; and "*Guided Intro*", leading to the model-specific scaffolds. Learners were free to decide whether and when to stop using the scaffolds. Depending on learners' reaction to the scaffolds, two groups are created out of this situation: learners who engaged with the scaffolds (quasi-experimental); learners who opted out of the scaffolds (quasi-control). Then, we used regressions to compare the effectiveness of each condition on learners' engagement, with fixed effects to control the differences between models. Building on existing studies (Dewan et al., 2019), we used the following metrics from the log data to measure learning engagement:

1. **Time spent in the model (and excluding on Tortuga interfaces)**, to understand learners' engagement and if learners' engagement did increase other than simply reading the prompts;

2. **Total time spent in 8 scaffolded models within the 14-month period**, to reflect the extent of voluntary engagement with ABM & P, which suggests individual interests of learners (Michaelis & Weintrop, 2022);
3. **Number of exploration or tinkering events** (e.g. changed the value of a widget in ABM; added, changed, or removed programming blocks in ABP), to measure learners' deeper engagement with ABM & P.

We found that: 1) While all types of scaffolds improved learners' total time spent in the model, the **programming-oriented** condition performed the best (+223%), followed by **content-specific** (+57%) and **content-agnostic** (+31%). 2) **Content-agnostic** increased engagement mostly through reading prompts (no significant change), while other 2 conditions successfully improved engagement beyond them (+257%/+24%); 3) the **programming-oriented** condition performed the best in helping learners explore or tinker with the model (+666% in event occurences), followed by **content-specific** (+66%), while the **content-agnostic** condition saw a decline (-20%). 4) Learners in **programming-oriented** (+71%) condition engaged more with those models in the long run. All findings are statistically significant ($p < 0.05$).

Discussion

Tortuga is designed as a flexible technology system for developing interactive scaffolds for ABM & P learning activities while lowering the threshold. It could be used to design scaffolds as simple as two-screen prompts, or as complicated as a network. *What could be the cause of the different learning impacts between the conditions?* While the content-agnostic scaffold increased learners' engagement, it likely does that by requiring learners to follow steps. On the other hand, simply turning existing learning materials into interactive scaffolds, with a little bit of story-like framing, could produce significant gains in engagement. The scaffold's understanding of the modeling space, as well as its ability to support open-ended programming activities, could also be powerful, as shown in the programming-oriented scaffold. That being said, our study is limited by a certain learning context (online, out-of-school, informal). To better support learning designers and learners of ABM & P, it remains on us to conduct further studies with learning designers and learners in more diverse learning contexts.

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An Investigation of Knowledge-Based AI vs. Human Evaluation in the Context of Academic Summary Evaluation: Similarities, Dissimilarities, and Being Toward Mutual Understandings

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Abstract: This study aims to explore the similarities and dissimilarities of knowledge-based AI evaluations vs. human evaluations and discuss how they can be utilized for formative feedback in academic summary writing. Data were collected from 62 students who utilized AI-based formative feedback to make revisions to their summaries. We compared indices on three dimensions (surface, structure, semantic) that were automatically generated through this software with human-rated evaluations. MANOVA results of learners' initial draft and final revision showed learning gains in the semantic dimension and human-evaluated scores. Some significant correlations were observed between automatic and human-rated evaluations. Given that each measure can be interpreted to provide different insights, we suggest combining knowledge-based AI and human evaluations for rich and informative feedback.

Introduction

Instructors have used summary writing to assess reading comprehension and to scaffold students' concept learning (Dunlosky et al., 2013; Kim & McCarthy, 2021). Namely, learners can acquire knowledge while processing the given material, understanding its structures, identifying key concepts, and organizing these into words. To support this process, evaluating learner performance and providing timely feedback is important.

A typical means to evaluate summaries of texts is either through knowledge-based AI systems or human evaluation. The use of knowledge-based AI for evaluation is an emerging field, fueled by the development of natural language processing techniques (Hu et al., 2022). Technology-enabled assessment is perceived as objective, free from bias and stereotypes, able to produce timely feedback to learners, and having potential when there is a lack of human evaluators (Belz & Reiter, 2006; Lewis Sevcikova, 2018; Mithun et al., 2012). However, with many techniques still focused mainly on corpus-based metrics, key concepts have to be identified beforehand and only mathematically calculatable variables are able to be judged (Belz & Reiter, 2006; Mithun et al., 2012). Thus, there have been arguments that automatic evaluations are yet to replace human evaluations (Hu et al., 2022). On the other hand, human evaluation is able to judge summaries holistically, taking argument qualities and aesthetic styles into account (Lewis Sevcikova, 2018). However, human ratings consume much time and effort, and training evaluators is also a challenging task (Brookhart & Chen, 2015; Lewis Sevcikova, 2018). There is also the issue of human raters showing low correlations between each other, especially when no clear rubric exists to evaluate (Belz & Reiter, 2006; Hu et al., 2022; Mithun et al., 2012).

As such, the characteristics of these methods of evaluations differ in many ways. In this study, we aim to use academic summaries to explore the relationship between the two evaluation indices and discuss how they can supplement each other.

Methods

Research context and data source

Data were collected from 62 students across six semesters of an instructional technology course. The course was offered in an asynchronous online format, with learners participating in weekly summary writing, quizzes, and discussions. While learners submitted their summaries directly to the university learning management system for most of the semester, they used a web-based technology that provides knowledge-based AI evaluation and formative feedback for one week. The system provided learners with multimodal feedback, including visual and textual information, and learners were allowed to make as many revisions as they preferred. We used the summaries and indices generated from this interaction for this research.

Knowledge-based AI evaluation

We used the Student Mental Model Analyzer for Research and Teaching (SMART) system to compute knowledge-based AI evaluation indices. SMART is an automated summary evaluator which provides formative feedback on submitted summary by utilizing concept maps as re-represented mental models. Based on graph theory (Wasserman & Faust, 1994), SMART generates concept map parameters for surface, structural, and semantic dimensions (3S). These measures are then compared to a reference model (an expert model) and 11 similarity measures are calculated. The resulting indices are shown in Table 1.

Table 1
SMART-Based Evaluation Indices

Dimension	Similarity Measures	Definition
Surface	S-Number of Concepts	The total number of concepts (nodes)
	S-Number of Relations	The total number of concept relations (links)
	S-Density	The cohesiveness of a concept map
Structure	S-Average Degree	The average number of degrees
	S-Mean Distance	The closeness of concepts (average geodesic distance)
	S-Diameter	Understanding broadness (largest geodesic distance)
Semantic	Concept Matching	Semantically identical concepts
	Propositional Matching	Fully identical propositions
	Balanced Sematic Matching	Propositional matching divided by concept matching
	Recall-C	The proportion of key concepts
	Recall-P	The proportion of key relations

Note. Modified from Kim & McCarthy (2021, p.691).

Human evaluation

Human evaluation was conducted by two researchers based on the rubric introduced by Gao et al. (2019). Each summary was scored on a scale from zero to five in terms of their content quality, content coverage, content coherence, and argument quality. Cronbach's Alpha was used to examine the interrater reliability of the five indices. Content quality ($\alpha = .88$), content coverage ($\alpha = .83$), content coherence ($\alpha = .74$), and argument quality ($\alpha = .90$) showed sufficient levels of reliability (Graham, 2012).

Data analysis

To explore if there are gains between learners' initial and final summary submissions, we conducted one-way repeated-measures multivariate analysis of variance (MANOVAs). A total of four MANOVAs were used to examine the three dimensions of the SMART-generated similarity measures as well as the human evaluation. The relation between the two types of indices were explored using Pearson's coefficient of correlation.

Findings

We conducted a series of MANOVAs to investigate if revisions could lead learners' summaries to become similar to the reference (Table 2). Surface level indices showed some improvement in terms of descriptive data but were not statistically significant (Wilks' Lambda = 0.95, p = 0.35). This could have been due to the assignment having clear guidelines about the length of the summaries, leaving little room for change. There was also no significant difference for the structural measures (Wilks' Lambda = 0.95, p = 0.35). As with surface measures, having a clear restriction on the number of words could have limited structural changes from taking place. In terms of the semantic dimension, there was a significant difference (Wilks' Lambda = 0.32, $p < 0.001$). Univariate repeated-measures ANOVAs showed statistically significant gains for all semantic measures. Learners' revisions were focused on the semantic area, showing clear changes in the use of key concepts and relations. As SMART provides feedback focusing on terms and relations that should be included in summaries, learners seem to have been able to add such information through revisions. Human-rated indices also showed significant gains (Wilks' Lambda = 0.52, $p < 0.001$), with univariate repeated-measures ANOVAs confirming that these were present in all four indices. The findings suggest that from a rubric-based human view, learners performed better through revisions.

Table 2
Similarity Scores and Human Rated Descriptors: Means, Standard Deviations, MANOVA Results

Descriptor	Mean (SD)		(F – I)	*F*	Sig.	η^2
	Initial (I)	Final (F)				
Surface						
S-Number of Concepts	0.76 (0.14)	0.78 (0.15)	0.02	2.25	0.138	0.40
S-Number of Relations	0.72 (0.15)	0.75 (0.16)	0.03	2.94	0.092	0.50
S-Density	0.77 (0.14)	0.79 (0.15)	0.02	1.90	0.173	0.30

Structure						
S-Average Degree	0.95 (0.04)	0.95 (0.04)	0.007	3.27	0.075	0.50
S-Mean Distance	0.91 (0.07)	0.91 (0.06)	<0.001	0.01	0.916	<0.01
S-Diameter	0.84 (0.12)	0.84 (0.10)	0.005	0.08	0.779	<0.01
Semantic						
Concept Matching	0.26 (0.12)	0.36 (0.13)	0.10	69.59***	<.001	0.53
Propositional Matching	0.06 (0.05)	0.11 (0.08)	0.05	44.29***	<.001	0.42
Balanced Semantic Matching	0.21 (0.13)	0.28 (0.13)	0.08	26.08***	<.001	0.30
Recall-C	0.42 (0.16)	0.70 (0.22)	0.28	120.45***	<.001	0.66
Recall-P	0.29 (0.16)	0.61 (0.28)	0.33	113.68***	<.001	0.65
Content Quality	2.73 (0.58)	3.12 (0.61)	0.40	35.64***	<.001	0.37
Content Coverage	2.73 (0.58)	3.21 (0.56)	0.48	47.91***	<.001	0.44
Content Coherence	1.84 (0.49)	2.06 (0.59)	0.23	17.79***	<.001	0.23
Argument Quality	2.74 (0.56)	3.10 (0.62)	0.35	32.41***	<.001	0.35

Note. N = 62. ****p* ≤ .001

Pearson's correlation coefficients were calculated between the SMART-generated 3S similarity measures and human evaluations to explore their relationships (Table 3). For the initial summary scores, a statistically significant correlation was observed between Recall-P and content quality, Recall-C and content coverage, and Recall-P and content coverage (r(60) = .25, .27, and .30 with p = .05, .04, and .02, respectively). In the case of final summary scores, we observed significant values with structure and semantic indices. Specifically, the mean distance similarity values showed correlations with content coverage and content coherence (r(60) = .32 and .26 with p = .01 and .05, respectively). For semantic indices, concept matching, propositional matching, balanced semantic matching, and recall-C (r(60) = .35, .42, .43, and .25 with p = .005, .001, <.001 and .05, respectively) showed relations with content quality. There were also significant correlations between balanced semantic matching and content coherence, propositional matching and argument quality, and balanced semantic matching and argument quality (r(60) = .27, .29, and .30 with p = .03, .02, and .02, respectively).

In summary, some significance was identified, with a few within the range of previous studies on such relations (Jonsson & Svingby, 2007). While initial submission evaluations had few significant values, the final scores showed more semantic indices showing significance. Such differences could have stemmed from the characteristics of automatic assessment. SMART's indices measure similarities with a more micro view, focusing on if the certain concept or relation is explicitly stated within the text. On the other hand, human evaluators can have a more comprehensive view and are able to understand underlying meanings. Thus, this could have caused a discrepancy between SMART and human rater's judgements in initial summaries. As learners utilized SMART's feedback for revision, they could have been encouraged to identify more key terms and to state them clearly. This could have led to the higher levels of correlation between SMART indices and human evaluations and would be in line with the explanations given by Dang & Owczarzak (2008), who stated automatic evaluations could lead to low scores when differently phrased information is not correctly recognized.

Table 3
Correlation between Similarity Scores and Human Evaluations

Descriptor	Initial				Final			
	1	2	3	4	1	2	3	4
Surface								
S-Number of Concepts	-0.14	-0.07	-0.03	0.03	-0.09	-0.11	-0.02	-0.08
S-Number of Relations	-0.06	-0.01	0.03	0.08	-0.04	-0.1	0.03	-0.08
S-Density	-0.12	-0.03	-0.01	0.08	-0.12	-0.1	-0.04	-0.08
Structure								
S-Average Degree	0.02	0.01	0.00	-0.05	0.006	-0.12	0.08	-0.08
S-Mean Distance	0.01	0.11	0.04	0.13	0.16	0.32**	0.26*	0.20
S-Diameter	-0.16	-0.01	-0.02	0.03	0.02	0.16	0.11	-0.02
Semantic								
Concept Matching	0.07	0.17	0.06	0.12	0.35**	0.21	0.16	0.21
Propositional Matching	0.07	0.21	-0.05	0.08	0.42***	0.23	0.21	0.29*

Balanced Semantic Matching	0.06	0.21	-0.01	0.06	0.43***	0.23	0.27*	0.30*
Recall-C	0.22	0.27*	-0.01	0.14	0.25*	0.19	0.00	0.12
Recall-P	0.25*	0.30*	-0.04	0.16	0.25	0.18	0.03	0.11

Note. N = 62. *$p \leq .05$. **$p \leq .01$. ***$p \leq .001$ 1=Content Quality, 2= Content Coverage, 3= Content Coherence, 4= Argument Quality.

Discussion and implications

This study aims to explore the relationship between knowledge-based AI and human in academic summary evaluation. To this end, we compared SMART-generated indices alongside rubric-based human evaluations. We found that system-generated evaluation is quite different from human judgements. While knowledge-based AI can be objective, focuses on micro-level changes, and looks for explicitly expressed information, human generated measures are more subjective, comprehensive, and holistic. As such, each measure needs to be interpreted accordingly. Furthermore, knowledge-based AI and human evaluations can supplement each other to provide insights the other cannot. Thus, we believe that using both measures collectively would allow for more informative formative feedback.

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Expanding and Focusing Infrastructuring Analysis for Informal STEM Education

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Abstract: In our efforts to build transformative informal STEM learning environments, we must consider how innovative educational practices and tools are adaptable, sustainable, and equitable. The lens of infrastructuring allows us to attend to the ways that people, practices, and objects already present in these environments can be leveraged and redesigned to support equitable learning outcomes. Through qualitative analysis of 16 facilitator interviews across three informal STEM organizations, we determined six types of infrastructure that support engagement with computational tinkering in informal learning environments: institutional routines and resources, social and facilitation practices, institutional and facilitator values, facilitator expertise, tools and materials, and physical space. We also point out some critical gaps or challenges within these categories that can serve as points for reflection and redesign. This work has implications for researchers, designers, and facilitators/managers who work in informal STEM settings and aim to engage learners with STEM in new ways.

Introduction and purpose

Informal learning environments, such as museums, libraries, and after-school clubs, can support expansive ways of engaging with STEM, especially for learners from communities marginalized in STEM education (Calabrese Barton et al., 2017; Rahm et al., 2022). While informal spaces operate outside of some constraints of the formal school system, such as a government-mandated curriculum and strict training and evaluation protocols, informal learning environments have their own structures, policies, and practices that can either support or constrain learning opportunities. Studying infrastructure allows us to attend to the invisibilized and relational work at play within these local systems, practices, and environments (Star, 1999), which has implications for how we can effectively design educational practices and tools that are adaptable, sustainable, and equitable.

In this paper, we offer a study of infrastructure across three informal STEM learning organizations. We aim to understand how existing infrastructures at these sites can support facilitator and learner engagement with what our project team has termed “computational tinkering,” a novel approach to computing education that prioritizes relationships, joy, and creative explorations of physical and digital materials to create personally meaningful artifacts. We also looked for infrastructure gaps or challenges that hinder engagement with computational tinkering at each of the sites. Our work adds to the existing infrastructuring literature by focusing on informal learning environments as opposed to school classrooms. We also highlight how using a particular approach to computing (i.e., computational tinkering) as a lens for infrastructure analysis brings to light the ways that epistemologies are implicated in both the support systems and the infrastructure gaps.

Theoretical framework: Infrastructuring

Star and Ruhleder (1996) proposed the notion of infrastructure as a way to examine moments in which local practices and solutions intertwine with larger-scale structures and technologies. They argue that infrastructure is inherently relational due to its ties to people, practices, and things - an argument echoed by Bielaczyc (2013) in her social infrastructure framework. In this way, infrastructures are resources in a learning environment that should be designed around and with. Critically, infrastructures are not static, but can be redesigned and renegotiated by the people within a system - an action known as “infrastructuring” (Karasti & Syrjänen, 2004). In a formal education setting, Penuel (2019) uses infrastructuring to discuss efforts that are focused on creating the conditions of support for educators around educational innovations. Studying infrastructure means paying attention to how, where and when resources are taken up, and allows designers to understand how innovations can be implemented equitably across an educational system and be sustainable long term (Penuel, 2019).

Our work continues to build on these theoretical conceptions of infrastructure in design work and brings them into informal STEM environments. Informal learning environments can potentially engage youth and communities that have been systematically marginalized and excluded from traditional STEM learning spaces, particularly by creating a supportive environment that helps learners develop their interest and identities as people who are capable and motivated to pursue STEM fields (Bell et al., 2009; Bevan & Michalchik, 2013; Ito et al., 2009). Touted as spaces with great transformative potential outside of the constraints of formal education, it is important to recognize that these informal learning spaces also have their own deeply contextualized tensions, contradictions and gaps in infrastructure that designers engaged in design projects must recognize in order to design and implement sustainable and consequential learning innovations (Hladik et al., 2022). To that end our work proposes an initial framework of types of infrastructure that might be analyzed and reimagined in these environments, informed by the perspectives of facilitators within these spaces.

Research design

Context

This work stems from a multi-year collaboration between research institutions and informal STEM learning environments in the US, including a museum makerspace on the West Coast, library makerspaces in the Mountain Region, and community-based technology centers across the US. The purpose of the partnership is to collaboratively design, implement, and evaluate activities for "computational tinkering." To guide the co-design of our interventions, our project team articulated particular values as being central to the design of computational tinkering activities: engaging entry points, supporting multiple interests, allowing for deepening complexity within activities, the use of both digital and physical materials, experimental and playful practices, projects that are culturally and personally meaningful, positive affect in the learning experience, and a desire to create a sense of belonging in STEM for all participants. As part of this work, we wish to understand the relationship between this particular approach to computing and the infrastructures in these learning spaces.

Participants, data collection, and analysis

We aimed to examine infrastructures from facilitators' perspectives, as their professional practice requires daily interactions with these infrastructures. Based on nominations from institution leadership, we invited facilitators to participate in 90-minute interviews via the video conferencing software, Zoom. We interviewed 16 facilitators: 5 from the museum makerspace, 6 from the library makerspaces, and 5 from the community technology centers. Through a semi-structured interview, we asked them about their role, their organization's goals, their views on equity, and what they were excited to try in the future. We also asked them to bring an example of a computational activity, share how it was designed and facilitated, and detail the challenges that facilitators or learners faced during the activity. Interviews were recorded, downloaded, and transcribed.

While these interviews did not specifically ask facilitators about infrastructures for computational tinkering, we were able to gain some insight into infrastructures by looking for things that support their work, or challenges they are facing, across their responses. We drew upon grounded theory and constant comparative methods (Glaser, 1965) for this analysis. First, authors 1 and 2 engaged in open coding of three transcripts, looking at the data through the lens of infrastructure that supported facilitators' work in computational tinkering. We organized these codes into broader categories of infrastructures for an initial codebook. We then coded two additional transcripts separately and met to refine the codebook. We then coded the remaining nine transcripts individually, resolving any questions through discussion.

Findings

Our analysis revealed six types of infrastructure that support design and implementation of computational tinkering activities in informal STEM environments:

1. *Institutional routines and resources*: Institutional practices or rules that impact activities and how facilitators engage; resources that can be accessed by the wider institution
2. *Social and facilitation practices:* Learner and facilitator interactions that support engagement
3. *Institutional and facilitator values:* Values that align with ideas of computational tinkering
4. *Facilitator expertise:* Knowledge and attitudes of facilitators that impact activity design and implementation
5. *Tools and materials:* Procurement and use of computational tinkering materials; specific material properties that support engagement
6. *Physical space:* Arrangement of resources within the physical environment

Our framework is applicable to any STEM learning approach when its materials and values are made explicit. To illustrate our findings, we next highlight examples from two different categories of infrastructure: (3) institutional and facilitator values and (5) tools and materials.

Institutional and facilitator values

Drawing on Bielaczyc's (2013) notion of cultural beliefs as a form of social infrastructure, we suggest that institutional and facilitator values around computational tinkering can either support or hinder the design and implementation of these activities in their organizations. More specifically, alignment between the values that made up the core of computational tinkering (as described in the context section) and established values of the space was an important factor in implementation and continued engagement.

For example, as computational tinkering is premised on the idea of both physical and digital materials being meaningfully integrated into a final project, spaces that already valued this diversity in materials were also more easily able to support CT in their spaces. However, this valuing of physical and digital materials was not always balanced; Primo (note, all facilitator names are pseudonyms) pointed out that families and youth within the CTC loved to have something to take home with them, making solely digital projects less exciting for their participants and possibly excluding some CT activities that do not lead to a final physical product. Another value that both supported CT and at times constrained that work was the desire for positive affect. Facilitators wanted youth to have joyful experiences working with computing, and at times, they perceived their learners' frustration in an activity as a barrier that hampered their engagement, such as an activity where a girl was not able to "immediately figure out" the "complicated vision for what she wanted the [Scratch] sprite to do" (Amy). Trying to determine the fine line between "true frustration" voiced by Amy and a productive struggle as part of learning something new (Warshauer, 2015) can be challenging, possibly leading to moments where facilitators step in to solve a problem or pivot to a different activity, leading to decreased engagement with computational tinkering.

Finally, a value that both supported facilitators in CT and also constrained their work at times was the desire not to mirror formal education settings. Facilitators spoke about wanting to encourage learning without strict outcomes or grades, instead aiming to get youth deeply involved in the iterative process of learning in a safe way. (Diego, Daniel, Eric). This aligns well with computational tinkering, where process is valued over a final product. However, the spread of popular computational tools into formal education settings where they may be introduced in more instructivist ways led some facilitators to avoid these tools in their spaces. As Diego said, "I just struggle when there are a lot of activities that are already offered in most of the school systems, so a lot of kids, they don't see it as something new, they see it as part of like, "Oh this is schoolwork." Several facilitators (Diego, Leonardo) mentioned that they rarely designed activities which used the creative block-based programming language, Scratch, because children associated it with their school settings - even though many youth already had some knowledge of Scratch and it is known to be a tool with the potential to promote creative, personally-meaningful learning experiences, especially for youth and families from marginalized communities (Roque, 2016).

Tools and materials

Perhaps unsurprisingly, having access to computational tools and materials was a significant part of the infrastructure to support computational tinkering activities at these organizations. Our analysis showed however, that *availability* was not the same as *accessibility*; Amy pointed out that "some of it is in very deliberately setting up a space in a way that materials and equipment, it's just open, it's just available and just out [in the space]," accompanied by explicit facilitator explanations and invitations to try it out, such as relating a Raspberry Pi microcontroller to a regular computer (Amy). Tensions also emerged between giving participants the opportunity to use computational tools and materials that they would not typically have access to, such as a laser cutter, versus ensuring that the tools and materials could also be used at home, such as looking for free software (Diego). However, even if the software was free, many facilitators spoke about how some of their visitors did not have access to computers or high-speed at home, revealing another infrastructure gap in how they could extend their impact beyond their organization's walls. Facilitators also mentioned that having different tools or software packages that could be used across different projects, such as using a digital illustrator software that could be used on its own or to create designs for a vinyl cutter (Eric), helped learners to be more comfortable with a variety of tools and take on new projects.

One of the most significant infrastructures related to tools and materials were the supporting resources, such as guides, videos, instructions, and example projects. In many cases, existing supports were not meeting the needs of their learners, due to a lack of detail or relevance to their particular project, or not including instructions in learners' home languages. Facilitators frequently filled these infrastructure gaps themselves, highlighting their agency in creating their own infrastructures. For example, Amy discussed how learners were having trouble understanding what a breadboard is and how the various rows are connected, so he decided to break one apart, "open it up and show the guts" so that learners could see, touch, and understand how to connect electronic components. Facilitators also created activity cards and visuals to spark project ideas (Eric), cards to explain basic coding principles (Jenna), sample projects (Emilia), practice sheets (Emilia), and instructional videos (Daniel, Eric, Katie). These resources were especially helpful when facilitators did not have the time to sit down and walk a learner through an activity 1-on-1 for an extended period of time, something that was very common across the library makerspaces and CTCs. In this way, facilitators designed their own infrastructures to deal with day-to-day operational challenges that occur in busy, drop-in, and under-staffed settings.

Discussion and conclusion

This work aims to expand our capacity to build equitable informal STEM learning environments by better understanding how infrastructure can be considered and leveraged in the design and implementation of educational innovations. We specifically highlighted two categories, facilitator and institutional values, and tools and materials, to show the complexity of systems and practices that may support or constrain uptake in the case of computational tinkering activities.

Our findings also show the impact of considering the role of epistemologies of STEM in an analysis of infrastructure. By using our specific lens of computational tinkering, we can make the epistemologies of STEM — that is, what STEM *is* or *should be* — visible. Values are built into approaches to STEM learning within the activities, pedagogies, materials and goals. We must be especially mindful when we are trying to promote or create space for new approaches to computing, because it may or may not be supported by the organization. Our work builds on previous scholarship about infrastructures in formal learning environments (e.g, Penuel, 2019) to highlight that informal learning spaces have their own affordances and constraints with respect to infrastructure that must be considered by researchers, designers, and practitioners in these spaces. We also highlight the important perspectives of facilitators in this work, further making visible the complexity of informal facilitator practices (Hladik et al., 2022).

We also want to make clear that this framework was built from data across distinct informal learning spaces. Our goal is not to collapse these organizations into a monolith, but rather to offer a framework to help designers use infrastructure as a lens to see the nuances of the spaces they are working with. In our future work we plan to more deeply investigate the agency of facilitators with respect to infrastructures: what infrastructures do facilitators have the power to redesign, and what more constraints remain. We will also continue to validate this framework through in-person observations of infrastructure as well as infrastructure-specific interviews with facilitators.

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Learning as Emergent Practice in the Transdisciplinary Civic Learning Collaborative

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Abstract: Conceptualizing learning as emergent practice, we explore the political learning of teachers in a teacher learning community. Drawing on data from two years of monthly virtual meetings, we identify four emergent practices that have come to cohere in the group: multi-vocality, interrogating boundaries, identity inquiry, and affective attunement. After a brief summary of these practices, we trace their negotiation in one interactional episode.

Introduction

As the world continues to stumble forward from the global pandemic, the jury remains out on how schools today may function as locations for pursuing education's liberatory potential (Ladson-Billings, 2021). Though central in this work, already overburdened teachers can hardly be charged with the added feat of transforming the school itself. Yet, teachers continue to work, often against the grain of schooling, to create conditions that support the learning, thriving, and meaningful participation of children. The Transdisciplinary Civic Learning Collaborative (TCLC), a voluntary teacher learning community, provides one example of how teachers work to transform learning possibilities for students, and in doing so, challenge the very nature of schooling. Contributing to questions about the political learning of teachers (Cochran-Smith & Lytle, 2015), and to better understanding the possibilities and potential of teacher learning in transdisciplinary, multi-grade teacher communities, this paper reflects early inquiry into the learning of this group, theorizing learning as emergent collective practice. Analysis asked: 1) What is being learned in and by the TCLC as evidenced in emergent practice? 2) How are these practices learned and negotiated in interactional moments of tension or conflict?

Theoretical framework: Learning as emergent practice

We draw on social practice theory (Holland & Lave, 2009) to frame learning as a fundamentally social endeavor through which individuals and groups make meaning and come to participate in shared practices that emerge both through moment-to-moment interaction and through the accumulation of these moments over time. Building from Freirean "culture circles" as a model (Freire, 1971), we conceptualize TCLC as an emergent community of practice (Wenger, 1999). Unlike more established communities of practice such as a trade or professional community, the practices of TCLC are immanently emergent precisely because there is no existing tradition of transdisciplinary, multi-graded, teacher-researcher design collaboration communities. Rather, TCLC reflects the coming together of highly diversified learning ecologies and experiences. Still, drawing from this literature, we conceptualize learning as the emergence of practice (Holland & Lave, 2009; Lave & Wenger, 1991). Rather than following the trajectories of individuals, we focus on the collective practices of TCLC as they emerge and are negotiated. We see the emergent nature of these practices as reflecting the early learning of participation—ways of being and knowing together—in the collaborative.

Transdisciplinary civic learning collaborative: History and context

In January 2020, a group of English Language Arts (ELA) and mathematics teachers convened virtually for the first time, brought together for their varied commitments to the liberatory potential of teaching, to articulate the possibilities of *quantitative civic reasoning* – the pairing of quantitative and literary practices to engage civic questions. Building from an expanded conception of civics as inclusive of all human activity that works to build democratic communities (Westheimer & Kahne, 2004), and responding to the provocation, "all teachers are civics teachers" (Nicole Mirra, personal communication), participants shared examples from their own practice and sought resonances, at times unexpected, between mathematics, ELA and civics. After the writing, production, and public launch of a teacher guide (Gargroetzi et al., 2020), many desired to continue meeting.

In response, participating teachers each invited a colleague from their own school to join the group, adopting our current name, the Transdisciplinary Civic Learning Collaborative. Currently, 12 teachers and researchers across content, location, and grade level meet monthly (virtually) to collaborate in a social design-based experiment (Gutiérrez & Jurow, 2016). Together we generate and examine new possibilities for youth transdisciplinary civic learning, designing for and reflecting on learning and practice in each of the three school sites. We believe the pursuit of radical new possibilities for identities, engagement, and creation, likely requires no less than the transgression of traditional boundaries of academic disciplines, grade levels, and institutions.

Methods

The TCLC social design experiment includes multiple layers of design, implementation, and reflection, with much focus on designing for student-facing learning activities. The analysis presented in this paper, however, is a qualitative analysis of the TCLC meetings, examining the meeting space itself as a space of learning for TCLC participants. Taking discourse as a primary site for learning, we analyzed transcripts and artifacts from 14 90-minute virtual meetings spanning January 2021 – November 2022. The research team began with open coding and collaborative refinement of codes (Emerson et al., 2001) to identify recurrent TCLC practices. As both participants and researchers in TCLC, we layered this data-centered analysis with analytic memo writing (Emerson et al., 2001) focused on our own experiences in TCLC. Through this process, we identified and began to articulate the nature of four emergent practices reflecting the learning of TCLC. Ongoing analysis will include comprehensive coding of the data with further code refinement and the mapping of these practices as they emerged in and over time.

Theorizing social practice as emergent not only over time, but also in moment-to-moment interaction, for this paper, we selected for analysis an episode of tension that arose in the third meeting of the group (May, 2021). The selection was based on the understanding that conflict often indicates that a norm was transgressed (Goffman, 1971), and that the norms of a community may become salient in moments of conflict. Here we make use of episode analysis to illuminate the texture and negotiation of emergent practice as TCLC learning.

Preliminary findings

Four emergent practices were identified as reflecting the learning of TCLC over the first two years of collaboration. Each of these is briefly described below. Then, episode analysis illuminates each of these practices *in vivo* as they were actively negotiated, becoming immanently familiar and expected TCLC practice.

Multi-vocality as anti-hierarchical: Multiple perspectives and experiences were explicitly stated as valued in the initial "agreements" of the group: 1) Everyone is coming with *lots* of expertise; we need everyone's voice; and 2) We are here to build from and across different experiences and perspectives. In this sense, the design of the group was anti-hierarchical from the outset. Over time, this has come to be expressed in the multi-vocality presumed in conversational patterns wherein it is common for multiple contributors to provide insight on a topic before anyone speaks twice. Multi-vocality is also evidenced in the production of shared ideas wherein neither consensus nor majority-rule guides uptake; rather, ideas are often left open with multiple possible enactments.

Challenging boundaries as critical work: The collaboration is framed around transgressing boundaries; this includes the boundaries of academic disciplines such as civics, mathematics, or literacy, as well as the boundaries erected around our classrooms and schools as we seek to build intellectual and pedagogical collaborations across spaces and places. The practice of surfacing boundaries and challenging them, asking whom these boundaries serve and what it means to cross or bend them, became embedded lived practice as evidenced in discourse as well as in the design of the learning units and teacher collaborations at each site.

Identity inquiry: The practice of locating and inquiring into identity as an essential component of considering the purpose and impact of our work emerged in multiple forms, coalescing into a driving component of what we eventually articulated as the student-facing guiding question for learning units across sites: *How can we leverage our individual assets and identities to collaboratively imagine, create, and sustain thriving communities?* In settling on this shared guiding question, teachers observed that student-facing work must start with opportunities to explore individual identities in relation to their diverse communities.

Legitimate attention to affect and emotion as part of learning and human development: Throughout group interactions, and reflected in discourse about student learners, consistent attention and care are given to human emotion, affect, and experience. Reflected in the fourth "agreement," "care for yourself and the group," as well as in the opening check-in questions such as "What color(s) are your emotions today?" (9/27/2022) that launch each meeting, personal affective states are taken seriously in organizing the work of the group around trust and care, and are mirrored in attention to the same in the lives of students.

Learning shared practice in a moment of tension

During the third TCLC meeting, a literacy educator and group facilitator, Antero, asked if mathematics teachers might approach a moral quandary using quantitative thinking. Evan, a math teacher, responded by sharing a lesson in which his high school algebra students consider a scenario where a police chief concludes from a set of data that one group of people needs to be policed more than another group. Students then consider the data and make two opposing arguments based on the statistics. Evan explained,

> Without getting into all the math, if you look at it based on the number of people committing crimes total, uh, one group has a much higher incidence of people committing crimes. If you look at it as proportions within the populations, the other group is committing at a much higher rate. So, you've got two opposing arguments that can be effectively made with statistics. And the reality is that there are a lot of unanswered questions here. Students have come up with great responses, right? These are just the people who are being arrested and convicted, but is that actually who's committing these crimes? Is there some bias going on in terms of who's being arrested? A lot of this might depend on the crime, and the particular populations involved. The way the problem is set up, it's not based on race, but clearly, that's the mindset that is kind of intended… It definitely speaks to that idea that you can use quantitative reasoning to make arguments and prioritize, and answer ethical questions. But you can also do it well and you can do it poorly and ideally, it's going to bring up more questions than it answers.

Evan's example evidences his own emerging work to challenge the boundaries of what traditionally happens in math classrooms by not only using current statistical data, but tying it to a prevalent social, political, and racial issue. In presenting a situation that is initially posed as a mathematical problem, but then encouraging his students to articulate challenges to the premise of the problem and the data itself while connecting it to their daily lives, Evan pushes traditional borders of mathematics education into the civic realm. He likewise poses a challenge to the efficacy of mathematical problem solving without attention to the moral or political context of the problem.

Responding to Antero's prompt, Emma followed Evan's comment with another example of a mathematics task that pushed students to articulate underlying ethical dilemmas. Then, she indicated it was time to change topics. At that point, Min, a third math teacher, spoke up:

> I don't want to drag this on, but I was very uncomfortable reading Evan's slides, maybe the title and maybe the quote that was in it. It just like spiked my heart rate in, um, in reacting to it. And I think, Evan, you clarified like, we're not directing this project at any particular race, but you don't mention explicitly races in the project, but like I know what you're trying to get at. And, I think Emma said, not everything that we can quantify should be quantified. I think in the same way, not every intersection of quantification and civics should necessarily be brought into the math classroom. Um, and I, I'm just, I'm trying to capture how uncomfortable I am right now, and I don't quite know why. Like, maybe I do know why and I can't articulate it. Um, but that's, that's where my emotional space is right now.

Min's disruption of the flow of the meeting to announce her affective experience – the bodily discomfort produced in learning about the lesson Evan shared – was, at this early phase of the group's work together, a potentially high-risk contribution. Yet, she was compelled to do so, perhaps because it felt safe to do so, or perhaps because she knew if this group was going to be a safe and productive space to continue critical work, she had to find out if it was a safe place to do so. At this moment, the emergent practice of treating affect as a legitimate component of participation was tested. Instead of rejecting it, pursuant responses cemented this as an enduring shared practice. Kyra, an ELA teacher, was the first to respond.

> I really appreciate that Min. I struggle with this, generally, but part of the reason why I really liked it is because if that isn't happening- I'm thinking about my students, if nobody is breaking down the math, that that actually happened- Maybe part of what I am feeling, in terms of what you brought up is that it was left open, right? When really, we're talking about Black people, like Brown and Black people. But I want my students to know how people who get on the news are saying that this is real based in math. Like, my kids don't know that. Like, I'm a hundred percent sure. So, I think for me, there is this question of, yeah, I don't want to do this work because it does seem there's something inhumane about it. And like with my Brown and Black students, if we're not doing that work, there's some students that are going to walk out thinking that the math is backing up what folks are saying. So, I wonder, I mean, I don't know, I think that that's a question then. Do we do it, do we not? I don't know.

Kyra started by appreciating what Min shared, implicitly affirming rather than rejecting the affective pause that Min had counseled of the group. She then returns to the question of the implied, but not explicit, racial identification of the groups of people in the original problem. She connects this to the importance of considering the identities of the students in the room when also considering the potential value and impact of engaging with this or other complex racialized statistics. Invoking her own Black and Brown students, Kyra asserts that they have the right to learn what's behind math, even if it might feel "inhumane" to explore such topics. Kyra's insistence on moving identity – here in terms of racial categories – from the sidelines into the foreground reflects the emerging practice of centering identity inquiry. Her concluding words leave unresolved questions open, respecting both voices already shared, garnering alternative perspectives from others, thus reflecting emergent practice of anti-hierarchical multi-vocality.

The conversation continued for just over 17 minutes; contributions were shared by six of the nine participants. Antero brought up discussions regarding what types of questions should be considered up for debate. Janice, another ELA teacher, raised the importance of learning more about traumatizing issues paired with potential opportunities for taking action. Evan added a comment about providing choice and "opt-out" possibilities for lessons on sensitive topics.

When Antero spoke again, he pointed to the importance of Min's original comment where she voiced her discomfort, "It could have been really easy for us to move past this conversation, I think, Min, if you hadn't voiced anything. So, trying to recognize that might have been uncomfortable to voice… I'm really grateful… Maybe we can also just check in and see how are you feeling with the nature of this conversation? Not closing it either, but just to check in." At this moment, Antero validates and lifts up the importance of Min's pausing the group. He positions what she did as generous and expresses sincere appreciation. He checks in with Min to see how she's feeling now, and finally, he leaves the conversation open to continue as needed, affirming multi-vocality alongside the importance of the inherently affective dimension of work that considers painful social issues such as anti-Black police violence. Min responds, "I'm glad I named it. I think the fact that we discussed it for a bit, um, I think I'm able to move on now and thanks folks for engaging in that."

Discussion & conclusions

The preliminary findings from analysis of learning as emergent practice in the TCLC over its first two years, with attention to a critical moment of tension, begin to jointly illuminate both what might be learned in such a critical and transdisciplinary teacher-researcher collaborative space and also how it is learned through talk and interaction in each moment, and over time. Ongoing analysis will attend to how emergent practice is both immanently negotiated and accumulates over time to thicken into cohering practices of the group as we contribute to questions of teacher political learning.

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Supporting Framing Agency with the Wrong Theory Protocol in a Youth Radio Camp

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Abstract: STEM instruction commonly constrains learners' agency as a means to focus attention to specific content. One consequence of this is much more research has investigated problem *solving*, rather than problem *framing*. This study investigated how learners negotiate framing agency—that is, making decisions about how to frame a design problem. Set in the context of a coding camp, learners worked with micro:bits and paper template my:Talkies to pose a community problem that could be solved via radio systems. Noticing their fixation, we guided learners through an ideation technique that prompts them to generate humiliating, harmful ideas before generating beneficial ideas, which resulted in divergent designs. Interaction and discourse analysis of video recordings highlights how learners (re)framed.

Introduction

A persistent challenge in the design of instruction is learner agency. Instruction necessarily constrains agency as a means to focus attention to specific concepts. Out-of-school settings provide an opportunity to engage learners in meaningful design, creative making, and disciplinary inquiry activities that can relax some of these constraints, shedding light on how learners negotiate agency. The goal of this research is to foster learner agency and creativity during engineering design and making activities by understanding the potential barriers to generating divergent ideas. Learners wrestle with framing and reframing design problems, in part because they have typically had few opportunities to engage these practices. Teachers and informal educators working need more strategies for facilitating generative design activities, especially in maker-oriented environments. While these environments afford a wide range of tools, materials, and possibilities, informal educators have limited guidance on facilitating problem framing processes. This paper shares an analysis of a creative engineering task in which informal educators and group of novice designers—learners in a summer STEM camp—negotiated agency while working individually and together on a problem in their community. We examine how an ideation technique supported framing agency, guided by a research question: How might an ideation technique of generating bad before beneficial ideas support learners to negotiate their agency to frame design problems?

Theoretical framework

While much research has investigated learning through *problem solving*, a key part of design comes before this, *problem framing*. Problem framing involves gathering information, including about/from stakeholders, the context and design requirements—providing abundant learning opportunities (Dorst & Cross, 2001). Problem framing is also dependent on the designer, who brings unique preferences and judgment to bear as they use what they learn to make decisions that bound the problem space (Dorst & Cross, 2001). The ability to make consequential decisions about the problem frame is termed framing agency (Svihla et al., 2021). Designers use their framing agency responsively as they consider how possible solutions meet design requirements. Thus, in addition to learning about the problem, novice designers learn how to direct their framing process. In order to shift between framing and solving a problem, designers typically generate ideas. Common techniques suggest designers should generate many ideas, yet this probabilistic argument has failed to find support in research, in part because of design fixation—inadvertent adherence to flawed solutions (Alipour et al., 2018). Because fixation creates a narrower problem space, it also limits learning. One method for overcoming fixation, the Wrong Theory Protocol (WTP), tasks designers with generating harmful and humiliating ideas prior to generating beneficial ideas (Svihla & Kachelmeier, 2022), resulting in empathetic and creative solutions.

Methodology

We report on one iteration of a design-based research (DBR) study (The Design-Based Research Collective, 2003) in a radio communication camp that positioned learners as designers capable of framing and solving a problem. Radio crafters camp is five-day, museum-hosted summer learning experience designed to introduce a socio-technical topic: radio frequency communication. They use BBC micro:bits (programmable microcontrollers (Austin et al., 2020)) to build a conceptual model of radio and use craft materials and papercraft templates (my:Talkies, (Yu et al., 2022)) to build a radio communication system model to solve a problem. The first activities introduced radio communications and the paper my:Talkies and an initial framing of the design problem—create a system of radio communications that serves a newly-developed neighborhood west of the city, with the constraint that their solution needed to communicate with another local radio system. We prompted learners to consider problems that could be solved by having access to radio communications (contacting friends, getting announcements for the community) and to identify a list of stakeholders (kids, police or fire departments, businesses, etc.). Following the steps of the Wrong Theory Protocol (Svihla & Kachelmeier, 2022), we prompted learners, as a group and documenting their ideas on a large sheet of butcher paper, to create "the worst ideas for community radio, actively harmful." Next, they individually imagined beneficial ideas, planning for what they wanted to design with the micro:bits and my:Talkies. The camp concluded informal design presentations.

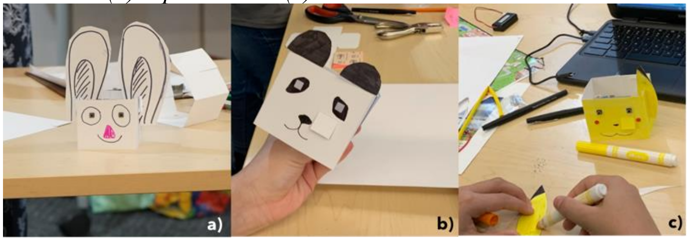
Two girls and four boys (ages 11 to 15) participated in the camp. Four identified as Hispanic/Latinx. Two reported some prior experience with block-based programming. Sessions lasted three hours over five contiguous days in a discovery-focused museum in the American Southwest. We collected short video and audio recordings from the camp, field notes, artifacts created by learners, and documentation from whole class discussions. We initially transcribed video and audio using Otter.ai, then corrected these, adding filler words, tone, and pauses. We used two analytic techniques to examine how learners used and distributed their agency. First, interaction analysis provided a way into the data (Jordan & Henderson, 1995), with particular attention to turn-taking, participation structures, and access to space and materials. We repeatedly discussed and reviewed data to test conjectures about fixation and problem framing. We used a discourse analytic approach to characterize agency in talk (Svihla et al., 2021), with particular focus on the subject and verb types in verbal clauses. In this way, "I" denotes individual agency; "we" denotes shared; third-person subjects denote attributed agency; modal verbs such as "going to" and "could" denote tentativeness characteristic of framing agency; and modal verbs such as "can't" and "have to" denote offloading of agency.

Results and discussion

In early pre-ideation activities, we saw evidence of fixation from the learners. One created a version of the Titanic (which was part of the initial framing of the camp about possible disasters of radio communication) while others mirrored the examples—a rabbit and a duck—creating Pikachu, a swamp monster, and a panda (Figure 1).

Figure 1

(a) Example of my:Talkie presented to the learners; designs subsequently made by learners: (b) a panda and (c) Pikachu

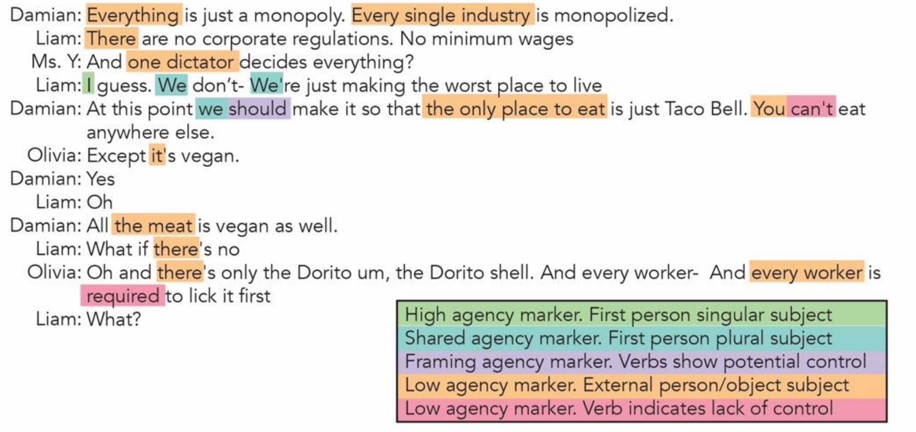


Thus, the learners seemed influenced by prior solutions, suggesting design fixation was at play and could limit the creative learning opportunities (Alipour et al., 2018) by limiting their framing agency. Responsive to indications of fixation, we implemented the Wrong Theory Protocol. We prompted learners to generate harmful and humiliating ideas related to the problem. Although the facilitators attempted to bring them back to the more specific problem space (radio communication), the learners framed the problem much more broadly as the "worst place to live," a framing that served as fertile ground for their problems and designing. After an initial period of tentativeness, one learner came up with the idea of faulty wiring causing electric shock and fire. They revisited the idea of fire throughout the whole session. At one point in the discussion, learners discussed a "nuclear football" (delivered to the president via faulty Amazon drone delivery) that would lead to nuclear holocaust, but decided there would be nothing left to harm nor humiliate, so they returned to fire again. As the learners developed more dystopian ideas on the large shared paper, they went back to scribble red marks over them to depict objects in the community, trees, and buildings catching on fire. This focus on fire is particularly important as during the camp, wildfires raged across the state, leading to smoke in the air.

Learners also drew on locally-salient societal issues. They considered ways Amazon could be used to facilitate specific harm, including delivering unwanted packages by drone and providing harmful working conditions, a local concern considering an Amazon distribution center had recently been built in the community they were designing for. Olivia suggested, "everyone has the same rights as an Amazon worker" and Liam showed his understanding of issues Amazon workers might face, adding "They don't ins—install toilets in houses anymore." Building on this, Damian and Liam discussed monopolies and removing regulations (Figure 2). In response, Ms. Y, a facilitator, suggested a dictator. However, Liam showed high individual agency over his evaluation that a dictator did not fit their dystopian vision, then shared agency with his peers over the framing. Damian then tentatively shared new direction—making Taco Bell "the only place to eat," and restricting envisioned community members' agency, a storyline picked up by his peers. This interaction illustrates how students drew upon their understandings of localized issues like wildfires and worker rights, using their agency to reject an idea as out of frame, before more playfully exploring a topic they may have suspected the facilitator would not be able to contribute to. In a classroom, such a shift in focus may have been discouraged or labeled "off task," but we interpret it in this context as a display of framing agency.

Figure 2

Vignette 1: Framing a harmful, humiliating design of an Amazon monopoly, determining that the idea of a dictator raised by the facilitator doesn't fit.



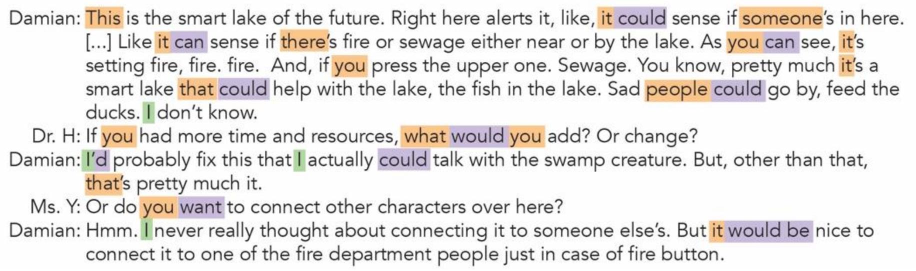
Damian: Everything is just a monopoly. Every single industry is monopolized.
Liam: There are no corporate regulations. No minimum wages
Ms. Y: And one dictator decides everything?
Liam: I guess. We don't- We're just making the worst place to live
Damian: At this point we should make it so that the only place to eat is just Taco Bell. You can't eat anywhere else.
Olivia: Except it's vegan.
Damian: Yes
Liam: Oh
Damian: All the meat is vegan as well.
Liam: What if there's no
Olivia: Oh and there's only the Dorito um, the Dorito shell. And every worker- And every worker is required to lick it first
Liam: What?

🟩 High agency marker. First person singular subject
🟦 Shared agency marker. First person plural subject
🟪 Framing agency marker. Verbs show potential control
🟧 Low agency marker. External person/object subject
🟥 Low agency marker. Verb indicates lack of control

After generating terrible ideas, learners generated ideas individually and developed these into their projects, which were diverse, empathetic solutions. Damian's smart lake showed empathy for community members' needs and varied uses of a lake. He emphasized the importance for privacy for someone who is unsheltered (and who had a need for bathing in the lake), respect for a family on an outing (who would be alerted if the lake was occupied), and solace for people who come to the lake to feed ducks when they are sad. The smart lake had the capability to take care of itself, monitoring sewage and the fish's home. Damian, in explaining his final project (Figure 3), demonstrated framing agency through his use of potential control verbs, like "could" and "would," demonstrating how he continued to consider possibilities. This reflects how designers treat their early solutions as tentative and as revealing much about the problem and whether needs have been met (Dorst & Cross, 2001). When a facilitator made a suggestion, he considered it but did not automatically take it up, indicating that while he was willing to take other ideas into account, he retained control over his design and the problem he had framed.

Figure 3

Damian retained framing agency as he considered possible changes

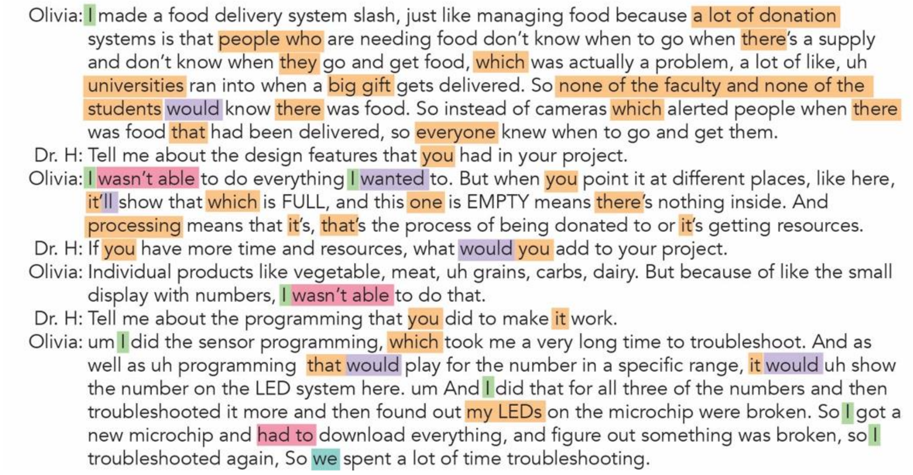


Damian: This is the smart lake of the future. Right here alerts it, like, it could sense if someone's in here. [...] Like it can sense if there's fire or sewage either near or by the lake. As you can see, it's setting fire, fire. fire. And, if you press the upper one. Sewage. You know, pretty much it's a smart lake that could help with the lake, the fish in the lake. Sad people could go by, feed the ducks. I don't know.
Dr. H: If you had more time and resources, what would you add? Or change?
Damian: I'd probably fix this that I actually could talk with the swamp creature. But, other than that, that's pretty much it.
Ms. Y: Or do you want to connect other characters over here?
Damian: Hmm. I never really thought about connecting it to someone else's. But it would be nice to connect it to one of the fire department people just in case of fire button.

Olivia created a system for alerting the community for needed food donations and availability of food for distribution. In describing it (Figure 4), she showed high individual agency over the problem, which she situated as an existing problem. When asked about design features, Oliva offloaded her agency, a shift that speaks to her disappointment in not fully delivering what she envisioned. Rather than suggesting she lacked framing agency here, we interpret this as an indication that she maintained a clear frame, but because of time spent troubleshooting, did not develop the solution she aimed to make. Concern about failure in ambitiously-framed problems can prompt educators to limit learner agency. Allowing learners to envision and tackle ambitious problems means being prepared to coach them through failures, positioning problems and learning as more important. Dr. H's response shifted attention away from what was not, to what Olivia accomplished—a positioning Olivia took up as she displayed high individual agency ("I did...").

Figure 4

Olivia showed high agency in describing her creation



Olivia: I made a food delivery system slash, just like managing food because a lot of donation systems is that people who are needing food don't know when to go when there's a supply and don't know when they go and get food, which was actually a problem, a lot of like, uh universities ran into when a big gift gets delivered. So none of the faculty and none of the students would know there was food. So instead of cameras which alerted people when there was food that had been delivered, so everyone knew when to go and get them.

Dr. H: Tell me about the design features that you had in your project.

Olivia: I wasn't able to do everything I wanted to. But when you point it at different places, like here, it'll show that which is FULL, and this one is EMPTY means there's nothing inside. And processing means that it's, that's the process of being donated to or it's getting resources.

Dr. H: If you have more time and resources, what would you add to your project.

Olivia: Individual products like vegetable, meat, uh grains, carbs, dairy. But because of like the small display with numbers, I wasn't able to do that.

Dr. H: Tell me about the programming that you did to make it work.

Olivia: um I did the sensor programming, which took me a very long time to troubleshoot. And as well as uh programming that would play for the number in a specific range, it would uh show the number on the LED system here. um And I did that for all three of the numbers and then troubleshooted it more and then found out my LEDs on the microchip were broken. So I got a new microchip and had to download everything, and figure out something was broken, so I troubleshooted again, So we spent a lot of time troubleshooting.

Conclusions and limitations

We find support for using WTP to mitigate the impacts of fixation and help learners use their agency to (re)frame problems—itself a learning process. WTP opened space for learners to draw upon their assets and understanding, sharing their awareness of everyday events and experiences, in turn shaping a broad problem space—far broader that the radio systems context that the facilitators envisioned. The learners' broad problem space served as fertile ground for them to frame diverse problems with empathy. When the facilitators tried to alter the scope, the learners displayed ownership over the problem space. We also identified examples of learners displaying framing agency as they reflected on their work, both as they treated their solutions as tentative.

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Emotion and Emotion Regulation Matter: A Case Study on Teachers' Online Teaching Experience During COVID-19

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Abstract: This study explored higher education instructors' emotional experience and regulation strategies as they shifted to online teaching during COVID-19. The purpose of this study is twofold: (a) to gain insight into teachers' perceptions of emotional experience in reacting to the transition from in-person teaching to online teaching during COVID-19, and (b) to investigate the strategies teacher adopted to regulate emotions when they teach remotely. Data for analysis involved in-depth semi-structured interviews. All interviewees were Canadian university instructors from a wide range of backgrounds. A deductive thematic analysis procedure and text mining technique were applied. Findings for (a): supportive relationships/good cooperation with colleagues promote teachers' positive appraisals; lacking connections with students/colleagues facilitates the feeling of isolation. And for (b): teachers applying reappraisal strategies in response to perceived challenges in online contexts enables them to manage negative emotional experiences. Implications for higher education in online contexts are further discussed.

Introduction

Due to the Pandemic, instructors in higher education were required to fast convert to online instruction, and these unprecedented changes may have elicited a range of emotional responses. It is not uncommon for teachers to report negative emotions such as frustration and anxiety in complex teaching tasks (Sutton, 2004). Emerging research examines the causes and consequences of teacher emotions (Donker et al., 2018); however, research on teachers' emotion regulation strategies in online contexts is relatively new.

Emotion regulation enables us to comprehend how people deliberately and unconsciously affect the strength, diversity, and duration of their emotions. The two most frequently studied emotion regulation strategies are cognitive reappraisal and expressive suppression (Gross & Thompson, 2007). Cognitive reappraisal interprets a potential emotion elicitor in a way that lessens the negative emotional impact, whereas expressive suppressive includes suppressing an emotional experience once it has been activated (Hagenauer & Volet, 2014). In high stake achievement situations, emotions can both help and hinder performance, therefore it is better to make efforts to regulate them. For example, teachers who perceived less control in achieving their instructional goal in the online context may experience negative emotions, which in returns, could impeded their instructional activities. However, if they appraise the tough situation differently, they might adapt to positive emotional experience as well.

This study is guided by the integrated model of emotion regulation in achievement situations (Harley et al., 2019) and seeks to answer the following question: what are teachers' emotional experience and how do they cope with negative emotions in response to challenges in online teaching during COVID-19?

Methods

Participant

The data are part of a larger study of teachers' online teaching experience in higher institutions during COVID-19. IRB was obtained and informed consent was obtained from all participants. Ten Canadian university teachers participated in the interview section. Among them, one case was tested for pilot study and it was not included in the further analysis. As shown in Table 1, the participants represented a cross-section of the subject areas (e.g., Engineering, Education, and Physiology) and various teaching experiences (1- 46 years).

Table 1
Interviewee Information

ID	Gender	Age Range	Domain	Teaching (Yrs)	Online Experience
2	Male	25-30	English	8	No

3	Female	45-50	Engineering	10	Yes
4	Female	30-35	Educational Policy	6	Yes
5	Female	25-30	Nutrition	1.5	Yes
6	Male	35-40	Educational Psychology	1	No
7	Male	60-65	Indigenous Teacher Education	42	Yes
8	Female	30-35	Educational Psychology	6	No
9	Female	35-40	Physiology, Biochemistry	15	Yes
10	Female	65-70	Educational Psychology	46	Yes

Interviews and data collection procedure

Ten semi-structured interviews were conducted remotely (Table 2). The interviews were audio-recorded and transcribed verbatim. Among the transcripts, nine use the language of English and one was conducted in French, according to the interviewees' preference. The second author interviewed the teacher in French and later translated the French interview transcript into English. Each transcript was assigned a unique code to ensure anonymity.

Table 2
Sample Interview Questions

Example questions	Example follow-up prompts
Have there been any particular changes to your course(s) with the transition to online courses?	Did you have to change the content, design, learning activities, assessment, …?
When you first learned that you might have to change something of your course, how did that go?	How would you describe your emotional state at that moment?
Could you briefly describe a specific challenging moment that you experienced in this online environment?	How did you respond to that?
How would you describe your comfort using technology for teaching and learning?	Would you say that you value a particular teaching and learning format more than another?
How has it been since? How do you feel about the way things are going now?	Can you tell me your feelings about teaching in remote instruction?
Did this experience change the way you do things or perhaps the way you plan on doing things in the future?	How did this experience change the way you do things? The way you think about online teaching?

Analysis

An in-depth qualitative analytic method was used to examine the participants' emotions and emotion regulation strategies related to online teaching experiences. Data analysis followed a deductive thematic analysis approach (Braun & Clarke, 2006) and a text mining technique to identify and interprete content relavant to the research question. In this case study, we adapted to Hagenauer and Volet (2014)'s qualitative analysis processes: initial coding of emotions, identifying emotion regulation strategies, and identifying themes.

The first and second researchers extracted text content containing relevant information about teachers' reported emotions. Teachers' emotions were divided into 'positive tone' and 'negative tone' (Hagenauer & Volet, 2014) and contained codes labelling distinct teacher emotions (e.g., stressful, angry, happy). This analysis step was undertaken using the software MAXQDA (version 20.4.1), which assists in data management and coding. Within minimum code overlapping rate of 90% at the segment level, two coders coded 20% of the emotions individually, and the coefficient kappa (Brennan & Prediger, 1981) of the interrater reliability reached 0.82.

To better understand teachers' both explicit and implicit negative emotions and how they cope with them, we applied text mining on the transcripts to identify and extract abscure negative expressions. Specifically, we used the meaning extratction method of the Linguistic Inquiry and Word Count (LIWC, Boyd et al., 2022) tool to locate relevant content by color coding words with negative tones from interviewees' transcripts. As a result, words with negative tones were identified two hundred and ninty-six times from the transcripts and we used these colorcoding scripts as a complmentary evidence to our emotion-related pool.

The next stage involved scrutinizing the adjacent segments within each emotion-related code. The answers to this question were first paraphrased from the interviewees' narratives and then brought to significant broader patterns of meaning (Braun & Clarke, 2006). The last stage of analysis involved identifying overall themes. The themes served as a reflection of the content of the entire data set. By delving into the situations where teachers' negative and positive emotions were mentioned, specifically teachers' appraisals related to achievement of instructional goals, we identified three general themes that are subsequently used to organize the findings.

Results

In the interview section, most interviees expressed more negative emotions than explicit positive ones while recalling their online teaching expereince. Particularly, they mentioned negative emotions in specific teaching situations (e.g., anger when students lack of engagement). Furthermore, they expressed more types of distinct emotions (e.g., stressful, scared). Specifically, one interviewee claimed that she found it easier to talk about specific emotional experiences through interviews than answering in the emotion scales. Additionally, three themes were identified in terms of teachers' emotional experience and coping strategies in online teaching: (a) supportive relationships/good cooperation promote teachers' positive appraisals; (b) lacking connections with students/colleagues facilitates the feeling of isolation; (c) applying cognitive reappraisal strategies in response to challenging moments enable teachers to manage negative emotional experience.

Table 3 extracts interpretation on concrete examples where teachers applied emotion regulation strategies. Regardless of teachers' teaching experience and domain, most of them reported negative feelings (e.g., panic, traumatic) when the Pandemic hit and expressed negative emotions (e.g., exhausted, nervous) towards challenging moments in online teaching. Besides, teachers' positive experiences were also reported when good connections were built with students:"Through that individual feedback, I noticed that we started to develop like individual dialogues, individual conversations, you know. So I was very surprised that at the end, like how connected I was with the students, although I had never seen them in person" (I6).

One frequently mentioned challenge that leads to teachers' negative emotional experience is the lack of connections with students and colleagues. One interviewee described challenging situations where students do not engage in the instructional activity: "I feel like it's very impersonal, like you are not connecting with the students" (I5). Another interviewee mentioned: "I feel less effective like you need to connect with students, it's so much harder to have it happen over like a screen rather than like in person...Because they can't really see my body gestures and all those things that go into like communication are kind of blocked in a way" (I4). Besides challenges in teacher-student interaction, lacking cooperation with colleagues can also lead to feelings of isolation. For example, the virtual class makes teaching more "independent" and "like I was in less collaboration which is essential to be a real person." (I2). Fortunately, we also received positive responses from teachers that they were able to manage these negative emotions. For instance, one interviewee positively appraised the situation in facing and overcoming this challenging moment as a precious story to tell in the future. Besides, some lower their expectancy and attribute teaching outcomes to other causes, thus drawing attention away from their emotionals.

Table 3
Extract of Types of Emotions and Emotion Regulation Strategies

Tone	Emotion Code	Sample Transcript	Paraphrase	Interpretation	Emotion Regulation
Positive	Appreciative	*Like I really (think) the pandemic has just kind of made me think, what makes me appreciate my life a lot, and in the teaching. I thought it's actually a really cool way to have one to have an excuse to do things a bit differently and to really think about teaching and assessing.*	Teachers manage to think of the positive side of the transition to online teaching.	Thinking positively towards the change and take the transitioning of teaching and assessing as a good opportunity to learn and think in a new and better way.	Cognitive Reappraisal
Negative	Angry	*I feel angry when students don't engage or have the cameras off. But like we do have to keep in mind that everybody in their home...You can be living with 50 other people, exaggerating, but*	Teachers view from the students' perspective and think of possible explanations that might lead to their	Standing from the students' side, understanding that they had their camera off for some personal reasons	Cognitive Reappraisal

	all other people in the background moving around... Those things like they cannot unmute and, you know, and have the cameras all at the same time just be distracting.	less engagement and camera off are able to manage their anger.	and forgive their lack of engagement in learning.

Discussion and conclusion

This study support previous research that continuous dialogue in a community benefits online learning environment (Regan et al., 2012). Furthermore, good cooperation with colleagues allows teachers to perceive more control of online instruction activities which resulted in more positive emotions. Supportive relationships may lead to teachers' valuing the situation more as their opinions are accepted and supported. On the contrary, lacking connection with students and colleagues leads to teachers' negative emotional experience. This finding is partially aligned with previous studies indicating that teachers' emotions, to some extent, depend on the relationship teachers build with their students (Hagenauer & Volet, 2014). Additionally, instructors successfully coped with negative emotions by reevaluating the situations that could potentially lead to undesirable emotions. This finding reveals that this group of teachers practice cognitive reappraisal strategies that appear to be more effective than expressive suppression (Gross & Thompson, 2007). Examples of the interviews revealed that cognitive reappraisal allowed them to handle unpleasant experiences, to think more neutrally, and arguably more positively to continue moving forward in their day-to-day work.

To conclude, the study provides empirical evidence for the need to address teacher emotions and emotion regulation in remote teaching/learning settings. The identified themes have implications for teacher education to help teachers understand and manage their emotions in online teaching. Supportive relationships and good cooperation are proved important and teacher community initiatives could be developed to help teachers share encountered emotional experiences and instructional concerns. These initiatives could also include cognitive reappraisal emotion-regulated strategy workshops for online teaching settings to maintain positive emotions. This study also replies to the call for empirical studies on emotions that highlight the importance of field studies and qualitative data. It delves into teachers' emotional experiences, including those expressly mentioned (explicit) and those implied (implicit) during in-depth descriptions of lived experiences. The study also investigates how teachers manage their negative emotions in online teaching contexts. It is one of the few papers that focus on teachers' emotions in online settings, particularly in response to the COVID-19 pandemic.

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Curriculum as Seed: Designing and Supporting the Use of Open Education Resources to Promote Teacher Agency and Innovation

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Abstract: As open education resources (OERs) continue to proliferate, teachers will likely utilize these freely available resources to design and enact disciplinary instruction. While OERs have transformative potential in shaping classroom instruction, their open-access and availability also introduces new questions about how teachers will learn to take up and utilize these curriculum materials. In this conceptual paper, we build on a metaphor introduced in the field of human-computer interaction to reconceptualize the relationships among OERs, teachers, students, and the local context. We expand on how this new metaphor foregrounds aspects of curriculum use that have been backgrounded in previous conceptual frameworks, including the timescale and evolution of curriculum use, teacher creativity and agency, and the role of educational systems in shaping curriculum use.

Curricula as tool for education reform

Designing and disseminating high-quality curricula has historically been a main vehicle for supporting large-scale reforms to transform mathematics and science learning in K-12 classrooms (Stein & Kim, 2009). While curricula such as NextGen Storylines and OpenSciEd (OSE, 2022) are examples of such an effort within science education, there are also other disciplines, including Artificial Intelligence (AI) education, that are taking similar approaches to curriculum development. Curriculum materials can be a key lever for supporting disciplinary learning because they serve as boundary objects between reform initiatives (e.g., NRC Framework, NGSS) and the design of classroom instruction (Penuel et al., 2011). The tasks, tools, and representations that constitute the curriculum communicate what aspects of the discipline are worthy of pursuit in the classroom, as well as (potentially) new visions of teaching and learning (Sherin et al., 2004). Teachers play a pivotal role in bringing these curriculum materials to life by using their actions, ideas and experiences in ways that transform the written curriculum into the enacted curriculum (Ball & Cohen, 1996).

Open education resources (OERs) are materials that can be freely shared and, with many licenses, freely adapted. As they become more prevalent in the educational landscape, there are new opportunities and challenges for using materials as resources for supporting disciplinary instruction. For example, OERs remove financial burden as a barrier to accessing high quality materials. However, materials tend to represent a specific approach to disciplinary instruction and cannot be designed to meet the needs and interests of all students across various education settings. In addition, many embody visions for teaching and learning that may be unfamiliar to many educators. Thus, teachers will need to engage in professional learning experiences that help highlight the principles underlying these materials to enact them in sustainable and responsive ways within their classrooms. Teachers, curriculum materials, students, and local contexts must be considered together for curriculum materials to become a lever for both teacher and student learning (Short & Hirsh, 2020).

Our conjecture is that the proliferation of OER resources opens up new opportunities to engage with different metaphors that can help us transform the relationships among teachers, students, curriculum materials, and the contexts in which they are enacted. One prominent conceptual model in both science and mathematics education foregrounds different orientations of teachers with respect to how they engage with curriculum materials (Remillard, 2005). Remillard's framework outlines the knowledge that teachers and curriculum materials bring and how these forms of knowledge interact to transform the designed curriculum into the planned and then enacted curriculum. In this framework, the students and contexts are seen as inputs that shape the enacted curriculum (see Figure 3, Remillard, 2005). New metaphors are needed, both in the age of OERs and given what we know about curriculum adoption and sustainable change to practice of teaching. First, teachers orient in different ways to and learn from curricula in different ways, and their use of curriculum materials is varied and dynamic (Arias et al., 2016). While curriculum designers have been increasingly and intentionally embedding educative features (Davis & Krajcik, 2005) to support teacher learning in the context of curriculum use, attending to all these features each time curriculum is used is unfeasible. Supporting teachers' use of educative features must be supported intentionally through professional learning, and yet, we seldom acknowledge that this process takes time, as teachers utilize and become more familiar with the materials themselves. One would expect that the relationship between the teacher and curriculum would shift over time, as each additional use is an opportunity to better understand how the teacher can leverage their knowledge and experience and attend to different curricular features when enacting the curriculum materials.

Second, existing frameworks do not provide guidelines or account for how teachers might become more agentive in their use of the curriculum materials over time. Current forms of professional learning around the use of OER materials largely focus on guiding teachers through a curriculum storyline, although recent efforts have shifted to emphasizing local adaptations that explicitly address the lived experiences of students. Understanding how teachers make sense of the design principles that undergird curriculum materials and learn to make principled adaptations (DeBarger et al., 2013) in alignment with these principles is a timely and critical issue to take up within the learning sciences community.

Finally, current frameworks do not sufficiently account for the role of contexts in shaping curriculum use. Teachers make sense of curriculum materials through (and not in the absence of) the lens of the policies, practices, and instructional routines that are at work in their teaching contexts (Allen & Heredia, 2020). Moreover, students' sensemaking of the curriculum is shaped by the experiences they build within their community. Decades of learning sciences research suggests that disciplinary instruction ought to leverage and build on these robust and localized experiences for disciplinary learning to be meaningful (Barab & Luehmann, 2003). In other words, local contexts are not just backdrop in which curricula are enacted; they should inform the design of the curriculum if they are to be used in responsive and locally relevant ways (Buxton, 2010). For these reasons, the field needs new metaphors to help us rethink the ways in which teachers, students, curriculum materials and the local context work together to create new opportunities for expansive disciplinary instruction.

A new metaphor: Curriculum as seed

We draw on Fischer's work (Fischer et al., 2002; Fischer 2007; 2011) from the field of Human-Computer Interaction and propose *curriculum as seed* as a new metaphor for the relationship between teachers, curricula, students, and the local instructional context (see Table 1). We draw on literature from HCI because of its focus on generating novel technological tools that can expand the potential for human functioning and learning (Bannon, 2011). In contrast to the grammar of schooling that typically frames the curricular tools as static objects that are handed to teachers to use, HCI scholarship acknowledges that design problems in the real world require designing for open systems that end users inevitably modify and adapt to fit their needs (Fischer, 2007, 2011). The *curriculum as seed* metaphor similarly acknowledges the open-ended nature of the design space; curriculum materials are viewed as starting points (*seeds*) for greater innovation that materializes through the hands of teachers and students. Seeds, unlike germ cells, have a specific potentiality when they are cultivated in conditions that allow them to thrive. They also hold specific trajectories for adaptations, based on its survivability in various environmental conditions. For example, large seed size is advantageous for growth under low light conditions, but, due to their weight, large seeds cannot be borne on small plants (Linkies et al., 2010). Likewise, curriculum materials embody the collective inheritance (e.g. design principles, approach to teaching and learning) that were brought forth in their creation, and yet their survivability and thriving depends on the ways in which these materials are taken up by teachers and students' to address the needs and goals of the local environment. Teachers are local users who drive its growth and evolution because they have the agency, ownership, and knowledge that is needed to deliberately restructure, enhance, and "remix" the starting materials in ways that best address the needs and interest of their students. The *curriculum as seed* metaphor challenges the notion of teachers as enactors and conduits through which curricula get "delivered" into the classroom. Rather, teachers are seen as the innovators and designers, drawing on their knowledge of their instructional contexts, their students, and their funds of knowledge in ways that can enrich and transform the materials and the design of disciplinary instruction (Brown, 2002). This view of the teacher is directly related to the emerging scholarship around teachers as co-designers, and the value of co-design as a valuable space for expansive learning (see Ko et al., 2022).

Table 1
Curriculum as Static Object vs. Curriculum as Seed

Curriculum as Static Object	Curriculum as Seed
Curriculum designers have all the knowledge	Teachers have the knowledge and agency to creatively adapt curricula
Curriculum materials are over-designed to include all possible supports for teachers and students at the outset	Curriculum materials are under-designed, and become well cultivated seeds that evolve into a localized version of the curriculum that is

	realized in the hands of teachers and students
Curriculum use remains more or less the same over time	Curriculum use is dynamic and continuously evolves in response to the local context
Curriculum enactment is evaluated based on alignment with original intent	Curriculum enactment is used to deliberately restructure and enhance existing curricula
Teachers use curriculum "as intended" by designers	Teachers are informed participants who actively contribute to the evolution and creation of new curricular designs
Initial curriculum = intended curriculum	Initial curriculum = starting point for building new sociotechnical infrastructure within the school and/or district

What does this new metaphor enable?

Fischer expands on the *curriculum as seed* metaphor by describing the process of design and redesign as *seeding, evolutionary growth,* and *reseeding* (SER). *Seeding* comprises a largely planned set of activities, such as developing tasks, identifying phenomena, and embedding instructional routines into a unit. From an Indigenous perspective, seeding also involves collecting, growing, and sharing seeds to promote cultural diversity for future generations (Native American Food Sovereignty Alliance, 2022). The initial seed then undergoes *evolutionary growth*. During this phase, designs are treated as open systems that users can tweak, adapt, and play with. Depending on their effectiveness in supporting student learning, adaptations may lead to more permanent deliberate modifications and enhancements to the original materials – leading to a *reseeding* of new materials. To us, SER reflects a more expansive conceptualization of curriculum design and use. Curriculum materials are positioned in the larger context of instructional systems and *expected* to evolve in response to the needs and desires of that system. This conceptualization also blurs the boundary between the practice of design and the use of the curriculum materials. Instead of packaging materials to include all possible supports, curricula are intentionally open systems that teachers are expected to modify (and not "adhere to" or enact "with fidelity"). It also leaves room for – and explicitly encourages – customization and transformation.

One might push back on the "idealistic" vision of curricular uptake and innovation that are implied by this metaphor, arguing that "lethal mutations" (Brown & Campione, 1996) will result when teachers are left to their own devices. We respond to this by arguing that a corollary of the *curriculum as seed* metaphor is that new forms of professional learning are required to support teachers in this complex, long-term endeavor. We need professional learning opportunities that support principled improvisation (rather than fidelity of implementation approaches) to promoting teacher learning. Teachers cannot engage with a "one size fits all" professional development (PD) in which they are walked through the curricular sequence and expected to adhere to the curriculum as a script. Instead, we draw on prior scholarship to conceptualize teachers' curriculum use as one that requires *principled improvisation* (e.g. Philips, 2019). This metaphor creates new demands for teaching: teachers can make principled adaptations to curriculum materials (and other technological innovations) only when they understand its underlying architecture and the principles that undergird the design of lessons and the arc of the unit (Frank & Zhao, 2003). Moreover, different approaches to PD may be needed, depending on one's familiarity with the innovation being introduced (Frank et al., 2011). Teacher educators and PL designers will need to design opportunities to make the purpose and curricular structure visible and invite teachers to adapt the curriculum materials in ways that align with and address the needs of their local context (Penuel et al., 2009). What counts as "curriculum" is not just the initial seed, but instead encompasses the sociotechnical infrastructures that arise to support the design and use of the modified curriculum. The resulting curricular innovation and evolution is evidence that the seed has been taken up, cultivated, and carefully nurtured.

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Supporting High School Science Teachers in Developing Pedagogical Content Knowledge for Data Literacy

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Abstract: As the world becomes increasingly awash in data, there is a growing need for greater focus on data literacy at the K-12 education level. Since high school teachers are often trained in one specific subject, they need additional support to teach data literacy as an integrated STEM topic. In addition to providing subject matter knowledge of data literacy, this support must focus on pedagogical content knowledge (PCK) which connects the content to the pedagogy for teaching it. As there is a major dearth of research on PCK for data literacy this study seeks to apply existing strategies and design mechanisms that can support teachers in developing their PCK to the subject of data literacy to better understand how a new conception of PCK can be surfaced and understood.

Introduction

While the field of data science has expanded over the last few decades to address the explosion of data and the way it permeates so many aspects of life, K-12 education has not yet caught up, resulting in strong calls for greater focus on data literacy at all levels (e.g., Wolff et al., 2016). As the need for data literacy grows, the way we seek to teach students to interact with data also needs to change to promote a broader relationship with data that prepares students for working with the big, messy data sets that imbue research, industry, and society (Kjelvik & Schultheis, 2019; Lee & Wilkerson, 2018). Teachers need additional support to develop knowledge and tools for integrating that type of data into their classrooms, including both subject matter knowledge about data and knowledge about how to teach with it (Lee & Wilkerson, 2018). Pedagogical content knowledge (PCK) encompasses the professional knowledge that teachers hold about how to teach particular topics to particular groups of students (Shulman, 1987). While research on PCK for data literacy is mostly lacking, research on PCK for STEM integration has shown that in order to successfully integrate STEM learning in their classrooms, teachers need to understand how students learn and apply ideas in topic-integrated contexts and be able to ground the varied STEM concepts in the learning context and prior knowledge of their students (Vossen et al., 2020). This suggests that pedagogical strategies for data literacy implementation, are unique from teachers' existing PCK for the subject they teach. Therefore, any professional development (PD) that seeks to improve teachers' data literacy implementation should explicitly teach and model these strategies (Aydin-Gunbatar et al., 2020). However, the lack of research on PCK for data literacy makes it difficult to determine how to support teachers in developing it. As such, this project explores how to support teachers in developing their understanding of PCK for data literacy. Through a semester-long workshop with four in-service high school science teachers aimed specifically at examining their PCK for data literacy, this study asks, how did the components of the PD workshop support teachers' surfacing and development of PCK for data literacy?

Background

Data literacy is an emerging concept without a clear definition, and the overlap between data science, data literacy, computational literacy, and statistical literacy is still nebulous (Wolff et al., 2016). In an attempt to distinguish data literacy from some of the other fields, Kjelvik and Schultheis (2019) chose to define data literacy as existing in the overlap between quantitative reasoning and data science where data is grounded in an authentic context. This framework is useful in outlining some of the important components of data literacy, namely that it involves applying mathematical principles, working with computers and other technologies, and understanding the context of the data. The need to ground data literacy in real-world contexts and focus on *using* data rather than simply analyzing it is a common component across data literacy research (Rubin, 2020; Wolff, et al., 2016). However, authentic real-world data is often complex, messy, and unlike most of the data typically used in secondary school classrooms and teachers haven't always been taught how to engage with this data or the pedagogical strategy that is required to teach it (Kjelvik & Schultheis, 2019).

In order to engage teachers with pedagogical practices specific to teaching with and about data, we applied the framework of PCK to better support teachers' knowledge and learning. PCK is a distinct form of knowledge separate from subject matter knowledge (Gess-Newsome et al., 2019; Vossen, 2020). In the case of data literacy, the subject matter knowledge needed in the development of PCK draws from multiple disciplines across science, statistics, and technology. For this project, the subject matter focus included a knowledge of the context of data, the role and purpose of data visualizations, and how to build inferences from data (Rubin, 2020). While most teachers have extensive PCK for subjects they received training in and have experience teaching, considering data literacy as explicit subject matter rather than a tool for teaching math or science is often new to teachers and they may need to develop additional PCK for data literacy in order to enact it successfully in the classroom. While PCK can develop through experience alone, studies have shown that PCK development can be guided and enhanced through PD that aligns with teachers' learning needs and goals (Aydin-Gunbatar et al., 2020; Gess-Newsome et al., 2019). However, there has been little to no empirical research published on PD specifically for developing knowledge for teaching data literacy. The theoretical research on potential strategies for teaching data literacy (e.g., Lee & Wilkerson, 2018) have been developed without engaging teachers with those strategies during PD. As such, this study relied on a method shown to develop PCK within PD interventions (e.g., Loughran et al., 2012) and applied those strategies to the development of knowledge for teaching with and about data.

Methods

This research engaged in an early-stage or exploratory study in which the goal was to examine how the knowledge teachers held about teaching for data literacy could be surfaced and developed.

Designing for PCK development

The intervention relied on a common method for engaging teachers in building and refining their PCK: Content Representations (CoRes, e.g., Loughran et al., 2012). CoRes were originally developed by Loughran and colleagues (2012) as a way to guide teachers to think about their practice in creating PCK around a particular big idea. A CoRe is a template which prompts a teacher or group of teachers to think about teaching a particular subject through big ideas with questions such as: *Why is it important for students to know this? What else do you know about this idea that you do not intend students to know yet? What is your knowledge of students' thinking which influences your teaching of this idea?* Loughran and colleagues (2012) found that CoRes could be used to develop PCK by enabling teachers to make their practice, and their thinking on their practice visible in a way that allowed them to then reflect on that knowledge. While teachers often struggle to construct big ideas for a subject and answer the questions in a CoRe individually, when building knowledge collaboratively they have more success (Aydin-Gunbatar et al., 2020). Using a CoRe as an artifact allows teachers to develop a shared language around the content knowledge and the PCK for teaching a particular topic (Loughran et al., 2012).

Context and participants

This study took place within the larger context of an intervention designed to support teachers in implementing a STEM-integrated unit on bioinformatics in their existing secondary school science classrooms (Yoon et al., 2022). An extension workshop was conducted with a subgroup of four teachers in which participants met virtually for about 20 hours over the course of five months while implementing the bioinformatics unit in their own classrooms. The workshop sessions relied on a number of different strategies, including explicit discussion of PCK, implementation discussions, and review of data literacy content components. During the workshop, four CoRes (and framing for a fifth) were discussed. The four participants all taught in the same large urban school district in the northeastern U.S. Three of the teachers (Hallie, Will, Manisha) had over ten years of teaching experience, while the fourth (Mary) was only in her second year in a formal classroom but possessed over 15 years of experience teaching informal science education. Two of the teachers (Hallie & Manisha) were teaching biology, two were teaching environmental science (Manisha & Will), and one (Anna) was teaching agriculture.

Data sources and analysis

The data for this paper came from transcripts of the workshop sessions and post intervention interviews. The nine sessions of the extension workshop series were conducted over Zoom and each session was recorded using Zoom's built in recording feature. A total of 15 hours, 20 minutes of video was captured and transcribed. Additionally, at the end of the workshop series, a semi-structured interview was conducted with each participant. The interviews asked teachers about teaching data literacy (e.g., *In your view, is data literacy important to teach in a science class, why or why not?*) as well as asking them to reflect on the components of the workshop series and how they affected their knowledge and learning (e.g., *What parts of the workshop series did you find most supportive of your growth as a teacher?*) The interviews ranged in length from 40 minutes to 58 minutes with an average length of 49 minutes and a total time of 3 hours and 19 minutes.

The transcripts of the workshops and interviews were organized in Delve Tool, a qualitative data analysis software and a constant comparative analysis (Glaser, 2008) was conducted to generate themes related to participants' perceptions of the intervention and its design components.

Findings

While the larger project that this paper is a part of focused on understanding what the components of PCK for data literacy are (Miller, 2022), this paper focuses on the process by which they were developed. The most valuable and tangible shift in teachers' PCK was simply becoming more aware of the knowledge they already held and being able to articulate it in a way that made it easier to apply to their implementation. To that end, the primary theme from the design of the workshop is that the CoRes, and especially the development of big ideas provided a successful framework for surfacing and organizing PCK for data literacy.

The CoRes served as a framework that allowed space for reflection. All four participants thought the CoRes were a useful component of the workshop series. They primarily reflected in their interviews about how the CoRe Template provided them a specific framework that allowed for more nuanced and focused reflection. Hallie and Will both reflected during their interviews about the usefulness of the conversations engaged around the CoRes. Hallie spoke to how being forced to articulate her own thinking to fit into the framework of the CoRe led to deeper thinking for her. She said in her interview, "So, I'll say just the brainstorming around what to do and how to do a thing because it's a lot easier for me to think deeply about a thing when I'm trying to express it to someone else than it is when I'm just trying to turn it around in my own head." Similarly, Will focused in his interview on how listening to other people articulate their thoughts in response to the CoRe framework was useful for him, reflecting during his interview, "I was more looking at what the other teachers were talking about. Seeing what other teachers were focusing on and what they knew opened my eyes: oh, I hadn't thought of it that way. So that was very beneficial to change my thinking in how I was going to present this." In this reflection, Will was talking about how the discussions around the CoRes and the ideas that the other teachers came up with and the knowledge they surfaced helped him to grow his own knowledge. They opened his eyes to new concepts and new strategies that he hoped to employ in his own classroom going forward.

While the CoRe template was useful for guiding discussions and reflections on teaching with and about data to be more focused and nuanced, perhaps the most useful part of completing the CoRes was identifying the big ideas for data literacy. Teachers were not used to thinking about data literacy as subject matter that needed to be explicitly taught rather than as a tool to be used to teach other concepts in science. There was extended time in the workshop sessions for discussing and identifying big ideas before building each CoRe, yet it was often still not enough. Simply coming up with big ideas that were appropriately specific but also appropriately generalized was a challenge for the teachers but a challenge that led to a lot of growth and recognition and articulation and refinement of knowledge that the teachers already held. One example of this is in attempting to develop big ideas for the concept of data in context, teachers landed on a big idea of interest: *interrogating data is useful and necessary*. The identification and refinement of this big idea led to the surfacing of PCK in that teachers then connected this to what they knew about how students' perceive data and strategies for teaching it. Specifically, they identified that students are not used to questioning data, and that therefore students would need to be explicitly taught how to interrogate data through tools such as employing text analysis to data representations.

The teachers came up with many more big ideas than they ended up focusing on in the CoRes they built, however having the CoRe as a framework allowed them to decide which of the big ideas were the most important or salient. So, while the brainstorming process for the big ideas was a crucial piece of surfacing knowledge about teaching data literacy, the CoRes allowed the participants to focus on specific big ideas and connect those to knowledge about students' understanding and specific teaching strategies, important components of PCK.

Discussion and implications

While the exploratory nature of this study did not allow for an exploration of the extent to which teachers developed additional PCK as a result of this intervention, it was clear that they became more aware of the concept of PCK and more inclined to reflect on their practice within the PCK framework. Engaging in development of big ideas for data literacy and subsequent completion of CoRes for those big ideas supported teachers in developing a better sense of the strategies they were using, language to describe them, and tools to reflect on them more productively. Unpacking the components of data literacy in order to determine the big ideas led teachers to, if not increase their subject matter knowledge of data literacy, certainly approach it with a different perspective. This supports previous research that shows CoRe development can support teachers' knowledge growth (e.g., Aydin-Gunbatar et al., 2020) However, most previous studies were conducted within disciplines that had well established big ideas and frameworks for PCK. The field of data literacy does not have that. So, while one implication of this research is to suggest that these tools continued to be used to help teachers develop knowledge and confidence for teaching data literacy, another implication is that the field needs to engage further with teacher knowledge for teaching data literacy. As Hallie reflected in her interview it would be nice if teachers had an established set of knowledge about students' preconceptions for data and teaching strategies to engage those preconceptions, but the field is not there yet, partly because there has been so little research conducted on teacher knowledge.

The use of CoRes in PD can guide teachers towards best practices for using authentic complex data in their classroom, but first a set of best practices needs to be established so that teachers can be supported in using those best practices to teach data literacy. Previous research has found that teachers often lack the content knowledge to engage in integrated STEM activities such as the use of complex authentic data (e.g., Aydin-Gunbatar et al., 2020) and this study supports that research. However, the larger struggle for the teachers in this study was not the subject matter knowledge of data literacy but the strategies for how to teach it. While the teachers already had knowledge of strategies for teaching science and engaging with data in the context of a science class and were able to reframe that knowledge in a way that applied to data literacy, most of them still felt at the end of the intervention that they were in need of additional support to grow their strategies for teaching with and about data.

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"TERFs are a Thing. And I F*cking Hate Them": Developing Solidarity Through Emotion and Ideology

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Abstract: In this paper, I investigate gender marginalization and the desire for belonging from similar (non-binary) and divergent (misgendered male versus female) experiences. The study occurs within an immersive virtual reality experience designed to deepen understanding of gender and sexuality-based marginalization. My analysis extends Sara Ahmed's queer phenomenological concept of orientations, bringing it into conversation with learning sciences theories of ideological stance-taking and emotional configurations. I highlight moments of emotional-ideological sense-making where learners reflexively negotiate between themselves and marginalized people and engage in *reorientations* that support new kinds of solidarity for participants. An analysis of the interaction between the narrator's story, Clare, and the researcher reveals how differences in experiences of marginalization, despite a shared identity, can produce divergent emotional configurations and ideological stances. Further, the analysis shows that interactions with the VR experience and the researcher supported the development of shared ideological stances and emotional-ideological *reorientations* toward solidarity.

Introduction

In this paper, I investigate gender marginalization and the desire for belonging from similar (non-binary) and divergent (misgendered male versus female) experiences of non-binary people. I use the term non-binary when referring to the identities of the participant, researcher, and VR narrator. I also use the term trans (short for transgender) as an umbrella term that includes non-binary people. Trans is defined as having a current gender that is different from the gender assigned at birth.

This study occurs within an immersive virtual reality (VR) experience designed to deepen understanding of gender and sexuality-based marginalization in science, technology, engineering, and math (Paré et al., 2021). The VR narrative features a nonbinary but societally-assumed female, queer individual's emergent and cumulative experiences of exclusion and marginalization. The purpose of this paper is to offer a close analysis of the learning processes and outcomes of an interaction between the participant, the researcher and a section of the story told by the VR narrator that highlight a moment where differences in experiences of marginalization, despite a shared identity, can produce divergent emotional configurations and ideological stances.

I draw attention to how experiences of identity difference go beyond the categorical and are deeply rooted in the phenomenological, where who we are is not simply what we call ourselves, such as "non-binary." Rather, our identities are embodied life histories that are always in the process of becoming (Paré et al., 2019). Our identities shape how we experience ourselves, how others see us, and how we are allowed to extend ourselves into spaces (Ahmed, 2006). I argue that reorienting ourselves toward the marginalized other involves emotional-ideological sense-making processes where learners reflexively negotiate between themselves and the marginalized person. This paper highlights how equity and justice-seeking work in the learning sciences can be strengthened by attending to critical, queer phenomenologies of being and becoming and *reorienting* processes toward solidarity and care.

Rising fascism and trans-antagonistic politics

Access to women-only spaces is a complex political issue. Women's spaces are typically created to address the barriers women face to accessing men-dominated spaces in learning and careers. However, they have intentionally and unintentionally excluded trans and non-binary people who experience gender marginalization and could benefit from similar support. The issue has been further politicized by explicitly trans-exclusionary radical feminists (TERFs), who expressly argue for excluding trans people, especially trans women, from women-only spaces. In the past decade, TERFs have acquired global media attention through highly visible TERFs such as the well-known British author of the Harry Potter series, J.K. Rowling and British-Australian theorist Sheila Jeffreys (Bassi & Lafleur, 2022).

Bassi and Lafleur (2022) draw upon Traverso's (2019) description of postfascism to explain the connections between the current cultural moment of neoliberal individualism, enduring fascist discourse, and trans-exclusionary ideologies. For example, trans-antagonism is propagated through the fascist and neoliberal concern with women's safety and the constructed, transphobic discourse that "transgender identities allegedly offer an excuse for 'predators' to infiltrate women's spaces" (2022, p. 315). Bassi and Lafleur (2022) explain that in these discourses, trans women are portrayed within neoliberal individualizing frames as an "example of individual behavior that is perverted and deviant" (p. 315). Conversely, cisgender women are portrayed in neoliberal discourse "as an ontological state whose normativity derives from its putative naturalness" (Bassi & Lafleur, 2022, p. 315). Bassi and Lafleur (2022) connect this to the similarly framed ideologies of Fascist Italy, where fearmongering about women's proper roles was used to pressure women to "conform to state-sanctioned femininities deemed natural, chiefly that of the fascist housewife and mother" (p. 315).

Trans and non-binary people's access to supportive learning environments that address all forms of gender marginalization is a critical issue in education (Keenan, 2022). In the United States, 200 anti-LGBT bills were introduced in the first five months of 2022, with many of the bills aiming to limit transgender students' access to educational facilities and activities (Mangin et al., 2022). Rhetoric in support of these bills takes the form of what Elster (2022) terms "insidious concern" that is centred on the "moral policing of the reproductive order" (p. 416). Elster (2022) juxtaposes the concern shown for children generally, who "often symbolically represent heteronormativity, the family, and whiteness" while "actually existing trans children are simultaneously configured as imperilled subjects requiring protection and dangerous actors in need of regulation" (p. 412).

Research questions & methods

I researched the following question: How do the reorienting experiences in the VR experience allow for new kinds of solidarity for the participants?

The VR experience was designed by myself and my team at Queer Code (queercode.org). See our design-focused paper for further details about the VR application design (Paré et al., 2021). This ethics-approved study was conducted over Zoom for 1-2 hours, in which seven participants (recruited via social media) were interviewed while they played the VR experience and shared their game screen and included a pre and post interview. The only inclusion criterion was that people have VR systems because people who are new to VR can become distracted by the novelty of VR. Participants self-selected based on interest in participating in a study on learning about gender and sexuality in VR. I present the case of Clare (pseudonym), a non-binary person in the United States who is in their early fifties and is misgendered by society as male. Like the VR narrator, the facilitating researcher is a non-binary person misgendered by society as female. Although all three share a marginalized identity as non-binary, how society misgenders each person differently significantly affects their sense of belonging in learning spaces that are not inclusive of non-binary people. I chose this case because a close analysis of the interaction between the narrator's story, Clare, and the researcher reveals how differences in experiences of marginalization, despite a shared identity, can produce divergent emotional configurations and ideological stances. I recorded and transcribed videos and identified emergent themes further refined through my theoretical focus on identifying occurrences involving reasoning about gender and sexuality through ideological stance-taking and emotional configurations.

For my analysis, I extend Ahmed's (2006) queer phenomenological concept of orientations with complementary learning sciences theories of ideological stance-taking, where "every stance exists in a triangular relationship among the stance taker, the object that is being evaluated, and other subjects" (Philip et al., 2018, p. 196), and emotional configurations, the "situated and reciprocal interrelationships between feeling, conceptual sense-making, and practice (including linguistic practice) that give emotion social meaning (Vea, 2020, p. 315). I highlight moments of emotional-ideological sense-making where learners reflexively negotiate between themselves and marginalized people and engage in *reorientations*–meaning recognizing and resisting normative enforcements of docility and reorienting toward counter-hegemonic and non-normative actions and people (Ahmed, 2006; Paré, 2022; 2021) that support new kinds of solidarity for participants. In particular, the case study in this paper demonstrates a form of solidarity between trans people, called trans care (Malatino, 2020), in which transgender people show up for one another when socio-political systems fail.

Findings

I present an illustrative case of Clare's reflection upon the narrator's story of seeking to belong to a women's coding group. Clare initially struggles with the narrator's reluctance to access a women-only space because Clare desires this access to feminine friendship and belonging but is denied because they are misgendered as male.

> **Turn 1 Researcher:** So how did that last story kind of sit with you?
> **Turn 2 Clare:** Is it possible to die of wistfulness? … Like, It's kind of relatable in a certain way, except like it's, so like, my experience is so different because. The person who's narrating the experience, it's like clearly, is someone that people would tend to code as female. Right? [**Researcher:** Yeah]

In turn 1, I asked Clare about their reaction to the story because I had noticed Clare both agreeing during the story, saying "Yeah," but also in some parts saying that it was not like their experience as someone seen by others as a cisgender man. I also interpreted Clare's heavy sighs as a sign that this story was emotionally difficult for them. In turn 2, Clare explains their sense of difference by checking with me about the narrator's identity as societally "coded" or misgendered as female, which I confirm.

> **Turn 3 Clare:** That's how they would be clocked. And, umm, you know, [sigh] maybe it's just my own projecting or something, but I've long thought that that would be easier. You know? So it's like, I felt empathetic for what they were going through. But at the same time, there is a part of me that was like, "Wow, you're so lucky that people see you as female so that you can just be in those spaces." And like I find, I tend to find women-dominated spaces more supportive and safe. So like. [sigh] I can see how it would be difficult for them, but it seems like it would be easier that way than the opposite. Which is sort of more my scenario.
> [**Researcher:** Right.] [**Clare:** Yeah]
> **Turn 4 Researcher:** Yeah, that makes sense from your own perspective. You're in this position of like, how can you take for granted? The narrator, how can you take for granted that you have access to these supportive spaces? When you're like, you want that, you know, that's where you'd like to be.
> [**Clare:** Right.] [**Researcher:** Yeah, that's really understandable.]

In turn 3, Clare expresses that while they felt empathetic for the narrator's experience, their ideological stance was that they thought it would be easier to be societally seen as a woman, even if one is non-binary. Clare explains that they believe, based on their experience, that women-dominated spaces are more supportive and safe. In turn 4, I hesitated before answering because my own experience as a non-binary person who is misgendered as a woman (like the narrator) informed my ideological stance that neither men-dominant nor women-dominant spaces are more safe or supportive. Despite my disagreeing, I wanted to stay with Clare's experience because I recognized that while my experience was represented in the narrator's story, Clare's experience of marginalization was not represented and needed to be heard. I affirm Clare's experience by reflecting aloud on how Clare might feel upon hearing how the narrator can access the spaces that Clare is denied. I empathize with Clare's desire to belong and frustration with the narrator when they seem to take this access for granted.

> **Turn 5 Clare:** But at the same time, I know that it's not perfect, right? I mean, like TERFs are a thing. [**Researcher:** Yeah.]
> **Clare:** And I fucking hate them. [**Researcher:** Yeah.]
> **Clare:** You know, and it's like. [big sigh] So it's pretty easy to imagine by analogy. Somebody being like, OK, either they're assuming things about this person that are not true and that could hurt, or if they sort of came out and were like, "Hey, I'm nonbinary," then I can imagine some people having the reaction like, "Oh, well, this is a space for "real" women." And then it would be like, "Well, fuck you, then," you know?
> [**Researcher:** Right Yeah.]

In turn 5, Clare then reasons about the socio-political systems that fail us as non-binary people. They draw upon their socio-political knowledge of TERFs (trans-exclusionary radical feminists) and how society fails non-binary people by propagating or allowing the propagation of gender essentialist beliefs about "real women." Clare's emotional configuration toward the narrator shifts from "wistfulness" for the narrator having access to something Clare does not toward a redirected anger at TERFs for making women-only spaces exclude gender-marginalized, non-binary people.

Clare thus reorients toward a shared experience with the narrator and researcher by leveraging this ideological-emotional stance against TERFs as a resource to establish this shared experience with the narrator of being excluded from women's spaces by gender essentialist beliefs and trans-antagonist actions. Despite their initial emotional disconnection with the narrator's experience, Clare reorientates toward a new kind of solidarity that does not rely on a shared interpretation of women's spaces as safer. Clare ultimately demonstrates trans care (Malatino, 2020), a kind of preservative love, where the commitment to showing up requires acknowledging how socio-political systems fail us and how "recurrent, habitual, and mundane" trans care work is integral to our survival (p. 70).

Summary and discussion

Reorienting ourselves towards a marginalized person's experience involves emotional-ideological sense-making processes where learners reflexively negotiate between themselves and the marginalized person. A phenomenology of reorientation can support analyzing solidarity as a *turning* or *reorienting* process (Ahmed, 2006; Paré, 2022; 2021) that supports new kinds of solidarity for participants. This reorientation toward the marginalized other involves negotiating emotional configurations (Vea, 2020) and ideological stance-taking (Philip et al., 2018) with the marginalized person (or VR narrator). Further, identifying how reorienting processes occur between marginalized people with different marginalizing life experiences demonstrates how solidarity is an accomplished interaction, not a state of being, even among those with shared marginalized identities.

The participant, facilitator-researcher, and narrator share a socio-political experience as non-binary/trans people threatened by the global rise of fascist ideologies and the intertwined trans-antagonistic discourse and action. The growing threat to trans survival informs the facilitator's reorientation toward Clare's experiences of marginalization and need to be heard. It also informed and reoriented Clare's ideological stance-taking from a focus on difference to a shared struggle against gender essentialist ideology and toward the shared emotional configuration expressed in their statement, "TERFs are a thing. And I fucking hate them," to which the researcher agreed. This analysis highlights how trans people show up for one another by acknowledging how socio-political systems fail us and how "recurrent, habitual, and mundane" trans care work is integral to our survival (Malatino, 2020, p. 70). I believe that this preliminary analysis demonstrates how equity and justice-seeking work in the learning sciences could be advanced with further empirical analysis using a phenomenology of *reorientations* to analyze how solidarity is achieved in social interactions and how emotion and ideology coordinate sense-making toward these reorientations. This case could also inform how educational researchers and practitioners might practice care for their trans colleagues and students by becoming informed of political contexts of trans-antagonism, creating space for hearing diverse trans experiences, and affirming and supporting trans people.

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An Analysis of Teacher Practices and Student Participation in Contrasting Activity Systems in an AI Educational Program

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Abstract: In this paper, we investigated the activity systems in two contrasting upper-elementary classrooms and drew on analyses of discourse between teachers, researchers, and students during an AI curriculum intervention. We examined the role teachers' practices played in setting the stage for classroom discussions and interaction. Despite the teachers appropriating different components of the same curriculum depending on their teaching strategies and classroom cultures, to attain the learning objectives, pre- and post-assessment results revealed that both teaching approaches led to similar student learning outcomes indicating that there are multiple ways to teach a pre-designed curriculum.

Introduction

AI education has begun to gain prominence in K-12 education (DeLyser & Born, 2021). However, there is little work exploring how classroom interactions influence students' understanding of AI concepts. Our project explores approaches to AI education along with the development of PrimaryAI, a curriculum for upper elementary-aged students (Glazewski et al., 2022). The curriculum has multiple resources, activities, and discussion prompts to foster classroom interactions. Differences in how teachers use these tools and resources can lead to varying forms of classroom engagement (Hmelo-Silver et al., 2015), which raises the question of the impact that these different enactments may have on student learning depending on how the curriculum resources are used to mediate learning. We provide a comparative case study between two classrooms where the teachers taught the same unit of the AI curriculum regarding teaching practices, mediators and tools, and learning outcomes. We observed how depending on teacher practices and classroom cultures, the same lesson from a unit in the curriculum was delivered in a different manner and yet yielded similar student learning outcomes.

Method

Our team collaborated with two teachers in the Midwest to design an AI curriculum to introduce AI learning experiences into their upper-elementary classrooms, 35 4th graders and 27 5th graders. The pre-and post-tests were administered at the beginning and end of each unit respectively. Implementation of Unit 1(computer vision), Unit 2(machine learning), and Unit 3(AI planning) were completed in both classrooms over three weeks.
This study investigates two primary questions:

1. What is the impact of different teacher practices on discourse and students' understanding of AI concepts?
2. What are teachers' perceptions of the AI curriculum, and what is the relationship between these perceptions and teacher practice?

Theoretical framework: Activity theory

Activity theory (AT) was used to understand the role of the teacher's instructional strategies aligning with the idea that learning always occurs in social and cultural contexts (Levinson et al., 2000). Our focus was to understand how the teachers use different resources as mediators to facilitate learning. Viewing the two classrooms as complex activity systems, our goal was to compare these two systems to explore how learning was mediated in these two contexts and to understand its impact on student learning outcomes. Activity theory offers a conceptual framework for studying human behavior and provides a framework for conceptualizing different social interactions, materials, resources, and norms that enable and constrain what individuals and a collective group can accomplish (Leont'ev, 1978). The six core components of an activity system include subject, object, mediating artifacts or tools, rules, community, and division of labor (Engestrom, 1987). In this study, we compared the two activity systems that represented the different entities and interactions in the two classrooms.

Data sources and analysis

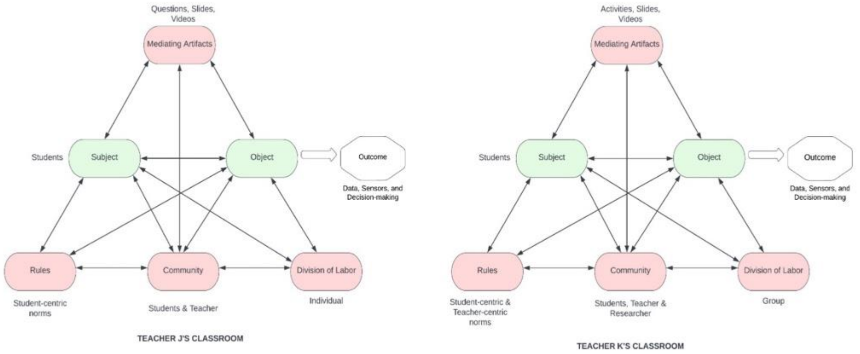
To understand the student interaction, discourse, and teacher role in the two classrooms, we examined a total of 8 hours of video data from both classrooms. Field notes were also used for analyzing classroom interactions and teachers' pedagogical practices. To evaluate student learning gains in both classes in this study, we calculated descriptive and within-group inferential statistics. We applied mixed methods to analyze the pre-and post-test data quantitatively and analyze representative clips from the video data qualitatively. For the video data, we conducted a moment-by-moment analysis to investigate the discourse during the learning process, mainly focusing on teacher-student and teacher-researcher-student interactions. To further understand the teachers' mediating and discourse practices, we attempted to gather their perspectives through semi-structured interviews. We qualitatively analyzed the data inspired by thematic analysis to find evidence relevant to understand the teachers' strengths and how they leveraged them to mediate classroom interactions and appropriate the curriculum.

Results

Activity system comparison

We analyzed the classroom videos and our field notes from two classrooms and observed that they varied in context, classroom culture, and the role of the teacher, leading to different student interactions and discourse. Both teachers taught the same lesson: data, sensors, and decision-making from Unit. However, they differed greatly with respect to the way they introduced the concepts and engaged with the curriculum resources and materials. This had a subsequent impact on classroom dynamics including the different teacher-student and student-student interactions. We compare the two activity systems representing the classrooms for similarities and differences as shown in Figure 1. We summarize the classroom interactions between teachers and students in these two activity systems, by each component, where the teachers taught a lesson from Unit 1(Computer Vision), which was designed with the objective that the students will leave with the idea that "humans use data to see or create an informed decision, and computers also behave similarly when it comes to gathering data through different sensors to make decisions."

Figure 1
Activity System Comparison



<u>Mediating artifacts</u>

The key mediator that Teacher J used to her strength was the leading questions from the curriculum that she posed to encourage student interactions and discourse. A moment-by-moment analysis showed how students interacted with the teacher and engaged with the content through conversations. The first question she posed was: "*How does a computer learn?*" A few open-ended student responses that were based on their prior knowledge included "*maybe a human teaches it," "some program," "maybe it is programmed to do that," "it has a thing inside it that allows it to change the program and learn new things."* These responses revealed that although the students did not have a clear understanding of how computers learn, they knew that there was some training involved –*" a human teaches," "some program"* and that it is a continuous process– "*allows it to change."* Teacher J summarized these responses and introduced a new concept "*computers learn using data..*" She talked about the different types of data and presented examples on slides to help students visualize these different types. She first introduced the new concept and then used the slides from the curriculum resources to further build on it. By weaving multiple student responses and the content from the curriculum, she gradually built their understanding of each new concept that was introduced.

She did not feel comfortable with a lot of the activities and curriculum resources due to her lack of familiarity with the content. In her interview, she talked about how she did not understand how to facilitate learning through many of the activities in the curriculum because she was not convinced about the concepts that they were meant to address as she was not a content matter expert, and the activities did not have enough guidance for novice AI teachers:

"Again, sometimes I think I wasn't able to explain AI very well. So maybe if the teacher did have a little more guidance. When we started getting to examples of what is AI or what is not AI, sometimes I wasn't sure if they were or not. We aren't experts on it. When you are trying to explain or teach it, a little more scaffolding "

Instead, she leveraged her strength of leading classroom discussions and facilitated learning by eliciting student answers to the questions and then introducing the new concepts after gauging their level of understanding at that moment. She guided student thinking by asking these questions and modeled how to critically think about AI concepts.

Teacher K, on the other hand, used classroom activities, curriculum resources, and the researcher on-site's assistance as the main mediators to facilitate learning. She introduced a couple of AI concepts together using the slides, and instead of asking questions from the curriculum resources, she relied on classroom activities to help students get involved with the content. These concepts included “*AI computers learn and make decisions,”* “*They learn through data,*” and *“How computers get data, let's think about how animals and humans get data.”* After introducing three new concepts she posed her first question to the class, “*how do they get this data?*” She got a few responses like “*books,” “google,”* and “*other adults.*” She acknowledged these responses, but instead of building on them, she moved on to an activity to delve deeper into how humans use their senses to get data: "*We're going to play a game, with make-belief scenarios to help us think about how humans get data. Once we see how humans get data, we can see how computer scientists mimic these processes in computers. The best ideas come from nature. We are going to create groups for this activity.”*

She was comparatively more comfortable using the curriculum resources like the videos and activities to facilitate learning. There are two factors emerging from her feedback interview that can be attributed to this: One, for activities that had underlying AI concepts she was not too confident about, she used the researcher-on-site’s help to clarify the area of confusion:

> “This is the part where we had to ask her (the researcher) a lot of questions and she had to study and answer them”

Two, she was more comfortable depending on the videos and the activities because she wasn’t the only one talking, and sources of information were distributed, and this helped when she was not too confident about her AI knowledge:

“I loved the little bits of information because me being you know..a little uncomfortable with it but also it's not me talking the whole time..I learned something new as well”

We observed how Teacher K introduced new concepts from the curriculum, and instead of having conversations about these concepts, she engaged the students in activities to further understand these new concepts by leveraging her strength in science teaching.

Community

In Teacher J’s classroom, the community members included the students and the teachers. However, in Teacher K’s classroom, there was an additional member, a researcher from the curriculum development team who assisted the teacher with resources, co-teaching AI concepts, and answering student questions.

Rules and division of labor

Teacher J’s classroom was more teacher-centric where the conversations were mostly initiated by the teacher and the interactions were between the teacher and the individual students. There was not much student-student interaction unless the classroom activity required them to work together.

In Teacher K’s classroom, there were more classroom interactions between the students. Even when they were engaged in a discussion, we observed students building on each other’s answers, agreeing with or disagreeing with each other’s responses. It was more student-centric and the teacher encouraged students to express their freedom with how they decided to take part in an activity. Students walked around and enacted the scenario from the activity in their groups.

Learning outcomes

We analyzed the pre-and post-test scores quantitively. There was an overall increase in the average scores in the post-tests across both classrooms in comparison to the pre-tests. Paired t-test scores for all the comparisons for two out of three of the constructs were statistically significant ($p<0.001$). Cohen's *d* values for the first two content areas were >1.0 across both classrooms indicating a large size effect with no differences between the classrooms.

Discussion and conclusion

Teachers' instructional strategies and practices play a critical role in helping students engage in conversation and build an understanding of the content being taught. Our results support the notion that the same curriculum with the same set of resources and materials can be taught in different ways depending on an individual teacher's teaching practices and strengths. Although the PrimaryAI curriculum had multiple resources, activities, videos, and discussion questions, our findings revealed that while one teacher relied more on the discussion questions and slides as resources to mediate learning, the other used more of the activities and the videos to do so. The presence of an onsite researcher who had content matter expertise in the second classroom (Teacher K), helped her leverage curriculum resources that addressed AI concepts she wasn't too sure of. While Teacher J in the first classroom did not have this support, she used her years of teaching expertise to her strength and used guiding questions to mediate learning. The interaction in this classroom was almost always initiated by the teacher, but it was not didactic. Instead, it was more inquiry-based, helping the students to think critically about the AI concepts one at a time. Pre- and post-test results revealed that there was a considerable gain in students' understanding of AI concepts across both classrooms, indicating that there are multiple ways to teach a pre-designed curriculum. The two teachers leveraged their strengths to ensure that the outcome was met. Activity theory, with its emphasis on mediation, provided a useful lens for identifying what these strengths were and how the classrooms were viewed as complex systems. Contrasting classroom cultures could be visualized with the help of the framework and let us identify the different social and cultural interactions that took place between the teachers and the students. Teacher interviews helped us recognize ways in which we can refine the curriculum by adding support for the teachers and provided us with their perspectives on how they and the students interacted with the curriculum. The curriculum offered multiple resources, activities, discussion questions, and additional material to teach each AI concept that was introduced which provided the teachers with the choice of working with whatever they were comfortable with and best suited their teaching styles. Unfamiliarity with the content led to both teachers not feeling confident about explaining many of these concepts.

Both teachers in this study discussed challenges with the content matter they had to deliver highlighting the need to prepare teachers through professional development courses. Further future research should explore how to build teachers' capacity and capabilities for AI education, which includes pedagogical knowledge and understanding of AI and AI ethics. Future efforts could also be directed towards understanding how these strategies to support teachers with AI knowledge can influence teachers' outcomes such as confidence and motivation, and hence impact student engagement and learning outcomes. This program highlighted teachers' experiences and challenges while teaching an AI curriculum providing researchers with the opportunity to develop teacher development programs to address these challenges and improve the curriculum.

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Improving Technology- Enhanced Immersive Learning With Design-Based Implementation Research

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Abstract: While research on learning with immersive virtual reality (VR) to date has primarily focused on technology-focused or media comparison experiments, the field of learning sciences increasingly calls for research that accounts for classroom constraints to better translate findings to practice and instructional design. This paper describes the benefit of design-based implementation research (DBIR) as a method for studying immersive learning technologies and a work-in-progress study of VR that employed DBIR to illustrate its application. The process surfaced learning outcomes and instructional methods that would have been difficult to find in a lab experiment, including the benefit of knowledge-building discourse for students' development of curious dispositions about scientists' work.

Introduction

The field of learning sciences increasingly recognizes the value of research accounting for implementation in education systems to better impact policy and practice and advance our understanding of learning. For example, McKenney (2018) invited more research focused on collaboration between research and practice, attending to issues of implementation to better impact learning at scale. Learning scientists have pointed to design-based implementation research (DBIR) as a fruitful method to advance research and practice (Yoon & van Aalst, 2017). Such methods may be particularly useful for technology-enabled interventions with transformative aims to be effective and usable in education systems at scale (Fishman et al., 2004).

Despite this call for research that centers collaboration and implementation, learning with immersive virtual reality (VR) is most often studied in laboratory experiments leading with questions about the technology rather than problems of educational practice. Reviews point to the prevalence of hardware-focused (Jensen & Konradsen, 2018) or media-comparison studies (Mayer et al., 2022), comparing VR to another device or value added by a specific feature. Many of these studies are conducted in laboratory experiments, and those conducted in classrooms are often in response to a brief experience (Markowitz et al., 2018) or unrelated to the curriculum (Petersen et al., 2022). Much research on VR has been conducted with state-of-the-art technologies to understand people's behavior in these environments, not as learning tools (Bailenson, 2018; Slater & Sanchez-Vives, 2016). While this research points to important issues of VR learning design to account for issues like cognitive load and avatar choices, their translation into classroom practice is a challenge. Questions that remain include the impact of the technology as its novelty wanes, appropriate instructional designs incorporating VR in lessons, assessing learning outcomes beyond content knowledge gains, and navigating constraints such as limited internet connectivity, time, and space. DBIR offers a useful framework to study learning with VR in authentic contexts and can be implemented systematically, what can be referred to as "state of the actual" (Southgate, 2020) or "state of practice" research (McKenney, 2018). This paper describes DBIR as a research method, its applicability for improving research on VR in authentic educational environments, and describes a study that is currently in progress to illustrate the benefits of conducting DBIR on technology-enhanced immersive learning.

Theoretical background

DBIR has four guiding principles, described in Table 1 (Fishman et al., 2013; Research + Practice Collaboratory, n.d.). These principles describe a collaborative research process to address problems of practice, design studies around classroom constraints, iterate implementation of interventions, and build capacity. In VR research, such approaches have not yet been widely used to study its impact on learning: most studies identify technology-focused research questions rather than problems of practice and focus on isolating causality with controlled experiments outside of classrooms. Using DBIR can benefit the study of immersive learning technologies by focusing on instructional designs that illuminate effective implementation and provide a better understanding of their impact on student learning in an authentic context.

A DBIR study of learning with VR

To illustrate the applicability of DBIR to VR learning research, this paper describes a work-in-progress study of VR field trips in two high school engineering classes and preliminary findings about students' learning that guided implementation. The study was conducted in 2021-22 at an urban public charter high school in the greater Boston area serving primarily low-income and minority students. Participants were 30 (5 female) 11th and 12th grade students from two engineering classes. 28 students were second-generation American, and one first-generation, primarily from Latin American and Caribbean countries.

Table 1
DBIR Principles and Applicability for Immersive Learning Technology Research

DBIR Principle	Description	Benefit for immersive learning technologies	Differences from typical VR learning research
Deciding on a focus for joint work	Teams form around a focus on persistent problems of practice from multiple stakeholders' perspectives.	Immersive learning interventions are developed within a curricular framework to address the needs of educators, making them more usable and useful in classrooms.	Focus on meaningful learning experiences rather than features of the technology.
Organizing the design process	To improve practice, teams commit to iterative, collaborative design.	Research findings include optimal instructional designs for immersive technologies by iterating their implementation, making the interventions more effective and scalable.	Research design adapts to the constraints of schools and classrooms, resulting in interventions in addition to evidence on learning with VR.
Doing research in DBIR	As a strategy for promoting quality in the research and development process, teams develop theory related to both classroom learning and implementation through systematic inquiry.	Research attends to questions of implementation, individual learning, and opens areas of inquiry valuable for classrooms including group dynamics and collaborative learning.	Research informs design but does not drive it. Findings provide thick description and insight into mechanisms in authentic environments.
Developing capacity for continuous improvement	Design-based implementation research is concerned with developing capacity for sustaining change in systems.	Educators and students get sustained exposure to technologies and develop modes of implementation.	Control of the technology given to educators and students.

The VR field trips addressed a challenge identified by the teacher and aligned to NGSS engineering standards: students struggle to identify and articulate problems engineering could solve in open-ended tasks. By exploring virtual environments and observing scientists working in extreme conditions, students could practice problem-finding and improve their ability to write problem statements, the first step in engineering design. The primary research questions were how the VR experiences engendered students' sense of agency (control over their learning) and presence (feeling of "being there" in the environment), and how their problem statements varied over time or by type of VR used. Students used Quest headsets over 4 lessons, two with 360-degree videos (filmed footage of the environment and people), and two interactive graphical applications (videogame-like environments to move and interact with objects). Two lessons were on Antarctica and two the International Space Station (ISS). Figure 1 depicts the VR applications and implementation. Students took a pre-survey one month before the first lesson and post-surveys after each VR application (measuring sense of agency, presence, and intrinsic motivation), and 8 students were interviewed. To assess learning, students wrote engineering problem statements about the VR experience. Class discussions and field notes were recorded.

Figure 1
Left: VR Applications (Clockwise from top left: National Geographic Explore, Mission:ISS, Space Explorers, Polar Obsession). Right: Students using interactive environment (left) and immersive video (right)

Lessons used a "plan, act, reflect" experiential learning model (Dede et al., 2017): students completed a pre-work activity, used the VR application, then participated in written reflections or discussions before writing problem statements. We iterated the lesson plan after the first lesson was rushed and students struggled to make meaning of what they had seen and learned. Figure 2 illustrates how students largely did not write statements (e.g. “I don’t know”), wrote about problems with the technology (e.g. vision difficulties), or wrote what the narrator had told them about the environment (e.g. climate change is impacting Antarctica). To address this, lessons 2-4 spread activities across multiple lessons and added small group discussions to scaffold student meaning-making before the assessment. Figure 2 illustrates how these discussions shifted the focus of students’ problem statements: in lessons 2 and 3 they focused on problems the people face (e.g. difficulties working on the ISS) which had been the focus of the discussions. Following lesson 4 many students wrote technology-focused statements, likely because the teacher also led a concluding discussion to reflect on the four VR experiences.

Deciding on a focus for joint work

The focus of the lessons and the research design were developed collaboratively by the author and the educator through their shared interest and multiyear partnership. This required designing a series of lessons that addressed the problem of practice the teacher faced (supporting students in writing problem statements) and the research questions that interested the researcher (how interactivity and embodiment in VR affect student experience and learning). The collaboration around dual goals led to several decisions that differed from controlled experiment designs, especially the need for all lessons to be experienced equally and for each VR application to provide a meaningful learning experience. Rather than restrict experiences of a control group, we varied the order in which they used immersive video or interactive applications, allowing for comparisons in response to varied interactivity and addressing space constraints, as only half of students in a class period needed space to move in VR (see Figure 1). To ensure VR was used in a meaningful way we used high-quality 360-videos rather than isolating interactivity in VR by giving some students a recording of an interactive application (e.g. Johnson-Glenberg et al., 2021). The result was the development of meaningful learning experiences with two different types of media, as well as a holistic understanding of students’ resultant learning and subjective experiences.

Organizing an iterative, collaborative design process

Implementing the lessons required flexibility from the teacher and researcher to make changes to the lesson plan and timing, rather than adhering to an inflexible controlled design. The most significant iteration came after lesson 1, when we saw in practice how the lesson did not address students’ need for more time and discourse to make sense of the VR experiences. We observed that students were eager to discuss what they saw and did in VR with their peers, but written reflections did not capitalize on this enthusiasm. When given the opportunity to participate in a facilitated small group discussion, they articulated more problems related to the scientists who work in these environments. The result was lessons that maximized learning and were practical for classroom implementation. This also revealed how the discussions can make concepts more salient for students, as the varied focus from lessons 2 and 3 (challenges facing scientists) to the final discussion (reflecting on VR) revealed.

Figure 2

Content of students’ problem statements by lesson

Doing research in DBIR

The iterative design process highlighted benefits for research on VR to understand group dynamics and assessment. The study intended to use students’ problem statements to assess learning outcomes. However, after recognizing students’ struggles to write the statements, using small group discussions as reflective activities provided a rich source of data on how students learned with the VR in ways not demonstrated on the assessment. While this analysis is ongoing, preliminary findings suggest students developed curious dispositions about what it means to do science and be a scientist. This suggests learning with VR is better understood as a collaborative exercise in meaning-making aligned with a knowledge-building framework (Scardamalia & Bereiter, 2005), than an individual endeavor. The compromises made by being flexible and suiting the intervention to learning rather than maintaining a controlled experiment therefore provided fruitful insights about how VR field trips can engender a rich learning experience, particularly when peer collaboration is engaged.

Developing capacity for continuous improvement

Conducting DBIR in classrooms required giving control of the technology to the teacher and students. While its novelty waned as students used the technology over time, their mastery increased. With each lesson, the students more easily set up and put away the equipment, navigated to the applications, and operated the controllers. In interviews and discussions, they shared critiques for how VR experiences could be improved. The teacher gained an understanding of VR's affordances and applications that would be valuable in his classroom. This points to the ways doing research in classrooms with teachers and students can help build their capacity to improve the implementation of emerging technology in education.

Discussion

While this study illustrates the benefits of using DBIR for studies of learning with VR, it also has several limitations. Future research should investigate longer-term implementations with multiple iteration cycles and capacity building such as training teachers to create and school-wide integration. The flexible and iterative process provided holistic description of student learning with immersive technology, but limits claims about causality and generalizability to other media or populations. However, collaborating with an educator to use VR to tackle a persistent problem of practice and answer the author's research questions about how young people learn with VR over time led to a set of lessons using VR field trips that are meaningful and feasible in classrooms, as well as research findings that would have been difficult to uncover in a more controlled experiment. Pivoting from individual written work to knowledge-building discourse revealed students' curious dispositions about what it means to do science, a learning outcome not captured on the individual assessments. The iterative collaboration also helped highlight the ways VR field trips need to be scaffolded to support student learning.

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Gamebooks for Environmental Education: Designing for Content and Pedagogy

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Abstract: The goal of this project is to design gamebook-based lessons, which include an interactive gamebook (a non-linear, branching narrative) and supporting dialogic lessons, to increase children's (7- to 11-years-old) engagement in pro-environmental behaviours. A design-based research approach was used to optimize the design, focusing on both the content of the gamebook and the supporting pedagogical methods. This paper details the early design processes, not typically covered in DBR papers.

Introduction

Although many individuals are aware of climate change and preventative measures, actual behavioural change is limited (Pruneau et al., 2010). To effectively tackle climate change, a more educated and action-oriented public is necessary, focusing on preventative and adaptive societal changes (Williamson et al., 2018). Developing early education materials can help promote pro-environmental behaviours in children and prepare them for a future where their behaviour must change regardless of personal desire. This paper reports the development, in relation to content and pedagogy, of educational materials that aim to increase children's engagement in pro-environmental behaviours (PEBs), defined here as any decision that leads to an action with a positive impact on the planet (e.g., walking instead of driving or recycling).

Gamebooks

Existing educational materials cover the scientific aspects of climate change but rarely aim to support children in undertaking PEBs (Lundholm, 2019). Educational gamebooks are proposed here to address this problem. Gamebooks are non-linear, branching narratives that allow readers to make choices that shape the book's ending (e.g., Choose-Your-Own Adventure™ books). Gamebooks provide readers with agency and may effectively demonstrate the potential impact of their actions, supporting education for behavioural change.

Theoretical background

This project utilizes the Reasoned Action Approach (RAA) to predict and change social behaviour (Fishbein & Ajzen, 2010). RAA has been effective in modelling predictors of behavioural intention and developing behavioural change interventions, including encouraging PEB (Steg & Vlek, 2009). The RAA model proposes that behaviour is predicted by intention, which is, in turn, influenced by three constructs: attitude towards the behaviour (i.e., consequences of the behaviour), perceived behavioural control (i.e., skills and agency to perform the behaviour), and perceived social norms (i.e., the behaviour of influential others). Each construct is formed from corresponding beliefs: attitude is based on behavioural outcome beliefs (e.g., by recycling, I reduce landfill), perceived behavioural control on control beliefs (e.g., I know how to recycle), and perceived social norms on normative beliefs (e.g., my friends recycle).

The RAA model suggests that behaviour can be changed by challenging influential beliefs through discussion, reflection and the use of implementation intentions (IIs). IIs are action plans that draw on environmental cues to support behavioural change (Gollwitzer, 1999). They focus on a specific behaviour in response to a specific trigger, usually with an IF-THEN structure (e.g., IF I am brushing my teeth, THEN I will turn the tap off between rinsing). Designing educational materials based on RAA involves targeting specific beliefs, as different beliefs may vary in their impact on the formation of intentions to undertake PEBs. De Leeuw et al. (2015) found that perceived behavioural control (based on control beliefs) had a strong effect on high school students' intentions to undertake PEBs, while attitude towards the behaviour (behavioural beliefs) had a smaller but significant effect.

Gamebook-based lessons

Drawing on the RAA, the educational materials were designed to target behavioural, normative and control beliefs, with behavioural beliefs reflected in different gamebook endings, control beliefs reflected in reader choices, and normative beliefs addressed through supporting dialogic pedagogies. Furthermore, it was necessary to consider the language used in the gamebook (Cleaver, 2010*),* risk of causing eco-anxiety (Pihkala, 2020), and how to integrate an engaging narrative with learning content to support intrinsic motivation (Habgood &

Ainsworth, 2011). Regarding the last element, the core mechanic of gamebooks is user choice, in this instance choice in carrying out PEBs, which reflects the educational aim of encouraging children to choose to undertake PEBs.

While the gamebook serves as the central resource, in practice, it is supported by teacher-led pedagogical approaches. As discussed, implementation intentions effectively support behavioural change, therefore, represent a suitable supporting activity. Another approach shown to be effective in similar contexts is dialogic teaching (Alexander, 2006), supported by talk moves (Michaels & O'Conner, 2012), where teachers facilitate group discussion to critically reflect on concepts and collaboratively develop a shared understanding. In the gamebook supporting lessons, dialogic teaching would allow children to explore the beliefs of others and develop a shared understanding of appropriate behaviour, which could positively affect normative beliefs. Taken together, these are referred to as gamebook-based lessons. In developing these gamebook-based lessons, careful consideration needed to be given to the content of gamebooks (e.g., creating a fun narrative) and the design of pedagogical approaches (e.g., design of suggested talk moves).

Research approach

This project used a design-based research (DBR) approach to develop and evaluate the gamebook-based lessons. The paper reports the first two cycles of material design, which cover the often underreported phase 1 of design-based research studies: preparation and design of materials (Bakker, 2018).

Conjecture mapping (Sandoval, 2014) was used to inform the design of the gamebook-based lessons. The following provides an overview of the conjecture map based on concepts discussed in the introduction. The high-level conjecture is that children's intention to engage in PEBs can be improved by increasing the three predictive constructs (attitude towards the behaviour, perceived behavioural control and perceived social norms) through challenging the associated beliefs (behavioural, control and normative). This conjecture is embodied in both the design of the materials and structures. Materials include the gamebook, the core mechanic of which allows for intrinsic integration of learning content, and the creation of implementation intentions to support behavioural change. Regarding participant structures and discursive practices, the gamebook is used alongside dialogic lessons. In these, children collaboratively reflect on choices made in the gamebook, supported by talk moves to help teachers guide discussion. The design conjecture between embodiment and mediating process is if children engage with the activities (reading the gamebook and forming implementation intentions) through the environment (dialogic lessons), they should: a) explore the impact of PEB; b) develop a shared understanding of what are appropriate PEBs; and c) generate personal action plans (implementation intentions). Mediating processes are theorized to lead to four related outcomes: understanding the importance of individual PEB; improved predictive constructs (e.g., perceived behavioural control); ability to review what are appropriate PEBs; and increased engagement in PEBs. The theoretical conjecture between mediating processes and outcomes is if mediating processes occur: i) influential beliefs are challenged, leading to increased PEB intention; and ii) environmental cues, via implementation intentions, increase engagement in PEB.

The following reports six research activities across two overlapping cycles of iteration completed in phase 1: cycle one focused on designing the content of the gamebooks, and cycle two covered the design of supporting pedagogical activities. Given space limitations, only the aim and outcome of studies are reported.

Cycle one: Designing for content

C1.1: Initial design of gamebook-based lessons

This section presents the initial design of the gamebook-based lessons. The gamebook's narrative is set during a week of school holidays, where readers take on the role of a child going on various days out. Each day includes choices about minor narrative content and pro-environmental choices grouped by areas of environmental action:

- Day A – Area of Action: material consumption; Act 1: clothes shopping; Act 2: visit the fair.
- Day B – Area of Action: travel and mobility; Act 1: visit the park; Act 2: trip to the cinema.
- Day C – Area of Action: food and diet; Act 1: explore the zoo; Act 2: go food shopping.
- Day D – Area of Action: heating and cooling: Act 1: visit the beach; Act 2: plan a holiday.

Days can be experienced in any order, after which it is revelated in a twist that readers were acting as 'time agents': individuals sent from a future badly impacted by climate change and tasked with carrying out PEBs. Readers are then shown one of two futures based upon their choices about engaging in PEBs. These futures depict the impact of climate change in 2050, based on current predictions, and show either 1) a worst-case scenario; or 2) a best-case scenario. The gamebook is written in *ink* (inkle, 2021), with the UI created using *Unity*. In theory, the gamebook challenges and encourages reflection on behavioural and control beliefs. A demo is available at www.enviroedgamebooks.co.uk.

In practice, gamebook reading is followed by two learning activities. Firstly, a book club where children, in small groups, discuss choices made in the gamebook. This acts as a dialogic lesson where children can co-construct understanding of PEB. It is supported by a set of generic talk moves to focus discussion on underlying beliefs and the rationale for behavioural change. Secondly, children create implementation intentions they can use in the following weeks. These are revised and refined each week. These activities target normative beliefs, as children collaboratively discuss their experience of the gamebook and develop a shared understanding of what are appropriate and practical PEBs.

C1.2: Determining viable pro-environmental choices

To integrate learning content through the core gamebook mechanism of reader choice it was essential that gamebook PEBs reflected actions that children would carry out in the real world. Consequently, a survey of 32 UK-based parents/guardians was conducted to develop a homogenous set of child-friendly PEBs. The analysis resulted in 40 child-friendly PEBs for which children would be at least *somewhat likely* to carry out.

C1.3: Affective reactions to gamebook content

To design engaging gamebook content for children and address concerns of eco-anxiety, a study was conducted to investigate emotional reactions, reading difficulty and narrative engagement. 18 children (7-14 years old) read shortened versions of the gamebook and completed a questionnaire. Results showed minimal adverse emotional reactions concerning eco-anxiety. However, parts of the narrative (e.g., the visit to the beach) required revision for greater engagement. The gamebook was suitable for the target age range in terms of reading level, and there was reported increased intention to engage in PEBs.

Cycle two: Designing for pedagogy

C2.1: Expert group review

A wider design team, consisting of 11 academics with expertise in initial teacher education, science education, computer-supported collaborative learning, design-based research, and gamebook writing, provided feedback on the design and use of educational materials at various stages throughout the project. In phase 1, they provided feedback on early narrative storyboards and reviewed the gamebook and lesson plans in focus groups and individual interviews. Feedback from the team in initial teacher education suggested supplementary materials should accompany the gamebook-based lessons. The group also suggested using visual indicators when readers faced PEB choices and highlighted the opportunity to increase inclusion and diversity in gamebook imagery, particularly disability representation. Changes to gamebook imagery were made in all following iterations. The group also called for more exploration of the emergent structure of learning to inform dialogic activities.

C2.2: Teachers' use of materials

A study evaluated the practicality of the gamebook-based lessons and adaptions made by teachers (two teachers and 53 children) using the gamebook-based lessons in classrooms across three lessons. Lesson 1: read the first half of the gamebook. Lesson 2: finish reading the gamebook, take part in a 'book club' to discuss choices made and book endings, and create individual implementation intentions that can be used across the following week. Lesson 3: review children's records of individual implementation intentions. Results showed that readers only received the better ending of the book (due to following PEB visual indicators), necessitating a mechanism for readers to view alternative endings to better facilitate group discussion. Teachers noted it was difficult for children to reflect on and revise their IIs. Like the expert group, teachers requested supplementary materials to extend children's environmental education. Finally, neither teacher was a science specialist. Still, they did not feel out of their depth discussing climate change issues or running the activities, suggesting that the intervention does not require additional subject-specific or pedagogic knowledge.

C2.3: Facilitating group discussion

While talk moves were designed for teachers to support children's discussion, predicting the types of questions children will raise and the prompts needed to guide discussion can be challenging. An exploratory study was conducted with 16 children (10-13 years old). The aim was to explore the emergent structure of learning activities. That is, what questions children raised and what talk moves were needed to focus group conversation. Participants read the gamebook, were observed participating in book club discussions and creating IIs, then provided feedback on gamebook design. The results produced a set of targeted talk moves to highlight the underlying position that all PEBs are beneficial. This ensures that IIs are both possible for children to conduct and focus on a specific PEB and introduces the time travel mission at the beginning of the book to act as a narrative hook. Finally, reliance on PEB visual cues was observed, as participants noted they signposted when to think about their actions.

Revision of materials

The six studies reported here demonstrate the need to design for both content of the gamebook and the supporting pedagogical approaches. The results highlighted the need to evaluate initial assumptions about child-friendly content design (see C1.2, C1.3, C2.3); for example, moving the time travel mission to the beginning of the book as a narrative hook. In terms of pedagogical revisions, targeted talk moves were developed (C2.3) to ensure they anticipated children's questions and better-guided reflection. Implementation intentions were found to be difficult for children to develop and revise. To support II development, children now create IIs in Lesson 1 (linked to school-based behaviour), in addition to those created in Lesson 2 (linked to out-of-school behaviour), with the two contexts covering different social norms (school and home). Lesson 3 now involves group discussion of PEB vignettes where children evaluate pro-environmental choices of fictional others and design IIs for them. Consequently, the initial conjecture map was updated to include PEB vignettes as additional material, leading to a new mediating process of reflecting on the behaviour of others.

The results of the studies led to two design conflicts. Firstly, both the expert group (C2.1) and classroom teachers (C2.2) wanted supplementary climate change materials to use alongside the gamebook-based lessons. A suitable pack has been developed; however, potential variations in use pose methodological problems that must be evaluated in future efficacy tests. Secondly, the use of visual cues (C2.1) within the gamebook to flag potential PEB may have guided children to predominantly select PEBs (C2.2, C2.3), limiting the experience of alternative endings and potential loss of reader agency. The use of such cues will be investigated in future studies.

Conclusion

Educational gamebooks are an under-explored resource that can be used to show individuals the impact that their actions can have. The studies reported here illustrate how to design for both content and pedagogy in developing gamebook-based lessons, including underpinning conjecture mapping. Such steps are crucial for others creating gamebooks for environmental education and other areas that focus on belief revision or behavioural change.

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Emotional Synchrony Through Regulatory Triggers in Collaborative Learning: A Facial Expression Recognition Study

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Abstract: Despite the importance of socially shared regulation of learning (SSRL) in collaborative learning success, there remains a paucity of evidence on how it could be detected and supported effectively. In this paper, we present an experimental study with a systematic analysis approach that utilizes facial expression recognition technology to examine emotional triggers for collaborative learning regulation. The study involved high school students (N=27) working in groups of three with a collaborative learning task. During the learning process, the collaborative groups were intervened with a controlled cognitive trigger followed by three emotional triggers. AI facial expression recognition was utilized for analyzing students' continuous valence and changes in emotions throughout the collaborative learning task. Cross-recurrence quantification analysis (cRQA) approach has been employed to examine emotional synchrony through regulatory triggers. Our findings present evidence for the regulatory trigger concept and offer novel insights into how the regulatory triggers facilitate emotional synchronization among learners in collaborative learning. Furthermore, the study also demonstrates the use of AI technology for examining collaborative learning regulation. The study further discusses not only the potential role of the trigger concept in generating a better understanding of the regulatory processes but also its contribution to establishing foundations for designing support for regulation in collaborative learning.

Introduction

There is a growing body of literature that acknowledges the importance of learning regulation in collaborative learning. Self-regulated learning (SRL) theory and socially shared regulation of learning (SSRL) framework have offered an understanding of the regulatory processes in collaborative learning through which group members negotiate goals, planning, and strategies for purposefully carrying out learning activities. It involves groups taking metacognitive control of the task together through negotiated, iterative fine-tuning of cognitive, behavioural, motivational, and emotional conditions as needed (Hadwin et al., 2018). Besides their ideas, knowledge, and skills, group members also bring their emotions and interpretations of other learners' emotions. Research has pointed out learners' need to control also their collective emotions in collaborative learning (Lobczowski, 2020).

Recently, research in (S)SRL has recognised the role of emotional and cognitive triggers for regulation and understanding small-scale adaptation in collaborative learning. Events and/or situations which may inhibit learning processes and, thus, require regulatory responses are defined as trigger events (Järvelä et al., 2023). Since measuring SRL and SSRL has been challenging (Winne, 2010), empirically identifying trigger events as markers for the regulation of cognition, motivation, emotion, and behaviours has great potential for advancing the field. Whilst some research has been carried out on triggers for collaborative learning regulation (Nguyen et al., 2022), no controlled studies have been reported for examining trigger events for regulation. In addition, the existing accounts to identify the trigger event in collaborative learning are limited.

The recognition of regulatory triggers and examination of learners' responses to them are essential to progress the current understanding of collaborative learning regulation and design appropriate and effective support for the learners. Nonetheless, SSRL's cyclical adaptive nature, high levels of interactivity, and dynamics make it difficult to measure, capture, and analyze the regulatory triggers and SSRL processes (Winne, 2010). The emotional and cognitive processes at the core of regulation are unobservable by humans, and it is difficult to capture these processes using traditional approaches. Fortunately, recent advances in Artificial Intelligence (AI) and machine learning have enabled new means to trace and analyze learning behaviors (Cukurova et al., 2020). Accordingly, this study attempted to examine the use of AI techniques to analyse emotional synchrony through regulatory triggers in collaborative learning.

Accordingly, in this study, we utilise AI facial expression recognition technique to assess emotional synchrony through cognitive and emotional triggers for SSRL. Particularly, this study aims to answer the following research questions: 1) How do regulatory triggers facilitate emotional synchronisation among learners in collaborative learning? 2) How do the learners' emotions change over time throughout regulatory triggers in collaborative learning?

Learning analytics and AI for socially shared emotional regulation

In collaborative learning, emotional regulation refers to the capability to recognize others' emotions and modify those emotions in social interaction, as well as regulate one's own feelings. Emotion is individually enacted but socially constructed. Emotional regulation involves the active utilization of various regulation strategies in interaction (Lobczowski, 2020). An effective regulator adjusts their strategic regulation accordingly to match the situational needs and ensures the most appropriate possible strategy to address the challenges and ensure solid emotional foundations for group functioning. In socially shared emotional regulation, awareness and sharedness of emotion among the group members invites for shared regulation. However, despite the learners' perceived emotions and overall learning experiences being evident, much less is known about individuals' short-term emotional states and the group's shared emotional states in SSRL. Emotional synchrony among short-term emotional states has been demonstrated to be a sign of individuals' affiliative bonding and empathy (Dindar et al., 2020). By capturing and understanding these temporal cycles of emotions and emotional synchrony, we would better identify SSRL's pain points and timely support the learners. Recently investigators have examined the shared emotional processes during collaboration by analyzing shared physiological arousal events (SPAE) (Dindar et al., 2022; Nguyen et al., 2023). To date, there are few studies that have investigated emotional synchrony with facial expressions in SSRL. From a methodological point of view, the use of AI facial expression recognition technologies facilitates the accurate frame-by-frame detection of emotional states for a granular analysis of emotional synchrony in SSRL.

In the context of learning sciences research, learning analytics and AI machine learning have offered exclusive methods for analysing and predicting learners' performance and their learning behaviours (Cukurova et al., 2020). For instance, Nguyen et al. (2022) utilised multimodal deep learning techniques automatically detect interactions for regulation in collaborative learning. Moreover, learning analytics and machine learning could identify and extract human cognitive and emotional activities, such as facial expressions of emotion (Dindar et al., 2020). Nevertheless, the gap between those who understand AI's methods and techniques and those who know how to improve learning and teaching remains significant. Prior research highlighted the challenges associated with aligning learning theories with technology to provide new insights and to provide real-time learning and teaching support (Cukurova et al., 2020). The implementation of time-stamped video-based facial expression recognition methods would be promising in the collaborative learning context for identifying temporal and cyclical emotions (Dindar et al., 2020). It provides fine-grained details, including, for instance, the exact moment when changes in facial expressions occurred, matching to the learning events confronted by the learners. Accordingly, this paper adopted learning analytics and AI machine learning as the methodological approach to examine socially shared emotional regulation in collaborative learning.

Research methods

To address these research questions, this study involved an experiment with regulatory triggers. The experimental setting was designed with 10 small groups of three high school students (N=30) working with a collaborative learning task for 30-40 minutes. Nevertheless, trigger time recording was missing for two groups, thus 8 groups were included in this analysis (N=24). After the first half of the learning task, the treatment groups will be presented with manifested emotional triggers in 3-minutes time intervals and up to three times in total. High-resolution video data was collected for facial expression analysis using Insta360 Pro video cameras placed in the middle of each group, and each student was equipped with an individual microphone.

To extract emotion, the faces are first detected and cropped from the videos based on Dlib, a toolkit containing machine learning algorithms. The emotion recognition from cropped faces is based on EmoFAN, built on a face-alignment network with two Unet followed by five 2D convolutional layers and a fully connected layer (Toisoul et al., 2021). EmoFAN provided one model pre-trained on the large facial dataset in the wild. The discrete emotions of five categories (neutral, positive, sad, fear, and surprise) were obtained and aligned so that their affective states could be analysed.

In this study, cRQA was conducted to compute the level of emotional synchrony among learners within the same collaborative learning group. In particular, the drpfromt method was employed to compute the diagonal profile of the recurrence plot for each pair of learners before and after the regulatory triggers. To validate the role of cognitive and emotional triggers in facilitating emotional synchronisation among learners in collaborative learning, we conducted paired sample t-tests to compare the means of maximum recurrence rates before and after regulatory triggers. In addition, Pearson's Chi-Squared and Cramér's V tests were applied to examine the distribution of emotions among different time periods (before and after each regulatory trigger). Furthermore, this study utilises visual analytics using Tableau, a commonly used data visualisation tool, to examine how learners' emotions change over time throughout regulatory triggers in collaborative learning.

Results

RQ1. How regulatory triggers facilitate emotional synchronisation among learners in collaborative learning?

Figure 1a shows the cRQA results with each maximal recurrence rate (MaxRR) observed and the delay (MaxLagAbs) at which it occurred from each profile. MaxRR denotes the alignment between two time series, i.e., the alignment between the learners' facial expressions of emotion in this case. High MaxRR implies that two learners had similar facial expressions of emotion over time. The paired-sample t-test showed a statistically insignificant difference with the cognitive trigger, $t(26) = -1.58$, $p = 0.13$, whereas there is some evidence for an increase in emotional synchrony after the emotional trigger, $t(26) = -2.70$, $p = 0.01$. The present study raises the possibility that different types of regulatory triggers have distinct effects on corresponding aspects of learning regulation. Whilst we found no significant effect of the cognitive trigger on learners' emotional synchrony, our findings suggest that a potential link may exist between emotional triggers and emotional synchrony in collaborative learning.

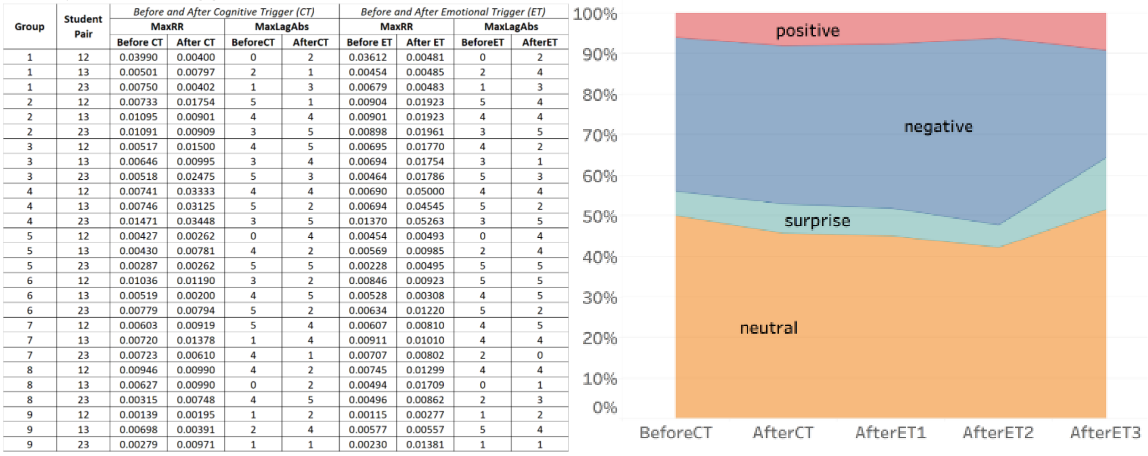
RQ2. How do the learners' emotions change over time throughout regulatory triggers in collaborative learning?

For the second research question, Pearson's Chi-square test shows a significant difference in the distribution of emotion among different periods (before and after each trigger), $\chi 2(12) = 268.00$, $p < .001$. However, a note of caution is due here since only a small effect size is reported with a weak Cramér's V, 0.06. To further inspect the change in emotion distribution before and after each trigger, we visualise this distribution over time, as shown in Figure 1b.

We observed a noticeable increase in negative emotions after the first and second emotional triggers. This could indicate the role of the emotional triggers pushing the groups to complete their task early. Nevertheless, a rise in positive and surprise emotions was noted toward the end of the collaborative learning task. This may be explained by the fact that they were happy with their products and had been waiting for the time up. Further research may investigate the effects of different types of emotional triggers.

Figure 1

(a) Cross-Recurrence Quantification Analysis (cRQA) Results and (b)Emotion distribution over time before and after each trigger



Group	Student Pair	*Before and After Cognitive Trigger (CT)*				*Before and After Emotional Trigger (ET)*			
		MaxRR		MaxLagAbs		MaxRR		MaxLagAbs	
		Before CT	After CT	BeforeCT	AfterCT	Before ET	After ET	BeforeET	AfterET
1	12	0.03990	0.00400	0	2	0.03612	0.00481	0	2
1	13	0.00501	0.00797	2	1	0.00454	0.00485	2	4
1	23	0.00750	0.00402	1	3	0.00679	0.00483	1	3
2	12	0.00733	0.01754	5	1	0.00904	0.01923	5	4
2	13	0.01095	0.00901	4	4	0.00901	0.01923	4	4
2	23	0.01091	0.00909	3	5	0.00898	0.01961	3	5
3	12	0.00517	0.01500	4	5	0.00695	0.01770	4	2
3	13	0.00646	0.00995	3	4	0.00694	0.01754	3	1
3	23	0.00518	0.02475	5	3	0.00464	0.01786	5	3
4	12	0.00741	0.03333	4	4	0.00690	0.05000	4	4
4	13	0.00746	0.03125	5	2	0.00694	0.04545	5	2
4	23	0.01471	0.03448	3	5	0.01370	0.05263	3	5
5	12	0.00427	0.00262	0	4	0.00454	0.00493	0	4
5	13	0.00430	0.00781	4	2	0.00569	0.00985	2	4
5	23	0.00287	0.00262	5	5	0.00228	0.00495	5	5
6	12	0.01036	0.01190	3	2	0.00846	0.00923	5	5
6	13	0.00519	0.00200	4	5	0.00528	0.00308	4	5
6	23	0.00779	0.00794	5	2	0.00634	0.01220	5	2
7	12	0.00603	0.00919	5	4	0.00607	0.00810	4	5
7	13	0.00720	0.01378	1	4	0.00911	0.01010	4	4
7	23	0.00723	0.00610	4	1	0.00707	0.00802	2	0
8	12	0.00946	0.00990	4	2	0.00745	0.01299	4	4
8	13	0.00627	0.00990	0	2	0.00494	0.01709	0	1
8	23	0.00315	0.00748	4	5	0.00496	0.00862	2	3
9	12	0.00139	0.00195	1	2	0.00115	0.00277	1	2
9	13	0.00698	0.00391	2	4	0.00577	0.00557	5	4
9	23	0.00279	0.00971	1	1	0.00230	0.01381	1	1

(a)

(b)

Discussion and conclusion

This study set out to examine emotional synchrony through regulatory trigger moments in socially shared emotional regulation by applying AI facial expression recognition techniques. These results play a role in confirming our theoretical predictions and determining the role of regulatory triggers in facilitating regulatory processes in collaborative learning (Järvelä et al., 2023). Furthermore, the study evicted the effects of different types of regulatory triggers on emotional synchronisation, one of the key facets of SSRL. The study also contributed to the contemporary discourse regarding the use of advanced technologies to further progress methodological and theoretical development in learning sciences.

This study continues the collaborative efforts in utilising AI and advanced techniques in examining SSRL in collaborative learning. It was designed to determine the effect of cognitive and emotional triggers on learners' socially shared emotional regulation in collaborative learning. By using AI techniques, we examined the learners' emotional synchrony via facial expressions of emotion. Our results indicated that emotional synchrony among the learners in a group was not significantly affected by the controlled cognitive trigger but by the controlled emotional triggers. Hence, it could conceivably be hypothesised that different types of regulation (i.e., cognition, emotion, and motivation) could be prompted by corresponding types of regulatory triggers. Further research should be undertaken to investigate the effects of various regulatory triggers on different SSRL aspects. A better understanding of the triggers for regulation will establish the foundation for the development of effective methods based on advanced technologies such as AI that will allow real-time detection of these "invisible" events to support the regulatory process. The study also highlights the potential of AI and learning analytics to advance learning theories.

The generalisability of these results is subject to certain limitations. First, with a small sample size, caution must be applied to the findings of this study. Further work is required to establish the generalizability of these results for different larger cohorts of learners. Second, the study is limited by the missing values from facial expression recognition due to the segments that learners' faces were covered in the video recording. Notwithstanding these limitations, the study offers valuable insights into the process of socially shared emotional regulation in collaborative learning. Moreover, this study has provided evidence for validating our proposed conceptual framework of regulatory triggers (Järvelä et al., 2023). A greater focus on cognitive, emotional, and motivational triggers for regulation could produce interesting findings that account more for understanding and supporting SSRL in collaborative learning.

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Teacher Noticing and Student Learning in Human-AI Partnered Classrooms: A Multimodal Analysis

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Abstract: Past research shows that teacher noticing matters for student learning, but little is known about the effects of AI-based tools designed to augment teachers' attention and sensemaking. In this paper, we investigate three multimodal measures of teacher noticing (i.e., gaze, deep dive into learning analytics in a teacher tool, and visits to individual students), gleaned from a mixed reality teacher awareness tool across ten classrooms. Our analysis suggests that of the three noticing measures, deep dive exhibited the largest association with learning gains when adjusting for students' prior knowledge and tutor interactions. This finding may indicate that teachers identified students most in need based on the deep dive analytics and offered them support. We discuss how these multimodal measures can make the constraints and effects of teacher noticing in human-AI partnered classrooms visible.

Introduction

Teacher noticing of noteworthy events in the classroom is argued to be a key teacher competency for effective pedagogical practice (Blömeke et al., 2015) and has been shown to matter for student learning and experience (Kersting et al., 2012). At the same time, research on human perception suggests that teachers may be limited in their attentional capacity when focusing on the multitudes of events happening in a classroom at a given point in time (Kahneman, 1973). Classrooms with artificially intelligent tutors (AI tutors) that collect moment-by-moment data on student learning and experience offer new opportunities for AI-supported teacher noticing. Through analytics derived from these data, teachers can react to classroom events that they otherwise might not have been aware of. Accordingly, AI tools designed to improve teachers' real-time awareness and sensemaking have been effective in improving students' learning (Holstein et al., 2018). However, we are yet to fully understand how teachers distribute their attention across students when provided with analytics that extend their current knowledge about classroom learning. These settings offer novel opportunities to study how teacher noticing and intervention relate to student learning and engagement with AI tutors. Besides being interesting in its own right, this kind of understanding could be helpful in designing better tools that support teachers' in-the-moment noticing and ultimately support reflection on their own practices. In this study, we relate three multimodal measures of teacher noticing to student learning in an AI classroom with a mixed reality teacher tool. We showcase how these measures can be used to better understand and quantify teacher noticing and its relationship to student learning.

Multimodal measures of teacher noticing in human-AI partnered classrooms

In this paper, we measure teacher noticing using multimodal data collected from a mixed reality teacher awareness tool. Lumilo is a smart glass system that sends real-time analytics about student learning and engagement (i.e., idle, rapid attempts, hint abuse, low or high local error rates, many errors after hints, hint avoidance, and unproductive persistence) to the teacher via indicator icons (Holstein et al., 2018; Holstein & Aleven, 2022). In addition to providing teachers with real-time analytics, the smart glasses are instrumented to gather multimodal measures of teacher interaction. We investigate three such measures: 1) the number of visual fixations teachers allocate to students (*gaze*), 2) how often teachers use the deep dive function of Lumilo to obtain more information on a student's progress in the AI tutor (*deep dive*), and 3) how often teachers visit students in person (*visit*).

According to the framework proposed by van Es and Sherin (2021), teacher noticing involves *attending* i.e., recognizing important aspects of classroom interactions and ignoring others, *interpreting* i.e., reasoning about what is observed using contextual knowledge and past experiences and *shaping* i.e., gathering additional information by constructing new interactions with the students while continuing to notice. We argue that our three multimodal measures (i.e., gaze, deep dive, visit) operationalize key components of van Es and Sherin's (2021) noticing framework in a manner that applies to the targeted classroom scenario. First, visual attention in the form of gaze is unequally distributed among students; it tends to be focused particularly on students who exhibit undesirable behavior (Wolff et al., 2017; Yamamoto & Imai-Matsumura, 2013). Prior work also suggests that students with low academic performance are more often in the teacher's visual focus (Chaudhuri et al., 2022). Based on these findings, teachers' gaze represents a coarse-grained measure of teachers' visual focus to identify noteworthy events (akin to *attending* in van Es & Sherin, 2021). Second, to gather further insight into noteworthy events, the Lumilo mixed reality tool, which generates the data analyzed in the current study, allows the teacher to open a deep dive analytics screen. This screen shows in-depth analytics on the given student's progress and instructional needs (e.g., areas of struggle; Holstein & Aleven, 2022). These real-time analytics augment teacher sensing, particularly concerning *interpreting* noteworthy events (van Es & Sherin, 2021). Still, teachers must connect multimodal analytics with contextual knowledge (e.g., prior knowledge of the students) to draw meaningful conclusions and guide further action (Deunk et al., 2018; Holstein & Aleven, 2022). Third, we view the use of the deep dive function and visit as forms of *shaping*, as defined by van Es and Sherin (2021). Shaping helps teachers amend and confirm assumptions gathered via attending and interpreting by gaining access to additional information.

We posit that it is worth investigating teacher noticing through multimodal measures for three reasons. First, multimodality offers a quantified lens into noticing. Second, multimodality offers a more complete representation of teacher noticing facets through multiple measures compared to a single measure. Third, multimodality allows for a lens into different levels of noticing, relating to theoretical stages of teacher noticing (cf. van Es & Sherin, 2021). In our context, we conjecture that gaze fixations, deep dives analytics lookups, and visits can be understood as stages of increasingly focused noticing of student needs for attention and extra help. Whereas the teacher's gaze wanders through the room or can be directed specifically to a student, calling up the deep dive function might indicate (perhaps especially when it involves a student just gazed upon) a heightened form of teacher noticing as the teacher proactively seeks further information about a student. In the same vein, perhaps visit can be understood as an action resulting from the preceding noticing events (attending, interpreting) to gather more information from the students directly. More research is needed to understand how teachers use different forms of noticing and how they relate to student learning. Hence, the guiding question for our analysis is: *how do multimodal measures of teacher noticing relate to student learning with AI tutors?* We hypothesize that physical teacher visits represent the most salient mode of teacher noticing from a student's perspective and is, therefore, most strongly related to students' learning gains compared to gaze and deep dive.

Methods

We analyze previously collected data from an intervention study investigating the efficacy of the mixed reality teacher awareness tool Lumilo (see previous section; Holstein et al., 2018). Our study sample included 173 students from ten classes taught by six teachers. Between pre- and post-test assessments of students' skills in the relevant mathematics (i.e., equation solving), students practiced math with the linear equation tutor Lynnette while being monitored by their teacher and supported when necessary. Each student worked with Lynnette for approximately 60 minutes across two classroom sessions. Their problem-solving behavior was recorded in the form of time-stamped log data. Lynnette has been reported to significantly improve students' equation-solving abilities. Teacher noticing variables were exported via Microsoft Hololens (see previous section). They include the number of times the teacher looked at a particular student (i.e., gaze), how often they used the deep dive feature to gather in-depth insight into a particular student (i.e., deep dive) and how often teachers entered the physical proximity of a student, defined as within a radius of four feet (i.e., visit). If a teacher entered the proximity of multiple students simultaneously, proximity was coded for the student closest to the teacher. From the tutor log data, we aggregated the following student-level variables: (1) tutor interactions, such as the average time students take for correct, incorrect, and all steps when working with the AI tutor, (2) in-system performance, such as ratio of correct to incorrect attempts, and (3) engagement behaviors, such as tutor misuse, estimated using previously-developed machine learning models for the AI tutor (cf. Holstein et al., 2019). Grade level, prior student knowledge, and class size served as control variables. As our outcome, we analyzed the association of these variables with students' learning gain after working with the AI tutor. Learning gains were operationalized as the difference between normalized pre- and post-test scores.

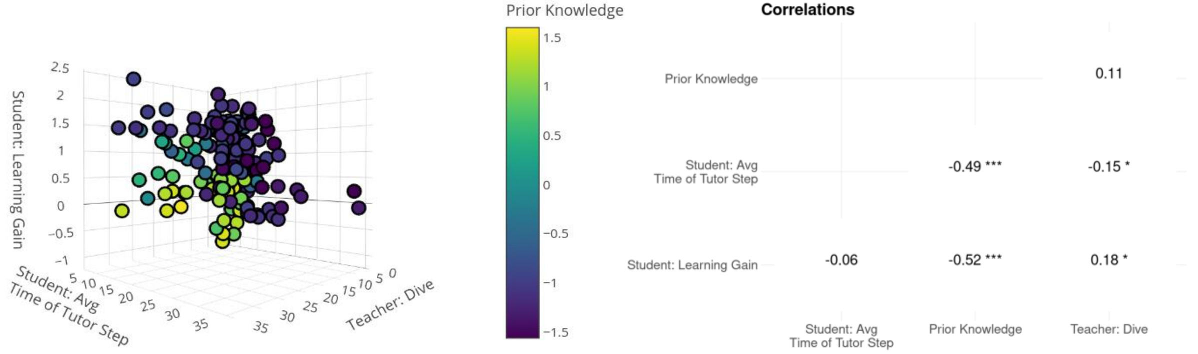
Results

We investigate whether a teacher visit is most strongly related to learning gains among our three multimodal noticing measures as it could be the most salient mode of teacher noticing from a student perspective. We employ an automatic feature selection procedure (AIC-based backward feature selection) for a linear regression model of learning gain, adjusting for prior knowledge, grade level and student-tutor interactions. Contrary to our hypothesis, deep dive, not visit, had the strongest association with learning gains after controlling for contextual factors and students' tutor behavior ($\beta = 0.19$ [0.07, 0.31], $p = .001$; Table 2). Dive explained 3.1% of the variance in learning gains beyond the other variables featured in the selected model. As deep dive was the only noticing measure selected by our procedure, gaze and visit did not explain a significant amount of variance in learning gains beyond deep dive.

Table 2
Linear model of learning gain selected via backward search based on AIC with deep dive being the only noticing measure that explained variance in learning gains beyond control variables.

Predictors	*Estimates*	*CI*	*p*
Intercept	0.69	0.56 – 0.82	**<.001**
Deep Dive	0.19	0.07 – 0.31	**.001**
Avg Time Tutor Step	-0.51	-0.78 – -0.25	**<0.001**
Avg Time Correct Tutor Step	0.16	-0.05 – 0.36	.129
Avg Time Incorrect Tutor Step	0.17	0.05 – 0.28	**.005**
Avg Tutor Misuse Score	-0.07	-0.15 – 0.01	.107
# Idle Tutor Sequences	-0.13	-0.26 – 0.00	.055
Avg Length of Idle Tutor Sequences	-0.13	-0.23 – -0.02	**.018**
Avg Peaks of Idle Tutor Sequences	0.09	-0.03 – 0.21	.155
Avg Peaks of Struggle Sequences	-0.07	-0.17 – 0.03	.173
Prior Knowledge/Pre Test Score	-0.69	-0.82 – -0.55	**<.001**
Grade Level [7th]	-0.11	-0.54 – 0.33	.632
Grade Level [8th]	0.10	-0.11 – 0.31	.347
Class Size	0.02	-0.11 – 0.14	.792
Avg Tutor Session Length	0.00	-0.10 – 0.10	.999
Observations	173		
R^2 / R^2 adjusted	0.529 / 0.488		

Figure 1
*3D scatter plot (a) of the most predictive variables of our learning gain model, with students standardized prior knowledge as color scale (light dots indicating low and dark dots indicating high pre-test score). Correlation heatmap (b) of the same variables' intercorrelations with significant levels (***p<0.001 **p<0.01 *p<0.05).*



(a) (b)

Next, we check heterogeneous effects of teacher noticing across students by plotting the most associated noticing variable (i.e., deep dive), tutor variable (i.e., average time spent per tutor step), and control variable (i.e., prior knowledge) in Figure 1. We observe three main trends. First, we find a significant positive (albeit small) association between deep dive and learning gains and a significant negative association between the average time per tutor step and prior knowledge. Second, teachers performed significantly more deep dives on students who spent more time per tutor step, while students with longer tutor steps had significantly lower prior knowledge. Third, a small (non-significant) positive correlation was found between deep dive and prior knowledge.

Discussion

The current study investigates how multimodal teacher noticing measures relate to learning in a human-AI partnered classroom. We hypothesized that physical visits would be most strongly related to students' learning. Contrary to that hypothesis, deep dive had the strongest positive association with learning gains. This finding may indicate that teachers identified students in need based on the deep dive analytics and offered them support, potentially acting upon diagnosed struggles and difficulties students experienced. However, since visits were less strongly associated with learning than deep dives, the support prompted by deep dives would, apparently, not always be in the form of an actual visit, consistent with field observations that some teachers using Lumilo would frequently provide feedback to students from across the room, without physically visiting them (Holstein et al., 2018; 2019). Perhaps other purposes of teacher visits not immediately related to student support, for example, looking over a student's shoulder without interacting with the student, celebrating the successful completion of a problem, or other social interactions might dilute the current signal for teacher support for learning captured by our visit measure. Another potential explanation is that teacher visits were actually helpful, but that visits nonetheless did not correlate positively with learning gains because these visits were infrequent. As teachers tended to perform deep dives on students with higher prior knowledge, mechanisms other than support could also explain the lack of association between visit and learning. For example, teachers' selection of students to perform deep dives might have been influenced by top-down selection effects (i.e., decisions informed by teachers' prior knowledge of the student rather than noteworthy classroom behavior; Chaudhuri et al., 2022). From post-study interviews with teachers during data collection, we know that teachers report using the deep dive feature on multiple high-achieving students in a row to calibrate their assessment of class progress (Holstein et al., 2019). Thus, the use of deep dives may sometimes represent teachers' efforts to gather classroom-level data rather than sizing up the extent of a student's struggle. Future research may look at how deep dives with different purposes might be distinguished (e.g., their duration might be different), which may re-inform or help extend prior conceptualizations of teacher noticing. In conclusion, our multimodal measures offer novel lenses into the study of teacher noticing in classrooms with AI tutors that we believe would have implications to designing tools for teacher orchestration and reflection.

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What If? An Invitation to Be in Someone Else's Shoes: Social Perspective Taking in Dialogical Contexts

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Abstract: Social Perspective taking (SPT) is the aptitude to consider others' thoughts, feelings, intentions, and motivations in a particular situation. Our goal was to gain a deeper understanding of SPT by focusing on its dynamic and social nature. Qualitatively analyzing small group dialogues in an 8th-grade humanities classroom, we explore the interplay between the level of *SPT acts* and dialogical moves. Our findings indicate that SPT in a group dialogue context is a complex practice in which students engage with different perspectives and evaluate how their perspectives differ (or do not differ) compared to the perspectives of others. Specifically, higher levels of *SPT acts* stemmed from explaining one's own perspective by inviting peers to put themselves in someone else's shoes.

Introduction

Social Perspective-taking (SPT) has long been acknowledged as an essential feature of human interaction (Selman, 1981). At its core, SPT entails "the active consideration of others' mental states and subjective experiences" (Todd & Galinsky, 2014, p. 374) and has been identified as a vital component in a variety of social and academic processes such as overcoming conflicts, productive collaboration, and reading comprehension (see Gehlbach & Mu, 2022 for a recent review). Paradoxically, although SPT is inherently an other-oriented process, most research has (implicitly) relied on an individualistic understanding of SPT, which focuses on the interaction between an individual and a novel perspective introduced in a text. The same is true for educational contexts, where it is rare that "students in social studies classrooms view their peers as valuable sources of wisdom" (Gehlbach, 2011, p. 316). To address this lacuna, we examined how students engage in SPT when collaboratively studying texts that elicit the need to engage with other perspectives. We collected data in one middle-school humanities classroom where students conducted small group dialogues around texts. Our goal was to deepen our understanding of SPT by focusing on this process's dynamic and social nature as we uncover the interactions between *SPT acts* in this context.

Theoretical background

Social perspective taking

SPT has been recognized as fundamental to the ability to reflect on and behave in line with the needs of others and to the development of empathy (Batson et al., 1997), and as a means of understanding members of other social groups (Wang et al., 2014). In addition, SPT has been identified as a key part of vital skills in today's world, such as collaboration, communication, and argumentation (Sadler, 2006). Finally, ongoing political polarization has highlighted the urgency of facilitating interactions across social groups, which necessitates transcending one's own perspective (Dishon & Ben-Porath, 2018). However, engaging in SPT is neither simple nor automatic, requiring motivation and continued practice (Lin et al., 2010). Moreover, researchers have distinguished between levels of *SPT acts*: (1) The *acknowledgment* of other actors and perspectives; (2) *Articulation* concerning the thoughts, feelings, preferences, and orientations of other actors; and (3) *Positioning* – which involves integrating the situational and personal factors that shape an individual's perspective (Diazgranados et al., 2016).

SPT is usually referred to as a cognitive process in which an individual tries to adopt or imagine another person's point of view. However, critiques have stressed the need to examine SPT through a social-relational lens, exploring interactivity, intersubjectivity, and metareflective forms of sociality and interpersonal negotiation (Martin et al., 2008). Yet, despite the rich body of research on SPT's potential benefits, little is known about how perspectives shift through social interaction.

Dialogue and argumentation in small groups

Though not explicitly focused on SPT, productively engaging with multiple perspectives is a fundamental tenet of research on dialogue and argumentation in education (Asterhan & Schwarz, 2016). Such efforts have been identified as indirectly contributing to the development of SPT by facilitating opportunities for discussion around engaging questions and dilemmas that require students to examine a given issue from various perspectives (Hsin

& Snow, 2017). More specifically, the transition from whole-class discussions instructed and guided by the teacher to small group interactions without teacher mediation can change the SPT dynamic as it shifts the structure of the conversation and the patterns of participation (Hofman & Mercer, 2016). In such contexts, interpersonal aspects related to student dynamics become more central.

Researchers have identified practices such as using specific *talk moves* (Michaels & O'Connor, 2015) that are vital for promoting discussions that are conducive to engagement in SPT (Hsin & Snow, 2017). Research shows that for group discussion to be productive, students should share their ideas as they support them with reasons, discuss different views, and resolve them to achieve group consensus (Hofmann & Mercer, 2016). To study group talk, researchers have developed different coding schemes that aim to support a systematic analysis of different types of *talk moves* in dialogical contexts (e.g., SEDA, Scheme for Educational Dialogue Analysis; Vrikki et al., 2019).

However, few studies have examined the connections between dialogical moves and the levels of SPT in small group work. Accordingly, rather than looking at how the discussion supports SPT via pre- and post-assessments, our research questions focused on studying (1) if and what level of *SPT acts* emerged during small group dialogues; and (2) whether there were connections between students' *talk moves* and *SPT acts*.

Methods

This study was conducted in one 8th grade humanities class, studying a unit centered on moral dilemmas over two months. The curriculum was built by the teachers and modified with the help of the research team to facilitate engagement in SPT. The intervention centered on integrating different dialogical practices and included seven sessions of small group work. During this time, we observed ten lessons and audio recorded five groups' discussions within the classroom (later transcribed). In this paper, we discuss findings from one group that included two girls and two boys. This group was chosen due to technical and substantial reasons. First, as data were collected during an uptick in the COVID-19 pandemic (January-March 2022), many groups suffered from inconsistent participation. Second, this group was characterized by relatively rich conversations in which participants presented diverse positions. In this respect, this group is not necessarily representative of the class as a whole and is not generalizable, but it allows us to bring into focus theoretical relationships that may apply to other contexts (Eisenhart, 2009).

Data includes transcripts of six group discussions with a total of 990 utterances. In each conversation, the teacher instructed the students to discuss a different text that reflects various moral dilemmas that the characters struggle with (stealing or lying for a morally noble cause) and one real-life example exploring the topic of euthanasia. In all cases, weighing the dilemma potentially involved SPT and our analyses explored if and how students practiced SPT within this learning activity. To account for the interplay between *talk moves* and the level of *SPT acts*, we developed a coding scheme (see Table 1) including three levels of SPT. Any utterance that indicated one's awareness of the perspective of the fictional character/classmate was coded as a case of SPT. We also coded *talk moves* that students performed to analyze students' dialogical process and argumentation as they engaged in SPT (based on Vrikki et al., 2019).

Table 1
Coding scheme based on Diazgranados et al. (2016) for SPT acts and SEDA (Vrikki et al., 2019) for talk moves

Code	Sub-code	Definition	Example
SPT Level	Acknowledgement	The act of identifying the various actors involved in a given social situation.	*"He said he had cancer."*
	Articulation	The act of describing the thoughts, feelings, or orientations to the action of distinct actors in a given social scenario.	*"He thought it was the right thing for him."*
	Positioning	The act of identifying the roles, circumstances, or attributes that qualify the position distinct actors hold in a social scenario.	*"A person who wants to commit suicide won't [...] go to work because he doesn't like his life."*
Talk Moves	Build on ideas/ Revoice	Building on, adding to, reformulating, or clarifying one's own or other's contributions.	*"What you are saying [is] that we need to respect the man's choice."*
	Challenge	Challenging / confronting others' view / assumption / argument. The challenge must be evident through verbal (or nonverbal) means, including questioning.	*"If you were given the money, would you take it?"*

	Invite	Invite others to build on or respond critically through explanation, justification, argumentation, analogy, use of evidence or speculation.	*"Do you have a way to convince us?"*
	Guide	Take responsibility for shaping and directing dialogue or activity, including encouraging student-student dialogue, offering thinking time, providing informative feedback or other scaffolding strategies.	*"Joni, what do you think? […] what dilemma are they facing?"*
	Reflect	Explicit self or group evaluation or metacognitive reflection on purposes/ processes/ value/ outcome of learning or activity or invitation to engage in this.	*"This is supposed to be a discussion."*
	Agree	State that one or more participants agree with others.	*"Yes, exactly."*
	Disagree	State that one or more participants disagree with others or acknowledge differences.	*"With this I agree less."*

Findings and discussion

We found SPT in a group dialogue context to be a complex practice in which engaging with different perspectives is constantly intertwined with social dynamics and interlocutors' argumentative concerns. Thus, students repeatedly evaluate how their perspectives differ (or not) with respect to their peers. First, with respect to the manifestation and level of SPT, we identified 356 *SPT acts* (out of 990 turns), of which 228 were at the most basic level of *acknowledging*, 84 were coded as *articulation*, and 44 as *positioning* (see Table 1 for examples). We focused on the highest level of SPT (*positioning*) due to its importance and high complexity (Kim et al., 2018). The use of *positioning* acts led us to conduct a more fine-grained qualitative analysis revealing that these SPT acts were motivated mainly by the effort to "put others in the other's shoes": to explain their own perspective, students often invited other group members to take on the fictional character's perspective while highlighting situational aspects they thought were vital. For example, *"think that your sister was dying and that you had the money [for the medicine], but he [Heinz] stole it."* Here, the student invited his peer to "put herself in someone else's shoes," a person whose sister is in a life-threatening situation and needs a particularly expensive and rare medication. Later, he explains that it is wrong of Heinz (the main character) to steal the medicine. Thus, an argumentative act of trying to challenge his peer and convince her of his perspective is pursued via a *positioning* act.

To examine the interplay between *talk moves* and *SPT acts* more closely, we examined the co-occurrence of SPT *positioning moves* with the various *talk moves* outlined in the SEDA framework (Table 1). Our findings indicate that *positioning* acts (overall 44) co-occurred with the high use of the two *talk moves*: *Build on Ideas/Revoice* (33 acts) and *challenge* (9 acts). We suggest that this indicates that SPT is a process of understanding, explicating, and communicating one's perspective as one positions it in relation to other perspectives (building, challenging, or coordinating perspectives). For example, *"Can you say that you personally knew this man? Do you know what he's been through?"* Here, the student is challenging his peer to recognize that she is not aware of the other's perspective, nor does she understand it. He demands her not only to acknowledge the other individual but also to position herself in his place. Thus, we uncover how students used a higher level of SPT to explain their perspective to their peers as an argumentative move. However, students did not take on their peers' perspectives; instead, they focused on explaining their *own* views in relation to those of others.

Our findings highlight the social nature of *SPT acts*. Students refined and expressed their perspectives as part of a conversation in which they tried to convince others to understand and adopt their own perspectives. Put differently, students practiced their social understanding of themselves in relation to the perspective presented in the text and to group members' diverse perspectives. This implied that individual SPT processes are already social: they include considering how one's understanding of a given situation stands in relation to another person's perspective (a fictional character and/or a classmate). Moreover, this highlights how *perspective taking* processes are entangled with *perspective making:* the process in which one develops and frames their own narrative of experiences (Boland & Tenkasi, 1995).

Conclusions

Our case study broadens the existing literature on SPT in educational settings by examining the manifestation of SPT in dialogical contexts and the connections between the level of *SPT acts* and students' *talk moves*. Our findings indicate that engagement in high levels of SPT could be potentially supported by opening the class to more student opinions, thus fostering student engagement as they relate to additional views. Also, exposing students to more perspectives on a given dilemma allows them to practice SPT as they better understand their peers. Moreover, we highlight that a central aspect of *SPT acts* revolves around *perspective making* – forming and communicating one's own perspective while positioning it in relation to others. This highlights that SPT is not merely an individual cognitive process but also a social effort that supports personal exploration within a group dialogue. Yet, in our data such perspective making acts often came at the expense of attentiveness to interlocutors' perspectives, an issue that should be further explored in future research. In this respect, though exploratory in nature, this study could offer a conceptual roadmap for future research that examines the social processes underpinning engagement in SPT.

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Virtual Reality Induces Awe but Possibly Not Accommodation

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Abstract: Awe is a transformative emotion associated with positive educational and psychological outcomes, and is caused by experiences of *vastness* that induce *accommodation*. Vast VR scenes have been found to elicit awe. We examined self-reported causes of awe among grade 3–8 students — a previously unstudied age group regarding awe — in a virtual environment portraying entities over 20 orders of magnitude from atom to Sun. Most students reported feeling awe, around half specifically enough to be coded based on *a priori* categories drawn from the literature. *Vastness of scale* (including both large and small entities, and large differences in scale) was the most common cause of awe. Surprisingly, no student responses were related to accommodation. *Vastness of evolution* and *degree of immersion* were identified as novel causes of awe. Thus, even young children can experience awe in VR, opening possibilities for productive VR in education at the elementary school level.

Introduction

Awe is a transformative emotion that can induce positive psychological and physiological changes (e.g., Piff et al., 2015; Rudd et al., 2012; Yang et al., 2016). The consensus view is that awe is caused by vastness and accommodation (Chirico et al., 2018; Cruz, 2020; Keltner & Haidt, 2003; Shiota et al., 2007; Valdesolo et al., 2017). Researchers have recently begun assessing whether and how experiences in immersive virtual environments portraying vast scenes induce awe (Chirico et al., 2018).

Understanding what elicits awe is important because awe has been found to drive scientific discovery, support science learning, and elicit constructive science behaviors (e.g., Jones et al., early view; Chirico et al., 2018; Gottlieb et al., 2018; Keltner & Haidt, 2003). However, the literature on awe is either theoretical or involves college-age or older participants, and little is known about how and why younger students experience awe; furthermore, there is little literature on awe and virtual reality (VR).

Our NSF-funded project has developed an immersive virtual environment called *Scale Worlds* that allows students to interact with virtual entities as they seemingly shrink or grow themselves over 20 orders of magnitude from atom to Sun. We studied whether grade 3–8 students experienced awe in this virtual environment, and what caused that feeling, guided by the following research question: What factors within a virtual environment induce awe among middle school and elementary students?

Theoretical framework

Awe

Keltner and Haidt (2003), in their foundational work, posit a prototype perspective where awe is characterized by two features: *vastness* and *accommodation*. "*Vastness* refers to anything that is experienced as being much larger than the self, or the self's ordinary level of experience or frame of reference. Vastness… can also involve social size such as fame, authority, or prestige" (Keltner and Haidt, 2003, p. 303, emphasis added). *Accommodation* refers to the Piagetian process of modifying existing mental schemas during new experiences that cannot be assimilated (Piaget & Inhelder, 1966/1969). In particular, "awe involves a *need* for accommodation" (Keltner & Haidt, 2003, p. 304, emphasis retained). If accommodation successfully takes place, then it may result in "feelings of enlightenment and even rebirth" (p. 304). If accommodation does not take place, feelings of confusion, disorientation, powerlessness, and fright may result instead (p. 304).

Yaden et al. (2019) developed the Awe Experience Scale (AWE-S). Their exploratory factor analysis identified a six-factor structure: *accommodation, vastness, connectedness, self-diminishment, time dilation,* and *physical sensations*. Like several other papers, their scale does not distinguish among causes (e.g., vastness) and consequences (e.g., time dilation) of awe.

Virtual reality

Virtual reality is a computer-generated environment that combines multisensory stimuli, affording users the ability to interact as they would with natural environments. Among VR systems are the Cave Automatic Virtual Environment (CAVE) and head-mounted displays (HMD). The CAVE is a small room size space with 3–4 projecting walls, a projected screen floor, and sometimes a ceiling; while the HMD includes a visual display for each eye. VR systems are immersive to varying degrees — high for HMD as the headset blocks out the external world, and medium for CAVE. Of the many conceptualizations of *immersion,* Witmer and Singer (1998) describe it as feeling "enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" (p. 227). They posit that there are three characteristics of VR that induce immersion: its ability to isolate the experience from the real-world, the user's self-inclusion, and a user centered interaction (1998). Unlike merely watching images on a computer screen, VR allows embodied interaction, as users can change their positions by walking, and can sense sizes relative to their own body (CAVE) or avatar (HMD).

Awe and virtual reality

Chirico et al. (2018) demonstrated that virtual environments for HMD that portray vast scenes induced awe more than non-vast scenes, attributing it to the immersive experience that elicits a sense of presence.

Methods

Participants

Participants (n=69) consisted of middle school (n=20) and elementary school (n=49) students participating in a STEM summer camp serving students of historically underserved and underrepresented groups. Students were recruited via our collaboration with the institution organizing the camp. We had one session for the middle school students, and split the elementary-age students into two sessions. Each session was approximately two hours long.

Student experience

All students experienced the CAVE-based *Scale Worlds* in groups of 3–5. Up to four at a time used the CAVE and the fifth student rotated in. Middle school students also experienced the HMD version, with groups of 3–4 alternating among two headsets. Each experience lasted 15-20 minutes and involved navigating across the 20 orders of magnitude from atom to Sun. The elementary students were guided during the CAVE activity by the first author; for example, he encouraged them to walk around the virtual entities, identify continents on the virtual Earth, compare their own size to the entities displayed, and keep track of the sizes in powers of ten. The middle school students were encouraged to freely explore. Students not in the CAVE or HMD rotated in their groups among other stations with educational technology (e.g., Sphero Robots), attended by graduate students.

Data source

To assess the impact of the educational experience and inform our research initiatives, we created a survey centered around the CAVE, scale cognition, and situational interest. The survey was administered immediately following the student's experience in the CAVE. The CAVE was chosen as the focus over HMD because its version of *Scale Worlds* was further developed. The survey consisted of various questions; the one analyzed in this paper was "Did you experience feelings of awe (amazement, astonishment, or wonder) during your *Scale Worlds* experience? If so, what caused those feelings? Please describe." The survey was administered on iPads.

Analysis

The first author analyzed the literature for previously-identified factors related to awe. The first two authors independently divided these into causes and consequences of awe, and discussed their analyses until they achieved consensus. The second author then constructed an *a priori* codebook that included definitions from the literature for each code. We added an example response for each as we encountered them while coding. An abridged version is presented in Table 1.

To obtain inter-rater reliability, seven questions (10% of the data) were selected at random using a random number generator and coded using the codebook, resulting in 50% agreement. To improve reliability, both authors discussed each statement to clarify definitions, and selected examples to add to the codebook. Hypothetical example statements were also generated to further increase clarity. Another seven questions (10% of the data) were randomly selected and coded, resulting in 86% agreement. With this level of agreement, the remaining student responses were coded by the second author.

Findings

Of the 69 students, 68 (98.5%) responded to the prompt about awe. Of those, 65 (95.6%) acknowledged feeling awe, while 3 (4.4%) indicated no feelings of awe. Over half (53.8%) of the responses (n=35) simply reworded the prompt (e.g., "it was cool") or were too general or vague to code (e.g., "Being in 3D and seeing it was super awesome sauce gamers!", "It was cool", "It was weird"). The remaining 30 (46.2%) responses did indicate cause(s) of awe, and were coded as follows: 16 vastness (24.6%), 5 sublime (7.7%), 3 gap in knowledge (4.6%), 2 novelty (3.1%), 1 violates expectations (1.5%), 1 incomprehensible (1.5%). Two responses cited a cause not in the codebook (3.1%). Of the student responses, 90.7% were single coded and 9.2% were coded for two categories.

Vastness

Responses coded for vastness included both very large and very small entities. One student indicated the size of the Sun while another student identified the size of the coronavirus as awe inducing. Another student indicated a difference in scale as awe inducing, referencing that "ants are so small but planets are so big." We propose reconceptualizing this cause of awe as *vastness of scale* rather than simply vastness.

Other causes

The second most common category (8.7%) was sublime. These responses included: "Yes it was so well engineered and very realistic," "the effort people put into the technology," and "only 6 people designed a VR masterpiece." The third most common category (7.2%) was a gap in knowledge (e.g., "I never knew the worlds were that big"). Students also reported a sense of novelty (e.g., "I had never done something like that"), violation of expectations (e.g., "amazing that people really made these things"), and incomprehensibility ("surprised you could do all this stuff with small glasses")" as causes of awe. No students identified explanatory power or social importance as a cause of awe. Some students' responses resulted in novel findings. One student expanded the idea of vastness, indicating that the evolution of humans over time was a cause of awe ("caused by me realizing how much humans have evolved"). Another student discussed the degree of immersion of the technology ("It was honestly how immersive the VR and the 3d screens were").

Accommodation

While a few students referenced a gap in knowledge, no students expressed any form of Piagetian accommodation. For example, a student indicated that they "never [knew] the worlds were that big," which induced awe. However, they provided no evidence that this resulted in the revision of their mental schemata, drawing attention only to the gap in knowledge. This is interesting because Keltner and Haidt (2003) identified accommodation as a prototypical cause of awe, and most subsequent authors are aligned with this idea.

Table 1
Abridged version of codebook of a priori codes for causes of awe developed from the literature.

Cause	Definition
Vastness	"Vastness refers to anything that is experienced as being much larger than the self, or the self's ordinary level of experience or frame of reference." (Keltner & Haidt, 2003, p. 303)
Incomprehensible	"a direct and initial feeling when faced with something incomprehensible or sublime." (Reinerman-Jones et al., 2013, p. 298); "difficulty in comprehension, along with associated feelings of…surprise." (Keltner & Haidt, 2003, p. 303)
Accommodation	"Awe… entails an inability to assimilate information into existing mental structures and a resulting need for accommodation" (Valdesolo et al., 2017, p. 217)
Violate Expectations	"awe is triggered by an unexpected event… awe seems to be evoked by major violations of expectations" (Valdesolo et al., 2017, p. 217)
Novelty	"when we are faced with a vast, novel stimulus that does not fit our current image of the world" (Cruz, 2020, p. 6)
Gap in Knowledge	"awe… involves the salience of a gap in knowledge" (Valdesolo et al., 2017, p. 217)
Explanatory Power	"it may also be elicited by more conceptual contents, such as great works of art and 'grand theories' (i.e., the theory of relativity)" (Chirico, 2018, p. 1)
Sublime	"we defined awe as a direct and initial feeling when faced with something incomprehensible or sublime" (Reinerman-Jones et al., 2013, p. 298)
Social Importance	"social size such as fame, authority, or prestige… symbolic markers of vast size such as a lavish office" (Keltner & Haidt, 2003, p. 303)
Overcoming Challenges	"However, a novel finding is that teachers perceived social aspects of awe experiences. Teachers described being awed by students' social behaviors or dealing with adversity or challenging situations." (Jones et al., early view, p. 21)

Discussion

Our work contributes to the literature by clearly identifying causes of awe (as distinct from consequences), and then operationalizing them into a protocol for qualitative analysis resulting in a codebook with definitions, sources from the literature, and examples. This codebook can be used by other researchers.

Most student-described causes of awe aligned with prior literature, with two notable exceptions. First, the total absence of *accommodation.* From our data we cannot distinguish between the possibility that students did not experience the need to accommodate their mental structures, the possibility that they did experience the need but lacked the metacognition to write about it, or other causes. We do believe that even young students should be able to voice the need for accommodation using phrases like "it blew my mind" or "I realized I had to change what I thought about [one or more entities]," but perhaps they did not feel that this constituted a legitimate "cause." Future research should address this gap, by conducting interviews with students of this age group, and researching older students to observe at what age they begin to generate descriptions of accommodation.

The second exception involved student responses beyond previously-identified causes of awe. One student indicated that the *degree of immersion* in VR induced awe, suggesting a unique technological affordance. This is consistent with Chirico et al.'s (2018) finding that the general effect and sense of presence simulated by virtual environments was associated with feelings of awe. Another student indicated *vastness of evolution.*

While vastness has long been identified as a cause of awe (Keltner & Haidt, 2003; Shiota et al., 2007; Cruz, 2020), our findings suggest a reconceptualization of this cause is needed. Rather than just considering entities, spaces, distances, or experiences (whether physical or metaphorical) that are larger than one's frame of reference, *vastness of scale* including tiny objects or large differences in scale may cause awe as well.

Our study shows that even young children can experience awe in VR, opening possibilities for productive use of VR in education even at the elementary school level.

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Teacher Reflective Noticing and Scaffolding for Student-Driven Knowledge-Building Inquiry

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Abstract: This study investigates a teacher's noticing and scaffolding in two Grade 5 science classrooms based on knowledge building pedagogy. The teacher observed students' inquiry and collaboration in the classrooms and online and kept weekly reflective journals to write about her noticing, reflection, and planning to scaffold deeper knowledge work. Qualitative analysis of the teacher's journal entries in connection with classroom data generated a detailed temporal view of the teacher's ongoing noticing, envisioning, and classroom actions, which responded to and further reshaped student-driven inquiry efforts. Through engaging in reflective noticing and envisioning of students' knowledge building progress, the teacher can devise responsive support to scaffold ever-deepening inquiry processes in which students enact epistemic agency.

Introduction

Reforms in education prioritize the need for students to develop deep knowledge and authentic practices by which knowledge is constructed (National Research Council, 2012). To cultivate authentic practices for knowledge building in science classrooms, teachers face the challenge of how to scaffold expansive inquiry processes in a way that enhances student epistemic agency for charting and reshaping the course of improvisational inquiry in a collaborative community (Scardamalia & Bereiter, 2006; Zhang et al., 2022). Existing studies have documented a wide range of scaffolding moves teachers take to facilitate students' knowledge building conversations (e.g., Hmelo-Silver & Barrows, 2008). Further research needs to better understand their ongoing pedagogical judgment and decision-making underlying their classroom moves (Horn, 2020; Watkins & Manz, 2022). Thus, the current study investigates a teacher's noticing and scaffolding in two parallel Grade 5 classrooms that implement Knowledge Building (KB) pedagogy with technology (Scardamalia & Bereiter, 2006). This study aims to produce a comprehensive and temporal account of the teacher's reflective noticing that informs her scaffolding of student collaborative inquiry. Our research questions ask: (a) What aspects of students' knowledge building work did the teacher attend to in her reflective journals? (b) In what ways did the teacher interpret the changes in student knowledge building and envision responsive classroom moves? And (c) how did the teacher scaffold student knowledge building based on her ongoing noticing and envisioning?

Conceptual and design framework

We propose a framework to guide our design and analysis of teacher noticing and scaffolding for student-driven knowledge building. Based on this framework, investigating teachers' reflective noticing and envisioning for knowledge building may demystify how teachers navigate the emergent changes and opportunities in students' inquiry work and make strategic choices to catalyze deeper conversations and sustain iterative idea improvement.

The key elements of the framework are elaborated on below.

First, teachers' reflective noticing and scaffolding revolve around student-driven knowledge building processes, treating students' authentic problems and evolving interests and ideas as the center of classroom dynamics (Scardamalia & Bereiter, 2006). Teachers use an open-ended approach to classroom planning: identifying *big ideas* and challenging issues in a curriculum area, sketching an overarching picture of how the collective inquiry may get started and evolve while leaving the detailed actions and processes open to be co-improvised with students as they step in the scene (Zhang et al., 2022; Zhang & Messina, 2010). Second, our framework highlights three interconnected elements of reflective noticing and scaffolding: Attending, Interpreting, and making pedagogical Moves (A-I-M). While these elements have been identified in the literature on teacher noticing (Barnhart & van Es, 2015), our framework further aligns such teacher efforts with student-driven action and agency for deepening collaborative inquiry and discourse. Specifically, in a knowledge building community, teachers need to (a) attend to students' evolving ideas and inquiry practices to detect dynamic information about what is going on and what is new and emerging; (b) interpret the classroom information to understand how students are thinking now, in relation to their work in the past and potential idea development in the future; and (c) in response to the evolving landscape of ideas, envision strategic pedagogical moves (choices), which catalyze or leverage student-driven efforts to further their collaboration and inquiry. Third, teachers' attention, interpretation, and pedagogical moves are guided by the core principles of knowledge building. For example, guided by the principles of *authentic problems, real ideas*, and *continual idea improvement*, teachers are attentive to students' evolving problems and ideas generated in personal and collaborative works. Capturing such information helps teachers make timely and intentional moves to advance students' knowledge building efforts.

Classroom context

This study was part of a larger project to explore classroom designs and technology for student-driven knowledge building in science at a public elementary school in the Northeastern U.S. The participants included one teacher, Mrs. G, who taught science in two Grade 5 classrooms, including her homeroom class (classroom G) and Mrs. W's class (classroom W). Mrs. G taught for over 20 years and was in her third year of teaching science based on KB pedagogy. There were 21 students in each classroom (20 boys and 22 girls), who were 10- to 11-year-olds and came from diverse ethnic backgrounds. In the school year of this study (2015-2016), Mrs. G worked with the students to study human body systems over eight months as part of their science curriculum. There were two science lessons every week, each lasting for 40 minutes.

In mid-September, students participated in the kick-off activities, each of which required them to complete a challenging task about various body parts. In the following science lesson, students from each classroom participated in a reflective conversation called a metacognitive meeting (MM), in which they shared a wide range of questions and, as a whole class, built shared interests in understanding the functions of the human body. Then, students with interrelated interests and questions worked together to formulate an overarching question to guide their inquiry in a shared "wondering area." As their discussion proceeded, they formed a spontaneous group with those having similar interests and conducted personal and collaborative inquiry activities. Major questions, ideas, and findings generated through the face-to-face activities were contributed to Knowledge Forum for online discourse. In the classrooms and online, Mrs. G worked as an attentive listener to understand students' interactive questions and ideas while offering support to help students further their inquiry and refine their collaboration. She kept a weekly reflection journal designed based on our conceptual framework to record her observation ("I notice…"), interpretation ("I think…"), and responsive planning ("In the following week(s)…").

Data source and analysis

The core data source was Mrs. G's weekly reflective journals. The teacher recorded 27 reflective journals to reflect on student inquiry in the two classrooms. Her journals contained 172 journal entries, including 92 entries reflecting on the inquiry work in her home class (classroom G) and 80 for classroom W. We analyzed Mrs. G's journals in connection with several other data sources, including classroom observations of students' inquiry activities and the archive of student online discourse in Knowledge Forum. We observed each science lesson during the human body inquiry and video/audio-recorded the major classroom activities, such as whole class metacognitive meetings.

To address the first two research questions, we analyzed Mrs. G's reflective journals using a grounded theory approach to understand what aspects of student inquiry the teacher attended to, how she interpreted, and the classroom moves she envisioned in response. Each entry (row) of reflection (i.e., an A-I-M set) was considered a unit of analysis. The first author read the journals multiple times to develop a general sense of Mrs. G's reflection. Then, she worked with the second author to develop initial open codes (raw codes) using a subset of reflection journals as applying open codes to characterize Mrs. G's reflection. The two co-authors then discussed the open codes and the related examples, reflected on the meaning and consistency of the codes, and refined the labels and definitions better to capture the teacher's points of observation and thinking. Through multiple rounds of discussions, the authors compiled an initial codebook and then reviewed all the open codes and examples to formulate salient themes that characterized Mrs. G's attention, interpretation, and planning of classroom moves. In the final analysis phase, the authors searched for connections across the themes of A-I-M sets, identifying how Mrs. G interpreted the observed knowledge work and considered various pedagogical moves. To address the third research question, we further examined Mrs. G's noticing points and scaffolding moves in the temporal context of student knowledge building processes in the actual classroom events, discovering patterns of teacher scaffolding that built on and further shaped student inquiry actions.

Results

What aspects of students' knowledge building work did the teacher attend to?

Through coding Mrs. G's writing in the column of "I notice...", we identified six salient categories (themes) representing what the teacher attended to when observing and monitoring student knowledge work as individuals, groups, or a whole class. As the most salient points of noticing, Mrs. G observed students' individual and collective efforts of ongoing idea improvement in existing lines of inquiry (A-2, 37.21%) while paying attention to the emergence of new inquiry interests and directions (A-1, 23.26%) and monitoring gaps in inquiry and contribution (A-6, 2.33%). She was also attentive to students' specific inquiry activities, emotions, and needs (A-3, 16.28%), their use and generation of resources and tools to support inquiry (A-4, 6.98%), and the meta-talk among students about knowledge building practices and norms (A-5, 2.91%).

In what ways did the teacher interpret new changes in student knowledge work and envision responsive moves?

The teacher's interpretation and sense-making of what was going on

Nine themes emerged from the coding of the teacher's journal writing in the "I think…" section, which recorded her interpretation and analysis of what was going on in student knowledge work. Mrs. G's pedagogical analysis and sense-making centered on understanding students' personal intent, needs, and emotions (I-6, 30.23%) while comprehending and appreciating their progressive ideas (I-1, 25%) to discern emergent opportunities and needs for further idea improvement and collaboration. As the related considerations, Mrs. G also reflected on specific gaps in student inquiry and idea contributions (I-9, 5.81%), analyzed potential opportunities for deepening ideas (I-2, 2.33%), expanded collective inquiry (I-3, 0.58%), and assessed the clarity of student ideas (I-5, 1.16%). She examined potential connections between different concepts and areas of inquiry (I-4, 3.49%), reflected on how students used and created resources/tools in their knowledge work, including their needs for support (I-7, 3.49%), and analyzed student knowledge building practices and norms reflected in the classrooms and online discourse for possible improvement (I-8, 2.91%). In her pedagogical sense-making, Mrs. G often positioned the specific events she had observed in the larger context of the core disciplinary ideas in the curriculum area, the past and future of the human body inquiry of the whole classroom community, and the knowledge building principles and norms.

The teacher's planning of responsive classroom moves

In light of what was going on in student work, Mrs. G envisioned ways to enhance student knowledge building in the coming week(s). Nine categories of classroom moves that the teacher envisioned. The most salient moves focused on (a) supporting students' needs to improve their learning experiences and enhance their knowledge building practices (M-6, 19.19%), such as by offering suggestions to individual students on note writing or meeting with a small group to address their needs, and (b) facilitating idea connection and collaboration among students (M-4, 12.79%), such as by highlighting a student's Knowledge Forum note during a metacognitive meeting for further discussion or pairing students who had posted interconnected questions to work as a group. As the relative classroom moves, she envisioned specific ways to continually trace students' inquiry progress and contributions and explore the further directions of the community's inquiry (M-9, 8.72%); to foster students' deeper understanding of concepts through continual inquiry efforts (M-2, 8.14%); to form new inquiry directions with students (M-1, 6.98%); to broaden the sharing and spread of inquiry progress (M-3, 4.65%), while supporting student use of resources/tools (M-7, 4.65%), knowledge building practices and norms (M-8, 4.07%), and misunderstanding (M-5, 2.33%) as needed.

How did the teacher scaffold student knowledge building based on her ongoing noticing and envisioning?

Our analysis investigated the dynamic links between what the teacher captured from student work, her envisioning/planning of responsive teacher moves, and the actual classroom processes that followed. For a temporal view, this analysis zoomed in two time periods: (a) from October to November 2015, when students were initiating their inquiry works on the various human body topics and establishing their knowledge building practices as a whole community; and (b) in December, when the classroom members continually reflected on their ongoing inquiry and worked on new opportunities to deepen and expand their knowledge. For each period, we identified and traced the co-occurrence of various themes of A-I-M associated with each row (entry) in Mrs. G's reflection journal.

For instance, we unpack one of the patterns: tracing ongoing student efforts in the unfolding lines of inquiry to enhance idea improvement, build connections, and address knowledge gaps. Students in each classroom co-formulated an initial set of wondering areas at the beginning of the human body inquiry, which guided students' personal and collaborative knowledge building. Mrs. G continued observing how student thinking deepened in each inquiry area (A-2), attending to student-generated inquiry interests, ideas, and activities. Anchored in what she had observed, Mrs. G engaged in pedagogical sense-making to understand students' progressive ideas and questions (I-1) and analyze potential opportunities/needs for students to further deepen their thinking (I-2). Based on that, she (a) facilitated deeper inquiry and understanding of concepts (M-2); (b) facilitated student collaboration and idea connection (M-4); (c) spotlighted the inquiry progress and ideas of an individual or a group of students to facilitate broader sharing and discussion (M-3); and (d) addressed misunderstandings reflected in students' work (M-5). From December, the teacher continued to observe students' ongoing efforts in the existing lines of inquiry to understand students' evolving ideas (I-1) while pondering their intentions of inquiry and needs for support (I-6). Such pedagogical analysis and sense-making helped the teacher to envision responsive moves to support student idea improvement and build connections across the various lines of inquiry (M-2, M-3, M-4) while addressing students' specific needs (M-6). As Mrs. G monitored students' ongoing progress, she also detected missing concepts yet to be incorporated in student discourse (A-6) and reflected on possible ways to bring such concepts to student attention (I-9), building on the questions and ideas they had generated online or in classroom-based activities. Instead of redirecting students to teacher-specified directions, the teacher built on student ideas and inquiry practices to introduce her responsive input. Students' inquiry works and artifacts were used as examples to facilitate meta-talks about how they should carry out their knowledge building as a community, leading to more elaborate inquiry practices, tools, and classroom norms.

Conclusion and implications

This study suggests that principle-informed reflective noticing and envisioning may function as a dynamic process that teachers can leverage to support student-driven knowledge building practices in science and potentially other content areas. Ongoing reflective noticing of student knowledge work, guided by the core principles of knowledge building pedagogy, reveals ever-emerging opportunities for further advancing students' inquiry and collaboration. Teachers then interpret and respond to such opportunities by devising possible classroom moves, which help catalyze students' epistemic efforts to develop deeper inquiry and discourse on an ongoing basis. Following each major classroom effort to reshape the community's inquiry works in specific ways, teachers co-engage in the subsequent knowledge building activities and discourse with students to observe how student inquiry efforts further evolve. Thus, teachers' reflective noticing and responsive scaffolding unfold as an iterative and recursive process over time as students' knowledge building proceeds (cf. Watkins & Manz, 2022). Given the challenging nature of teacher noticing in a constantly changing classroom environment, it is important to design classroom-oriented analytical support that can enhance teachers' ongoing noticing of students' dynamic inquiry in a collaborative community (van Leeuwen et al., 2019). The conceptual framework and empirical of this research may inform designs of the support and professional development resources aimed at helping teachers master the art of reflective noticing and scaffolding for collaborative knowledge building.

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Examining University Instructors' Conceptions and Perceived Changes in Knowledge Building Professional Development

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Abstract: This is a work-in-process research project aiming at examining the design of Knowledge Building professional development (KBPD) to foster university instructors' conceptions of teaching and learning and teaching practices. 10 instructors from the same university joined this study. Multiple sources of data were collected, including surveys, classroom and online artefacts, and interviews. Analysis of pre- and post-surveys showed that the participants hold more constructivist conceptions about teaching and learning after attending KBPD. The classroom reflection artefacts showed that they were more inclined to apply the KB principles in their own classes, and that they regarded the epistemological role of their students have shifted more towards knowledge constructors/creators in their classrooms after attending the KBPD. Interview analysis further showed in what ways they have changed their conceptions and perceived practices. Implications for future design of KBPD were discussed.

Introduction

This is a work-in-process research aiming at examining the design of Knowledge Building professional development to foster university instructors' conceptions of teaching and learning and teaching practices.

Knowledge Building is one of the computer-supported collaborative models in education (Scardamalia & Bereiter, 2014), emphasizing students taking collective cognitive responsibility to advance their community knowledge (Scardamalia, 2002). Knowledge Building has been widely studied and researched in K-12 education. Many existing Knowledge Building research has focused extensively on the role of Knowledge Building in fostering students' collaboration, learning, and cognition (Chan, 2013; Lin & Chan, 2018; van Aalst & Chan, 2007; van Aalst & Truong, 2011; Zhang et al., 2009; Zhao & Chan, 2014), whereas comparatively less is known about how Knowledge Building might support teacher learning. Even though there are initiatives to foster Knowledge Building teacher communities (e.g., Chan, 2011; Teo et al., 2021), and some also examined the role of Knowledge Building discourse in supporting pre-service teachers' learning (e.g., Chai & Tan, 2009; Hong & Chai, 2017), few studies have examined the design and impact of professional development (PD) on Knowledge Building for university instructors.

Teacher PD plays an important role in enhancing the teaching and learning in higher education. Effective PD could improve teachers' conceptions and practices, and therefore enhance students' learning (Fishman et al., 2014). In this project, we designed a Knowledge Building professional development (KBPD) program for university instructors, and we aimed to examine its impact on their conceptions and perceived practices. Specifically, we addressed two research questions: 1) Did the instructors change their conceptions of teaching and learning and views of Knowledge Building after attending the KBPD? 2) To what extent have the instructors changed their perceived teaching practices after attending the KBPD?

Methods

Participants and contexts

Participants are 10 university instructors (full-time faculty staff, N = 3; part-time instructors, N=7) in a public autonomous university in Singapore recruited through an invitation email sent to all instructors. The participants' age ranged from 31 to 65 years old ($M = 51$, $SD = 11.6$), with 3 female instructors and 7 male instructors. They had varied disciplinary backgrounds (e.g., Business, Law, Humanities and Social Sciences) and education levels (33.3% bachelor's degree, 33.3% master's degree and 22.2% PhD). Their teaching experiences ranged from 4 to 23 years. All participants did not have prior experience with Knowledge Building, but they had used other asynchronous learning tools in their classes (e.g Padlet, Miro).

Instructional design

The design of KBPD program was informed by Knowledge Building pedagogy and experiential learning, with the aim of fostering a Knowledge Building community. It included three successive synchronous sessions (each

3 hours) and asynchronous learning in-between, covering theory, practice, and reflection. Besides Knowledge Building principles (Scardamalia, 2002), a few other principles have also guided the design of KBPD program: 1) Activate prior pedagogical stances. Similar to the general conceptual learning where articulating prior knowledge is important, to help instructors change their conceptions of teaching and learning, it is important to let them articulate their prior pedagogical ideas. 2) Articulate epistemic goals for teaching. Epistemic goals are fundamental in influencing one's practices (Chinn, et al., 2011). To help instructors make sense of knowledge building, we tried to link their own epistemic goals with the epistemology of Knowledge Building. 3) Situated learning. KB is a principle-based approach, and it does not have predefined fixed steps for teachers to follow (Hong & Chai, 2017; Scardamalia, 2002). Therefore, to help instructors learn about Knowledge Building, we drew upon situated learning theories (Lave & Wenger, 1991) and engaged them in the Knowledge Building process themselves, including posting questions, constructing explanations, building on each other's ideas and continually improving their ideas online and offline.

The first session started with instructors' reflection of their current teaching practices. They were asked to articulate and elaborate where they were and where they wanted to move in terms of students' epistemological roles, ranging from learners as knowledge receivers to learners as knowledge co-constructors and creators. This led to the common goal of achieving idea-centred knowledge creation. Then KB was introduced as a pedagogy to achieve the common goal. The trainer discussed the rationales of KB, what KB looks like, and the principles of KB. Four principles were highlighted throughout the workshop, including authentic problems, improvable ideas, constructive use of new information, and epistemic agency. While only four principles were highlighted, other principles were infused and embedded across the PD process. The participants were also provided with a worksheet which asked them to rate the extent to which they thought the principles were important and were applied in the classroom. Following this self-reflection, they discussed in small groups about how they could use these principles to tweak their current teaching practices. Knowledge Forum, a computer supported platform for supporting Knowledge Building, was introduced to support their collective online inquiry.

In Session two, participants were asked to identify the promising ideas/questions in their online and offline inquiry, and then they engaged in a Knowledge building talk (Reeve et al., 2008) to further pursue inquiry on the identified questions. Knowledge building assessment (Lee et al., 2006; van Aalst & Chan, 2007) was also introduced, and the participants were asked to write portfolio notes to reflect on their collaboration and community knowledge based on the four KB principles. In the second half of the session, they worked in small groups to redesign a regular course (provided by participants) into a KB class informed by KB principles.

Session three focused on practice and reflection. There was a two-week gap between Sessions 2 and 3. Between which, the participants were expected to apply some of the KB principles and strategies in their own classroom. For the participants who were not teaching during that period, they were asked to redesign one of their courses with KB pedagogy and bring the redesign back to session three to share. During session three, two guest speakers who had extensive KB experiences were invited to share their KB practices with the participants. Building on the learning points from the workshop and the guest speakers, the participants worked in small groups to share and finetune their own KB designs. In the end, the participants were asked to reflect on their current teaching practices similar to what they did in the first session.

The participants were encouraged to write on Knowledge Forum between the sessions. Considering they are working adults who have various commitments, we also provided opportunities for them to write on Knowledge Forum during the sessions.

Data source

Conceptions of teaching and learning

To assess participants' conception of teaching and learning at pre- and post-tests, we adopted Teaching and Learning Conceptions Questionnaire (TLCQ) from Chan and Elliott's (2004). The TLCQ has 30 Likert Scale items (1-5) which measures two major dimensions: Traditional Conception of teaching and Constructivist Conception of teaching.

Views of Knowledge Building

As mentioned, participants were given a worksheet to reflect on their understanding of KB in the first and last sessions. The worksheet was both a reflection tool and also a measurement of their views of KB. It was adapted from Hong et al's (2011) instrument for measuring students' views on the importance and feasibility of KB (Likert scale: 1-5). As our participants were instructors, we changed the feasibility to application. In other words, instead of asking participants to rate the extent to which they think the principle is feasible, we asked the participants to rate the extent to which they have applied the principles in their classes. The pre- and post-worksheet were collected to understand the change of their views of KB.

Perceived teaching practices

In both the first and last sessions, participants identified where they were in their teaching practices, and these data were collected to examine the change of their perceived teaching practices. In addition, we also conducted individual interviews one month after the KBPD to understand how the program has impacted their teaching practices. We also asked them to elaborate further on why they put themselves in a certain place in the spectrum in the first and last session, and how their current teaching is different from their previous teaching (before attending KBPD). Thematic analysis was conducted to identify the themes and patterns associated with the change.

Preliminary findings

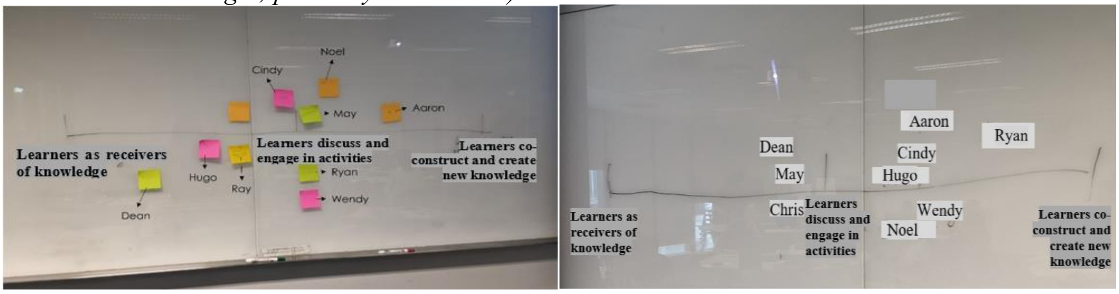
We conducted paired sample *t*-tests to analyse participants' conception of teaching and learning before and after the PD. There was no significant change in traditional conceptions before (M = 2.22, SD = .36) and after (M = 2.15, SD = .43) the KBPD. However, the participants' constructivist conceptions were significantly higher after the KBPD (M=4.21, SD=.40) as compared to before the workshop (M=4.06, SD=.42), $t(8) = -2.71$, $p < .05$. These findings demonstrated that the participants held more constructivist conceptions about teaching and learning after the KBPD, while their traditional conceptions remained the same.

We also conducted paired sample *t*-test to examine participants' views of KB principles, results showed that there was no significant difference in the perception of the importance of the knowledge building principles before (M = 4.17, SD = .47) and after (M = 4.25, SD = .50) the workshop, $t(5) = .79$, $p > .05$. However, a significant difference was found in the perception of their application of the knowledge building principles before (M = 3.57, SD = .13) and after (M = 3.88, SD = .26) the KBPD, $t(5) = 3.80$, $p < .05$. This indicated that they were more inclined to apply the KB principles in their own classes after the KBPD workshop, however, their understanding of the importance of the KB principles remained unchanged. This is probably due to their extensive teaching experience in higher education and they have already perceived KB principles as important prior to the KBPD program.

We also compared their perception/reflection of their teaching practices in the first and third session of the KBPD. As Figure 1 shows, most of them moved themselves towards the right side of the spectrum to a certain degree, except Noel and May. In the follow-up interview May clarified that she misunderstood the question asked and she should put herself in the same place as the first one. This suggested that in most of the participants' classroom, the epistemological role of their students have shifted towards active participants and knowledge co-creators.

Figure 1

Participants' reflection of their teaching practices in the first and last session (first session on the left and last session on the right; pseudonym were used)



Our preliminary interview analysis also showed in what ways they changed their conceptions of teaching and learning and teaching practices after the KBPD. While each of them perceived different changes, these changes showed that they were more aligned with constructivist approach and Knowledge Building. For example, while asked to describe their previous and current teaching practices, Cindy mentioned: "*[before] We[I] wanted students to participate and to answer questions. But I think, after the workshop you[I] realize that it's actually better if you[I] ….[encourage] students to think on their own and come up with their own questions".* This excerpt suggested Cindy has just started to realize the importance of students' questions in learning. Before it was mainly her asking questions, and now she planned to give more agency to students and encourage them to ask questions. Another participant (Hugo) mentioned how the KBPD has transformed him from merely one-way lecturing to providing students with opportunities to learn from each other: "*You know. We just teach, teach and tell, tell and lecture, lecture… I think being students they have to rely on whatever is given… but with this new methodology in place, the students not only learn from me but also from other students. So they sort of inevitably expand their sources and their levels of information that they can receive...*"

For participants who have been using constructivist approaches in their classes, they have even further deepened their understanding of constructivism and knowledge building. For example, one law lecturer mentioned that while he learned about the principle of "authentic problem", his immediate thought was that he had been using it in his classroom as they had lots of authentic law cases. Later he was questioning himself, "*the problem is very authentic but do the students see that it is authentic*". Soon he started to realize that if students could come out with problems they have seen or experienced, it would be even more authentic.

Discussion and conclusion

This study provided some preliminary insights about the impact of designed KBPD on university instructors' conceptions and perceived teaching practices. Previous studies that examined the role of KB in teacher learning mainly focused on teachers' online discourse (e.g., Chai & Tan, 2009; Hong & Chai, 2017). Our study extended previous studies by focusing on examining the design of PD on Knowledge Building and its impact. These university instructors are working adults who mingle between work and life and have various responsibilities and commitments. They usually have limited time for continual professional development. Our study showed the possibility of enhancing their conceptions and perceived teaching practices with three intensive KBPD sessions across one month.

Even though our PD focused on Knowledge Building, each participant seemed to have their own pace and their own ways of moving towards Knowledge Building. While their changes were not huge, we still regard the results as quite promising as they only went through a short intervention. As mentioned, this is a work-in-progress research project. Moving forward, we will further examine these instructors' learning process (e.g., online and classroom dynamics), to unpack how their change took place and how the designed learning environment had facilitated their change.

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What If Interaction Fails?
A Comparison of a Virtual and a Physical Learning Environment for Learning About Areas of Parallelograms

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Abstract: In what ways do virtual and physical interactive learning environments differ, what type of affordances or constraints may affect the use of them, and might this use influence learning and understanding? To address these questions, a physical material, designed to teach areas of parallelograms, was translated into an application with virtual manipulatives. The material (a virtual/physical frame and a virtual/physical deck of cards) was tested on 71 adults with different levels of prior knowledge in geometry. The participants followed instructions and performed exercises during a 15-30-minute session and thereafter took a test. The results show that many novices failed with one specific virtual interaction, which in turn had a significant negative effect on their learning outcomes. The findings also indicate that a material's effectiveness may not necessarily depend on if it's virtual or physical, but instead on the learner's prerequisites to use it and succeed with critical actions.

Introduction

Over recent years, and especially during the Covid-19-panedmic, there has been a rapid increase in virtual learning environments. But despite the perceived overall potential of such tools, their effect on learning is still unclear (Rau, 2020; Stull, 2013). Apparently, which material is most appropriate for learning depends not only on the medium itself, but also on the academic or work-related subject, the specific design, its content, and so on. Here, digital tools can afford valuable qualities, visualizing attributes and relations that are hard to perceive in reality, but also constraints, where irrelevant aspects of the real world (color, texture, size etc.) may be filtered out. At the same time, by digitalizing concrete artefacts, some properties (weight, force, dimensions, and so on) are infallibly lost. This changes the prerequisites for perception, interaction, and knowledge building.

A specific type of learning material is so-called *instructional manipulatives,* often used in STEM education (Pouw et al., 2014; Rau, 2020; Stull, 2013). Even if such material often is concrete, some researchers claim that it is not the actual *physicality* of these manipulatives that is important, but the possibility to interact with representations in a meaningful way (se for instance Sarama & Clements, 2009). However, with a more embedded perspective on cognition and learning (Kirsh, 2010; Pouw et al., 2014; Sawyer & Greeno, 2009), we may argue that physical manipulation offers a perceptual richness that not only may off-load working memory but also strengthen multimodal memory traces – all important aspects when we are trying to learn.

In this experiment, we have chosen to study understanding of geometry – an important subject where learners develop a series of skills, such as spatial reasoning, logical argumentation and proof (Battista, 2007; Jones & Tsekaki, 2016). School geometry is often taught by letting students interpret, measure, and draw standard figures with basic tools (pen, paper, ruler, compass, protractor). But, as several theorists and researchers have pointed out (Battista, 2007; Leontiev, 1978; Piaget & Inhelder, 1945), reshaping and reinterpreting geometrical objects may also be fruitful for learning. And since geometry – or at least Euclidian geometry – is profoundly anchored in our physical and spatial reality, one might expect that this subject would benefit from manipulating this reality (or virtual copies of it).

Being interested in how the understanding of geometrical relations can be mediated through transformations of a structured material, Sayeki and colleagues (1991) tested a method for teaching middle-school students about areas of parallelograms. In this study, students worked during 5-6 lessons with two manipulatives: a tile of paper sheets and a paper frame, reshaping them into different parallel figures. The students hereby learnt that the formula for the area of a parallelogram was the same as for the area of a rectangle (that is, the base times the height). This teaching method was concluded to be very effective, leading to a deep understanding of areas of parallelograms with different shapes (ibid.). A question that arises, in the present era of digitalization, is if this kind of manipulatives could be transformed into virtual ones without losing the supportive effect with respect to the learner's geometrical comprehension. Subsequently, the main goal of the present study was to evaluate such a transformation, by formulating the following research questions: i) Does the interaction with physical and virtual manipulatives, aimed to teach about areas of parallelograms, differ? In what way? ii) Do the materials mediate learning and conceptual understanding of the geometrical principle that is being taught? And does one material succeed better in doing so?

Method

The research questions were addressed by setting up an experiment with two variants of a stimulus – one physical and one virtual – inspired by Sayeki et al's (1999) material described above. The GUI was tested on a Swedish 6th grade in fall 2020 with interesting findings (Ternblad, 2022). However, due to the Covid19-pandemic, no visits at schools were allowed after this pilot. We therefore decided to address a broader adult population and to conduct the study in a controlled laboratory setting – well aware of the risk with attracting participants with too much prior knowledge. But, even if the concept of area often is taught as early as elementary school, many adults seem to struggle with understanding basic geometrical rules (Ojose, 2011). In addition, studies on adults' geometric knowledge are rare, and exactly how well these skills are preserved later in life is not well known (ibid.). Hence, studying this target group could also be of interest, even if the original material was designed for younger students.

Materials

In the physical condition, the participants used a concrete material (Figure 1) together with written instructions on paper and a set of papers with the correct answers. The participants started with interacting with the deck of cards, shaping different figures, drawing two-dimensional pictures, answering questions and correcting them. They were then given a frame with articulated corners with the same base as the cards but a bigger height. The participants inserted the cards inside the frame and were asked if they thought it would be possible to tilt the frame so that the cards would fill it. After guessing, they were instructed to try it out. The lesson ended with more questions regarding the properties of the frame and the deck of cards and how to calculate areas of parallel figures.

In the virtual condition, the application consisted of a two-dimensional digitized version of the card-and-frame-materials described above (see Figure 1), specifically designed for this project. The test persons interacted with the virtual frame and the virtual deck of cards, saving the figures on the screen. They completed the same exercises and answered the same questions as in the physical condition but received immediate automated feedback (right/wrong).

Figure 1

Presentation of the physical material (left) and the virtual interface (right).

Do you think it it would be possible to tilt the frame so that the cards would fill it entirely?

Participants and procedure

Participants were recruited online, where the experiment was described in loose terms without any references to geometry and mathematics (trying to avoid scaring people off). All participants filled in an informed consent at arrival, before taking part in the study, but after being informed about its specific content (i. e. geometry calculations). The entire experiment contained 4 parts: a pretest, a session with the learning material, a post test, and a brief interview. The participants interacted with the material at their own pace. Hence, the time for the procedure varied between 40 and 60 minutes depending on the participant's interest, carefulness, and expertise.

Pre- and posttest

All participants conducted a pre-test with questions on formulas for standard figures as well as questions aiming to assess their overall geometrical understanding, such as "Is it possible for two rectangles to have the same area but different perimeters?". The post-test contained area calculations for parallel figures (64%), checks for over-generalization (18%), and questions on how a frame – slightly different from the one in the exercises – could be tilted (18%).

Data gathering

The experiment was conducted from February to September 2021 in Sweden, during the Covid-19-pandemic. At this time, all experiments had to be conducted with only one test person and one researcher present. No body-mounted equipment was allowed, and the researcher and participant had to maintain a minimum distance of 2 meters. Since the screen activities in the virtual condition were impossible to observe from where the researcher was seated, these participants were told to speak out if they had any problems with the virtual interaction. The observations in the physical condition were simplified to a hands-on-protocol, writing down time slots (minutes) for different tasks, number and type of interactions etc. In the virtual condition, all screen activities were recorded.

Results

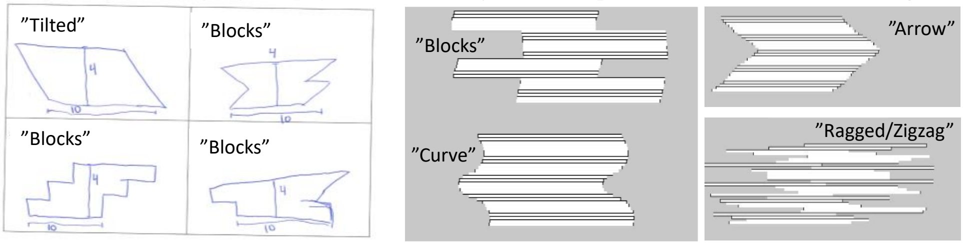
In total, 71 test persons (31 males and 40 females), with an age between 20 and 50 years (*median* = 35) participated in the study. No data had to be excluded. The result on the pre-test for the virtual condition were normally distributed, as per Shapiro-Wilk's test ($W = .95$, $p = .14$), but the result for the physical condition was not ($W = .86$, $p < .001$). The physical group (N=36, *mean* = .75, *median* = .83, SD = .25) also contained more participants with higher scores than the virtual group (N=35, *mean* = .72, *median* = .75, SD = .17). However, a Mann-Whitney's U-test revealed no significant difference between conditions ($W = 515$, $p = .21$).

Interactions with the deck of cards

The interactions differed between conditions in several ways. The participants in the physical condition produced fewer shapes with the deck of cards (N=36, *mean* = 4.7, *median* = 4) than the participants in the virtual condition (N=35, *mean* = 6.0, *median* = 5). The number of shapes for the virtual condition were close to normally distributed, as per Shapiro-Wilk's test ($W = .94$, $p = .07$), while those for the physical condition were not ($W = .89$, $p < .01$). A Mann-Whitney's U-test revealed a minor but still significant difference between conditions ($W = 825$, $p < .05$). In addition, the two conditions resulted in slightly different types of figures, and not all drawings of the physical deck of cards were perfect (see Figure 2).

Figure 2

Examples of drawings of the physical cards (left) and shapes with the virtual cards (right).



Interactions with the frame (and cards and frame together)

When analyzing the screen activities, it became clear that several participants in the virtual condition had problems with interacting with the frame, and in some cases, they gave up tilting it. This behavior was even more articulated when the virtual deck of cards was inserted into the virtual frame, and some participants treated the partly filled frame as a rigid object. In contrast, the physical group interacted with the frame very easily, and often pressed it quite far down, both when it was empty and when the cards were in it.

In sum, 40% of the participants in the virtual condition failed with properly tilting the frame and cards together, compared to 8% in the physical condition. A chi-square test of independence revealed a significant relationship between a successful tilt and condition: $\chi^2(1, N_{Dig,} = 35, N_{Phys} = 36) = 9.8, p < .01$. When looking at the participants failing with the tilt (or choosing not to perform it properly), these had a pre-test score on 0.63 (on average). This is clearly below the mean value for pre-test scores in both conditions.

Result on post-test

The result on the post-test was, as per Shapiro-Wilk's test, barely normally distributed for the virtual condition ($W = .95$, $p = .13$), but not for the physical condition ($W = .87$, $p < .001$). And even if the proportion of correct answers were slightly higher in the physical group (N=36, *Mean* = .80, SD = .19) than in the virtual one (N=35, *Mean* = .71, SD = .20), a Mann-Whitney's U-test revealed no significant difference between conditions ($W = 471$, $p = .07$).

To investigate if the performed interactions and/or the pre-test scores could have had an impact on the result, the following independent variables were used to formulate a linear regression model with post-test scores (*PostScore*) as dependent variable: Pre-test scores (*PreScore*), physical or virtual condition (*Cnd*), number of interactions with cards (*CardInt*), successful tilt of frame and cards together (*CardFrame*), as well as interaction effects between *Cnd*, *CardFrame* and *PreScore*. The best linear regression model was then fitted to the data set in a step-wise-step up procedure and resulted in the following: $PostScore = 0.33 + 0.44 \times PreScore + 0.15 \times CardFrame$. The overall model was statistically significant, but had a weak fit ($R^2 = .39$, $F(2, 68) = 21.4$, $p < .001$). Apparently, to succeed on the post-test, the participants had to i) have enough prior knowledge in geometry, ii) succeed with tilting the frame and cards together. If not, they learned less about areas of parallelograms during the session.

Discussion

The goal with the present study was to test the hypothesis that a virtual and a physical material – designed to mediate the understanding of the areas of parallelograms – would lead to different learning outcomes. We based this idea on an embedded perspective on cognition and learning, claiming that multimodal actions in the world may off-load cognition (Kirsh, 2010), as well as facilitate the understanding of abstract concepts (Pouw et al., 2014). Consequently, different types of interfaces could, due to different constraints and affordances, make the learner reshape the materials in different ways, but also give him/her different perceptual input from the materials themselves. Both these aspects might affect cognition and learning.

In this particular case, some of the virtual interactions differed from the physical ones, and several participants – significantly more so in the virtual condition – failed with tilting the frame and cards together. Such unsuccessful interactions had a negative impact on the participants' understanding of parallelograms and how to calculate them. The difficulties with tilting the virtual frame were primarily due to flaws in the design of the virtual interface, but a lack of prior knowledge in geometry also seemed to have an influence. Still, these failed interactions led to insights about how certain manipulations of a material may have a strong impact on the understanding of a concept, and thereby overshadow the significance of other variables – such as the number of shapes created with the deck of cards and the concreteness of the material as such (virtual or physical).

According to theories on embodied cognition, multimodal perceptual traces (including sensory input, motor schemas and body posture etc.) constitute core entities of human thinking and understanding. However, it might be the case, that the main function of such processes is to facilitate interaction, not the mere perception per se. The conclusion that the actual physicality of a material might be less important than its manipulability is in line with previous studies (Sarama & Clements, 2009; Stull, 2013). In the study by Stull et al. (2013), however, the lack of constraints in the physical condition (compared to the virtual one) lead to less learning gains. Thus, exactly when and how different affordances may support learning ought to be further investigated.

It also appears as if the interactions with the frame (and the frame and cards together) functioned as a necessary *complement* to the interactions with the deck of cards alone, giving the learner an additional perspective on parallelograms. This highlights the value of using more than one representation for describing the same concept – which is in line with theories on the value of multiple analogies (Gick & Holyoak, 1983). This would be of interest to study in more detail too. Finally, the results of this study reveal learning as a multifaceted process. Hence, research scrutinizing the use of instructional manipulatives could not only teach us more about how to design and utilize interactive learning environments, but also provide insights about human cognition as a whole.

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Taking and Getting Perspectives on Controversial Topics: How Does It Change Attitudes and Affect Learning?

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Abstract: Scenarios of argumentative knowledge construction often challenge learners to argue for perspectives dissonant to their own and are geared to prepare learners for debating divisive topics on text-based social media. Perspective-related approaches that aim to evoke empathy for the other side of the debate have a potential impact on learning and on attitudes in such scenarios. With this 2×2-study ($N = 421$), we investigate the near and far-transfer impact and interaction of perspective-getting (with vs. without) and perspective-taking (with vs. without), in a text-based medium, on subjective learning gains, argument elaboration, attitude change, speciesism value, health and environmental beliefs, as well as attitudes towards outgroups and towards other eating habits. Results show significant main effects of perspective-taking for attitude change, self-reported learning, and argument elaboration. No effect of perspective-getting or interaction effects were found.

Controversial topics and attitude change in education

Socio-scientific topics of interest are often controversial and society tends to be divided on them (Kauppi & Drerup, 2021). Present days' controversies are, for instance, the need for vaccination, climate change, use of nuclear power, the right to abortion, immigration policies, or vegetarian eating habits – the topic of the study at hand. These rich debates find a place in informal as well as in formal civic education, i.e., in school curricula within deliberative democracies (Hess & McAvoy, 2014; Oulton et al., 2004). Argumentation practices have been found to not only facilitate comprehension, but also promote epistemic growth, conceptual change, and attitude development on these debates (Chinn et al., 2021; Valladares, 2022; Vosniadou, 2012). Promoting argumentation around controversial topics can be relevant for fighting misinformation, avoiding oversimplification of complex issues, and promoting an open frame of mind that allows for productive outcomes from debating them.

In persuasive domains, some strategies have been devised for changing strong attitudes. Dual-mode processing models of persuasion propose that the receivers of a persuasive message process information in differently engaged ways (Chaiken, 1980; Petty & Cacioppo, 1986). However, research done in the context of strong attitudes has shown that interventions aiming at attitudinal change have often limited impact or are short-lived (Paluck et al., 2021). Recently, there is evidence showing the efficacy of *deep canvassing* and certain perspective-related narratives in facilitating attitude change with a more durable impact (Kalla & Broockman, 2021).

Deep canvassing and perspective-related strategies

Since the beginning of the 2000s, a group of activists, especially in the US, started experimenting with a new approach to political canvassing that is now being termed *deep canvassing*. Deep canvassing emphasizes dialogic, non-judgmental conversations, sharing different perspectives on life (Demetrious, 2022). It has been used for fostering open discussions on different controversial topics and it became more salient in the context of impacting exclusionary and discriminatory attitudes, such as intergroup prejudices, and transgender rights.

Deep canvassing employs different perspective-related narrative strategies, among them *traditional perspective-taking* and *perspective-getting.*

Traditional perspective-taking involves actively imagining oneself in the place of another. Here, one creates a narrative about someone else's experiences, trying to go through the story or event as if one were the other person – usually an outgroup. Studies on perspective-taking have shown that perspective-takers are likely to manifest empathy and feel emotions that resembled those of the targets, which is also referred to as self-other merging (Todd & Galinsky, 2014). Its effectiveness in persuasive contexts has been investigated, with mixed results regarding attitude change – sometimes working, sometimes not, sometimes even backfiring (Galinsky & Moskowitz, 2000; Skorinko & Sinclair, 2013).

Perspective-getting is defined as listening to or reading about someone else's experience, without the need to imagine oneself in the place of the other. Being exposed to one individual's experience, in contrast to a generalized experience from a group, was also found to promote reactive empathy (Lee & Feeley, 2016; Slovic, 2010). This is a more passive exercise in comparison to the other narrative strategies, and less active processing can result in more short-lived attitudinal changes. However, recent studies suggest that perspective-getting alone, rather than the full set of deep canvassing elements, has a consistent and relatively durable impact on attitudes (Kalla & Brookman, 2021).

This present study serves to investigate the impact of these two strategies, not only on attitudes, but also on learning, specifically in a text-based online environment (differently from deep canvassing's face-to-face conversational settings). Considering the context of an activity of reading and writing arguments, our main research question then focuses on the extent to which perspective-getting (with vs. without), perspective-taking (with vs. without), and their combination have near- and far-transfer influence on a) subjective learning gains, b) attitude change, c) elaboration of arguments, d) speciesism value, health and environmental beliefs, e) attitudes towards outgroups and f) towards other eating habits.

Methods

Study design, procedure, and participants

To test the influence of the perspective-related strategies on attitudes towards (vegetarian) eating habits, we designed a 2×2 study with the factors *perspective-getting* (with vs. without) and *perspective-taking* (with vs. without).

The sampled population consisted of 421 participants (54.2% female), native English speakers with a mean age of 45.2 (SD = 10.9). Their educational backgrounds were as follows: 25.5% primary and secondary education, 18.3 vocational higher education degree, 45.2% university bachelor's degree, and 11% master's and PhD degrees. The majority (92.1%) reported eating meat. Time on task was used as a criterium for exclusion, and accordingly, 43 participants were excluded since they finished the study in less than 10 minutes – a threshold established using pilot data.

Procedure

The current study involved two stages, separated by a gap of 5 weeks. In the first stage, the participants first filled out a pre-questionnaire with demographics, their eating habit, and the attitude-related, value and beliefs instruments. Then they got one counter-attitudinal argument to read, i.e., participants reporting to be vegetarians would be confronted with reasons in support of a meat-including diet and vice versa (with or without perspective-getting). After which they were asked to formulate an argument (with or without perspective-taking). The number of words was limited by the system (min. of 100, max. 500 words). Following this writing activity, participants filled out a post-questionnaire consisting in the self-reported learning and the attitude-change instruments.

After 5 weeks, the participants were again surveyed for their attitudes, values, and beliefs, and were asked to produce a text which would summarize the eating/not eating meat issue.

Perspective-getting and perspective-taking

The argument presented to the participants consisted of 3 main reasons, preceded or not by a personal, emotional narrative for *perspective-getting*. Subsequently, participants were asked to construct an argument consonant or dissonant with their own attitude for *perspective-taking*. Participants were randomly assigned to the four experimental conditions.

Self-assessed learning was measured by asking how much the participant considered to have learned on a scale from 0 to 100. With a scale of four items ($\alpha = .87$), measured in a 7-point Likert scale, we assessed attitude change, i.e., how much the participant considered to have changed attitudes related to the topic after the near-transfer reading and writing exercises. The behavior-change intention scale comprised of 5 items, administered before the intervention ($\alpha = .78$).

Results

Near-transfer effects on attitude change and self-reported learning

A multivariate analysis of covariance was conducted to assess significant differences in the linear combination of *attitude change scores* and *self-stated learning scores* between the levels of *perspective-taking* and *perspective-getting* after controlling for *behavior-change intention*.

The multivariate model showed a significant effect of perspective taking, $p = .008$, $\eta^2_{\mathrm{p}} = 0.02$. The covariate, behavior-change intention, was also significantly related to the dependent variables with a large effect size, $p < .001$, $\eta^2_{\mathrm{p}} = 0.24$. No statistically significant effects were found for perspective-getting, nor the interaction of perspective-taking and perspective-getting.

Attitude change

Regarding attitude change, no significant effect was found for perspective-getting nor for the interaction of perspective-taking and perspective-getting. The main effect for perspective-taking reached statistical significance showing a small effect size, $F(2, 414) = 9.07$, $p = .003$, $\eta^2_{\text{p}} = 0.02$.

Self-reported learning

Regarding self-reported learning, no significant main effect was detected for perspective-getting nor for interactions. The main effect for perspective-taking reached statistical significance showing a small effect size, $F(2, 414) = 5.63$, $p = .018$, $\eta^2_{\text{p}} = 0.01$.

Far-transfer effects on attitudes, values, and beliefs

A mixed model multivariate analysis of covariance was conducted to determine whether significant differences exist among the two time points for the targeted variables (beliefs on environment and health, speciesism values, and attitudes towards outgroups and towards other eating habits) between the levels of perspective-taking and perspective-getting after controlling for behavior-change intention.

No main effect of perspective-taking and perspective-getting was observed in the 5-week period for any of the dependent variables. The main effect for time in the model was significant $F(1, 228) = 4.04$, $p = .002$, , $\eta_p^2 = .081$, indicating there were significant positive differences (t2-t1) in pro-vegetarianism health beliefs $F(1, 232) = 12.148$, $p < .001$, $\eta_p^2 = .05$, and negative differences in attitudes towards other eating habits, $F(1, 232) = 4.373$, $p = .038$, $\eta_p^2 = .02$. (See Figure 2). No time-related effects were detected in the other variables, speciesism value, environment beliefs, and attitudes toward outgroups.

Effect of perspective strategies on argument elaboration

Argument elaboration was measured by counting the number of words in the participants' near- and far-transfer arguments, controlling for interest in the topic, which was measured by one item: "How much interest do you have in the debate of consuming vs. not consuming meat?"

Near-transfer

No significant effect was found for perspective-getting nor for the interaction of perspective-taking and perspective-getting. There was a significant main effect for perspective-taking, so that participants in the perspective-taking condition wrote less than participants without perspective-taking $F(2, 414) = 4.02$, $p = .046$, $\eta^2_{\text{p}} = 0.01$.

Far-transfer

As in the near-transfer, no significant effects were detected for perspective-getting nor for the interaction of perspective-taking and perspective-getting. The perspective-taking condition again showed to be significantly different, this time with the perspective-taking group writing significantly more than the without perspective-taking participants, $F(1, 228) = 4.46$, $p = .036$, $\eta^2_p = .02$.

Conclusion and discussion

Practices of argumentation that include taking and getting others' perspectives hold an interesting potential for civic education on controversial topics, as it can positively influence learning, as well as changes in attitudes and behaviors. We explored the impact of perspective-taking and perspective-getting in an online argument, which could bring us initial insights on the extent to which these strategies could be applied in formal and informal educational settings.

We had hypothesized that perspective-getting, as operationalized here, could impact the variables of interest, especially those related to attitudes, but it did not show any effect. Perspective-getting's effects may depend on circumstances that contribute to developing empathy for the other side. In this vein, perspective getting seems to strongly build on the face-to-face, dialogic interview situation in deep canvassing. Perspectives may be less easily conveyed in single online arguments.

Perspective-taking, however, showed to be an important element in such a text-based online context. Here operationalized as writing a counter-attitudinal argument, it revealed an impact on attitudes and self-reported learning. More than only reading, having to write the other side's arguments can imply that people, in the process of having to reason and elaborate on them, are led to reflect and engage with those arguments more actively, which could be the cause for the attitude change. This could be explained through the lens of dual process models of persuasion, such as the elaboration likelihood model and the heuristic systematic model (Chaiken, 1980; Petty & Cacioppo, 1986).

Perspective-taking also influenced participants' engagement in writing. Perspective-taking participants wrote less when asked to argue for an opposing side, as hypothesized with people having less arguments for the other side. But perspective-taking participants produced more comprehensive essays in the delayed writing task. Hence, taking perspectives by constructing attitude-dissonant arguments may facilitate comprehension and engagement of learners in reasoning about a controversial topic in the long run. Future research is needed to determine the validity of this claim.

The results on the self-reported learning gains provide first pointers to an untapped potential of perspective-taking for fostering learning in informal online contexts.

The differences in the health-related beliefs as opposed to the attitude towards other eating habits develop in opposite directions. Charity seems to begin at home when it comes to the health benefits of a vegetarian diet, which are being understood and accepted, but dealing with eating habits other than one's own may remain a nuisance.

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Knowing Together With Materials in Collaborative Creative Making

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Abstract: Making is characterized by intricate flow of creative acts that promotes deep investigations and material explorations, inciting meaningful knowledge construction. This paper expands the focus of Making beyond humans; towards material entities, to understand learning by making, and emergent creativity in collaborative networks. In this study, we examine the epistemic aspects of materiality in collaborative creative making, by specifically looking at data from two making contexts: 1) a medical device innovation camp, and 2) a maker activity-centered workshop, as ideas emerge and evolve as makers get involved in design problem-solving scenarios. Our findings suggest that the knowledge-building pursuit in the creative collaborative making is sociomaterially entangled, and shapes the course of subsequent creative actions. The emergent epistemic entities such as shared conceptual and design artifacts conditioned ideation, refinement, and further materialization.

Introduction

Making opens up learning opportunities, unexpected modes of play with material resources and drives creative movements as makers engage in invention projects (Dougherty, 2012). With the flattened ontology where matter is no lesser than humans, making becomes a dynamic exchange of agencies between humans and other-than-human actors, through which learning and creativity emerge (Latour, 1996). When makers come together and utilize the available material resources, knowledge transfer happens via building shared understanding and translating abstract ideas into various forms as visual, conceptual, and material artifacts. These shared design artifacts can serve as the anchor points around which further refinement in the pursuit of inquiry and collaborative processes takes place (Knorr Cetina, 2001). Also, the creativity emerging out of these sociomaterial encounters cannot be reduced to individualistic accounts but distributed across social, material, and temporal dimensions of the situated context (Sawyer & Dezutter, 2009). Prior studies on knowledge-building postulate ideas and conceptual artifacts as objects that materialize in a world where knowledge is shared and inspected by the community (Scardamalia & Bereiter, 2014). In making situations, makers approach materials with preconceived material properties, and materials 'talk back' to makers (Schön, 1983). Materials cannot be considered as dormant entities (Pickering, 1993), not only responding to the actions performed by makers but also directing the makers to creative actions. Even though researchers have argued the centrality of tools, artifacts, and the associated embedded knowledge to thought and action, characteristics of these entities are obscure and complex (Engeström & Blackler, 2005). The materialist and posthuman frameworks can be used to look into learner-learning environment entanglements which traverse the human and other-than-human entities of the situated context in a non-hierarchical fashion (Barad, 2003).

In this paper, we take an *epistemic standpoint to look at how sociomaterial entanglements influence collaborative creative making*, by specifically looking at data from two collaborative making contexts: 1) a medical device innovation camp, 2) a maker activity-centered workshop, as ideas emerge and evolve as makers engaged in design problem-solving scenarios. We consider making as a collaborative practice between human and nonhuman entities and position the related creative aspects as emergent (Sawyer & Dezutter, 2009).

Methods

For this study, we looked at two collaborative making contexts: 1) a medical device innovation camp, 2) a maker activity-centered workshop. The five-day medical device innovation camp was organized by the Biomedical Engineering & Technology Incubation Centre at a leading engineering institute in India. The organizers facilitated team formation to form a total of 16 teams around a predefined set of twenty medical problems generated by multiple doctors. The audio and video data along with field notes and observation logs for day 1 and day 2, of two teams - Team A and Team B- formed the data set from this setting, as the rest of the data was not available due to hard-disk storage failure. Team A consisted of a doctor- Subject Matter Expert (SME) (male), designer (male), mechanical engineer- M.E (male), and an electrical & electronics engineer- E & E. Engg (female). Team B consisted of a doctor - Subject Matter Expert (SME) (male), designer (male), software engineer (male), and market expert (male). Teams were provided with knives, scissors, screwdrivers, hand drill, pillar drill, pens, pencils, rulers, drawing chart papers, plastic sheets, tapes, glue, sticky notes, breadboard, LEDs, jump wires, battery.

The one-day maker activity-centered workshop was organized at a leading engineering institute in India. The participants comprised eight second-year mechanical engineering undergraduate students who responded to an open invitation. Four teams were formed based on the order of their response with each team consisting of two members. After the introductory session, participants were given a design challenge to conceptualize and model a semi-automated assembly line with static and dynamic robots using the resources available in the makerspace. A facilitator was present during the making sessions to support the teams with technical assistance. We followed the making activities of teams- P, Q, R, and S. Team P consisted of one female student (G1) and one male student (B1).Two male students (B2, B3) constituted Team Q, Team R had two male students (B4, B5) and Team S with two male students (B6, B7). The workshop was conducted at a makerspace with a work table, a whiteboard, a computer, and a desktop FDM 3D printer. The teams had access to two Lego Mindstorms EV3 kits, a 3D printing pen, knives, scissors, screwdrivers, cardboards, pens, pencils, chopsticks, play-doh modeling compounds, cable ties, tapes, glue, styrofoam sheets, a box with used cables, wires, defective electronic devices like earphones.

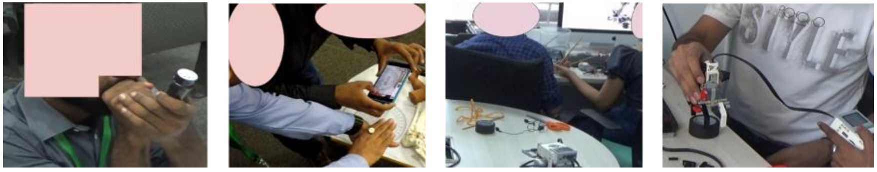
We used video data along with transcripts and field notes to unpack the moment-by-moment emergent actions during collaborative making by following the case study methodology (Merriam, 2007). We began the analysis by content logging and segmenting the data into phases of the making process - ideating, information seeking, sketching, prototyping, testing, and refining ideas, to get an overall understanding. We used the content logs to conduct interaction analysis (Jordan & Henderson, 1995) looking at talk, use of artifacts and technologies, turn-taking and participation structures focusing on maker-material agency (Svihla et al., 2020). The unit of analysis is idea units - episodes during various making phases bounded by idea entry, evolution, and exit.

Findings

We found that the making episodes were constitutively entangled with human and non-human elements of the situated making contexts. We present few representative instances from the making contexts to illustrate how different epistemic entities emerge and how ideas get shaped during the course of making, driving creative actions.

Figure 1

Designer testing PVC pipe prototype (a), Designer measuring angular values using the mobile prototype (b), Team P checking the Lego Mindstorms EV3 manual (c), Team Q testing gripper (d)



(a) (b.) (c) (d)

Case 1: Medical device innovation camp

Team A worked on developing solutions to remove the sputum from patients' respiratory systems. The particular episode discussed below is from Team A's prototyping phase where makers are concretizing the initial ideas of building a blowing unit.

SME: We use similar things like spirometer.. you know.. to check the patient's breathing .. I will show you something that I made.. [takes the PVC pipe prototype]..
Designer: How did you make this? [inspects the PVC pipe prototype]
SME: [Points to PVC pipe prototype] it's just a PVC pipe bent.. and this is a PVC pipe end cup. Then drilled a bigger hole in the end cap over which the marble is resting..
Designer: [Blows through the PVC pipe prototype] I can feel a resistance .. kind of vibrations
SME: Yeah.. these vibrations should go inside the lungs.. patients'..
M.E: Kind of.. maybe perforated balloons can be added at the end for more vibrations
Designer: Can I use something like .. placing a vibrating belt on my chest .. see same principle

In the above excerpt, the SME shared his experience with similar existing devices and introduced a crude PVC pipe prototype. As the designer tested the prototype, and experienced resistance against blowing (see Figure 1(a)). The feedback offered by the PVC pipe prototype prompted the makers to think about how the prototype functioned and shaped further questions. The shared understanding of the guiding principles related to air column vibrations developed from SME's inputs and encounters with the prototype, helped the makers to build on the core idea with that of perforated balloons and vibrating chest belts. The instance shows the entanglement of SME's prior experience, features of existing devices, PVC pipe prototype, guiding principles like air column vibrations and resistance in the path of knowledge inquiry, and the moment-to-moment evolution of the collaborative making.

Team B worked on the problem of quantifying the patient's clubfoot deformity, to arrive at a portable measuring system for monitoring the degree of deformity. The SME built an intermediate prototype using a mobile phone, transparent sheet with angular markings and tapes, by which photographs of deformed feet can be taken and processed to get angular measurements. As illustrated below, the prototype became crucial in developing a shared understanding of the guiding principles related to angular measurement. Here, the designer was not convinced by the property of constant angular measurements with heights. But the rest of the team members followed the concept, eventually pushing the designer to test angular measurements (see Figure 1(b)). The designer proceeded with testing, and acknowledged the concept of constant angular measurements with heights. The intermediate prototype thus becomes a shared entity through which the human and other-than-human entities expressed shared agency. The knowing is found to be materially grounded as the conceptual artifacts, material resources and related design artifacts acted as vehicles for the pursuit of knowledge and creative solutions.

Designer: I think we will have angular measurement problems with height..
Market Expert: No.. no, height will not change the angular measurement
Designer: No, the measurements will be different.
SME: Ok.. do one thing, check yourself.
Designer: [Draws an angle on a paper, uses the mobile phone prototype to take readings at different heights]..Yeah, measurements are same.

Case 2: Maker activity-centered workshop

For the design challenge, Team P started with the idea of a static parallel robot to perform the package pickup and place task. The following episode from Team P's prototyping session shows the intertwined states of maker-material elements that determine the making process as the makers attain insights on various design instantiations.

G1: I don't think it will work.. not enough.. support structure.. drop?
B1: Drop?.. mm .. then we will have to check the crane one.. search..
G1: [Opens Lego Mindstorms EV3 Classroom application] there are some models.
B1: Hey.. we can do that [points to serial robot model in the manual]
G1: mm.. but look here [points to manual diagrams].. these got some gear systems.
B1: Yeah.. but we can make these.. [picks up and shows gear parts from kit]
B1: but all these should hold together.. the stability thing
G1: mm.. we can make a bigger base this time.. rectangular ones..

The team tried to materialize the parallel robot idea by combining mundane materials like chopsticks, threads, tapes, and lego parts, but the resultant prototype probed the queries related to structural stability as it continued to break down. The makers were forced to drop the idea, check for alternatives, searched online resources and Lego Mindstorms EV3 construction manuals (see Figure 1(c)). They found a serial robot model in the manual and discussed the adoption of design features, looked at the available resources and gear arrangements by reminding themselves about the structural stability. The episode is an example where material entities resisted makers' actions and pushed the makers to search for other solutions. Initially, the makers didn't take into account the notion of structural stability in building the robot but became cognizant of the same with responses from the prototype.

In Team Q, a static two link serial robot was conceptualized along with a dynamic robot inspired from a forklift. The following episode from Team Q's making session shows how the construction manual and the gripper built, paved the way for evaluating and refining makers' understanding of gear mechanisms. Here, the makers worked on the problem of picking up the package. While testing (see Figure 1(d)), B2 pointed out the malfunctioning of gripper arms. Since B2 followed a few design ideas from the Lego Mindstorms EV3 Classroom manual to build the gripper, the exact functioning know-how of the gear combinations remained hidden. Although the makers had a basic knowledge of gear mechanisms, the incomplete prototype threw questions related to gear combinations, motion transfer and logic in the block program. These questions directed B2 and B3 to closely follow the functioning of gear combinations and links, to get deeper insights and modify the design.

B2: [Points to gripper arms].. not closing enough [gestures gripper arm movements]
B3: [Takes the gripper and inspects] lot of gears.. block program?
B2: Some are from the manual [refers to Lego Mindstorms EV3 Classroom manual]
B3: So.. this gear is connected to..one spur .. and here is the rack, pinion [points to different gear combinations used in the gripper]
B2: Ok.. then the shaft rotates and .. arms open up.
B2: [checks other gears from the kit] I think these can be used [takes larger spur gears]

Discussion and conclusion

We have presented few instances of collaborative making from two making contexts: 1) a medical device innovation camp, and 2) a maker activity-centered workshop, to show the ways in which states of design ideas evolve in relation to the social and material elements of making, focusing on the emergent epistemic entities. While looking at the maker-material encounters, we placed materials as more than dormant entities or mere mediators, and included non-human agencies, which revealed the active role of materiality in creative collaborative making, as various material resources involved in the process influenced the knowledge–building process and the moment-to-moment unfolding of the proceedings. The study highlighted the active roles of human and other-than-human entities in collaborative creative making in the respective contexts, which reiterates the distributed notion of collaborative creative emergences (Sawyer & Dezutter, 2009) The makers and material entities are found to be intertwined in cycles of inquiring, answering, and raising queries as the making progressed (Knorr Cetina, 2001). The material resources acted as springboards in the evolution of ideas and arriving at guidelines, which directed the next course of creative actions. For example, Team A makers' encounters with the PVC pipe prototype lead to the understanding of air column vibrations, and the ensuing generation of connected ideas. The design artifacts played a crucial role in idea stimulation, refinement, and advancement, as the incomplete nature of these entities continued to pose questions for the makers, and augmented shared understanding. For example, the incomplete dynamic robot design that emerged during Team Q's making actions raised questions related to gear combinations and motion transfer. The design artifacts actively helped in settling certain design aspects and transforming others, via temporary instantiations. As the Team B makers engaged with the mobile phone prototype, the concepts of angular measurements and the experimentations contributed to the realization of portable measuring devices. These material entities are in a constant relational flow of changes and can be considered to have an unfolding ontology. Notably, material references, metaphors, and features of existing devices came into play as makers recalled prior material experiences. SME of Team A recalling his experience with the spirometer and referring to the material features, and B1 of Team P referring to cranes can be pointed as such instances. Although the two settings differed in design challenges, resources available, and participant expertise, we see makers thinking, knowing, and making *together* with the material entities. Further studies are required to expand our understanding related to the sociomaterial entanglement in creative making contexts.

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Mechanistic Reasoning and Ethics of Caring in Engineering Contexts for Educators

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Abstract: Contexts of introductory engineering education hold potential to situate engineering within the cultural and sociotechnical dimensions of being and becoming, thus highlighting the transformative roles of engineering. In this paper, we pursue an articulation of care as a key learning outcome for preservice teachers in their first formal experiences in engineering disciplines. We present two explanatory themes, originating from (1) an extended bridge design task and (2) an investigation of machine learning image recognition processes. In both studies, preservice teachers engage in a process through which mechanistic explanations about sociotechnical systems give rise to an ethic of care (Silvis et al., 2022), narrowing the relational distance among the engineering contexts, themselves, and perceptions of students. We highlight affective connections between undergraduates' experiences in engineering and their trajectories of becoming teachers and explain how mechanistic sensemaking supported articulations of an ethic of caring concerning both engineering and learners.

Introduction

Reasoning about the underlying processes that give rise phenomena—especially in contexts of science and engineering—is often called *mechanistic reasoning* (e.g., Krist et al., 2019; Russ, 2008). In engineering education, learning to reason about systems also requires attention to the social, ethical, and political impacts of engineers' scientific and technological pursuits (Gupta et al., 2019; Philip et al., 2018). As recently argued by McGowan and Bell (2022), learners' critical and affective engagement in studies of sociotechnical phenomena *deepen* science learning opportunities, supporting learning to make sense of "the impacts of engineering and technology on their own communities and everyday lives" (p. 982) while also working toward more socially just futures for the learners themselves and their communities. This is consistent with recent studies of learning that conceive of affective dimensions of learning as a target of instruction (Vea, 2020) and meaningfully enmeshed with other disciplinary goals.

We examine how preservice teachers make sense of mechanistic relationships in both a traditional engineering education context (e.g., a truss bridge design unit) and in reasoning about artificial intelligence (AI) and machine learning. Our inquiry is guided by our desire to understand the relationships among preservice teachers' mechanistic reasoning (e.g., Russ, 2008; Krist et al., 2019) and the development of ethics of care (Farris & Tosun, 2020, Silvis et al., 2022) that impacts their teaching in relation to their students and technologies.

Mechanistic reasoning, modeling, and emotion

Reasoning about mechanism has longstanding attention in the philosophy of science (e.g., Bechtel & Richardson, 2010), in theories of cognition (e.g., Machamer et al., 2000), and in educational research (e.g., Krist et al., 2019). An affordance of mechanistic reasoning as an analytic frame is its fundamental commitment to systems perspectives—that is, the processes that underlie relationships within a system, including how components of one part of a system give rise to emergent behaviors of the system (Bolger et al., 2012; Russ et al., 2008; Machamer et al., 2000). Studies of mechanistic reasoning have often been concerned with ecological systems (e.g., Dickes et al., 2016), kinetic toys (e.g., Wineberg, 2020), and computational models of invisible processes in physical systems (e.g., Jacobson & Wilensky, 2006).

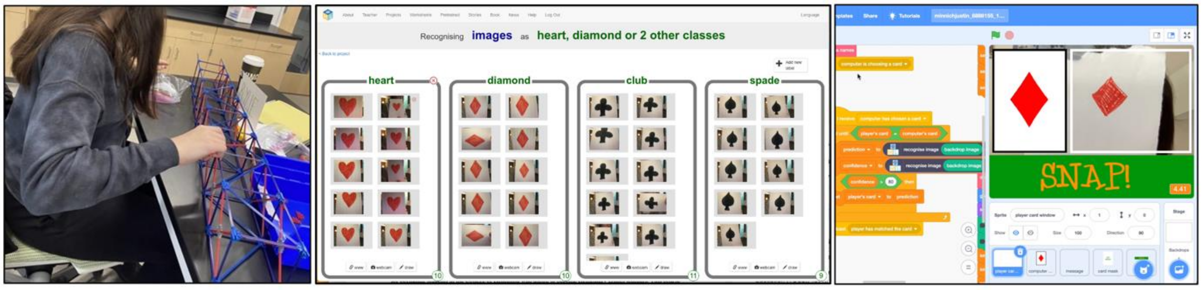
We seek to contribute to a deeper articulation of the connections between sensemaking and the affective and justice-seeking outcomes of that sensemaking, for self and others. In a recent example, McGowan and Bell (2022) illustrate how biology students' systems perspectives and modeling work about climate change and oceanic temperature ultimately supported learners' greater ownership of ecological care. In their study, the affective dimensions arise from figuring out the relationships among factors contributing to the prevalence of disease in sea stars. In our study, we examine a similar pattern with non-science major preservice educators. We ask, "What are the affective entanglements between preservice teachers' sensemaking in engineering contexts and their articulations of the work of teaching engineering?

Learning contexts and analytic approach

We have selected two contrasting disciplinary contexts for preservice teachers: (1) a truss bridge design unit in which students worked in and sustained collaborative teams, and (2) an explanatory modeling unit about image recognition AI systems. We position both as sensemaking in and about engineering contexts, however, the cases are contrasting in terms of the degree to which the societal impacts of the engineered systems were considered by the students. The truss bridge design project was intended to support students in an extended process of redesign around introductory mechanics concepts in a collaborative team, while the social implications of bridge design were given little attention. In contrast, in the AI example, we designed the learning activities to invoke preservice teachers' more examined awareness of AI in everyday life, as most laypeople do not conceptualize their daily interactions with AI in ways that are consistent with the dynamic nature of how those systems operate (Royal Society, 2017; Fiebrink, 2019. We were interested in how the teacher candidates could become more critically aware of applications of machine learning in their everyday lives. For example, we speculated that critical recognition of the unjust failures of AI—such as image recognition tools that consistently fail to recognize photos of dark-skinned people (Metz, 2021)—requires an informed explanation of how these image recognition systems are designed and trained.

Figure 1

(a.) An early iteration of Natalie's group's bridge, (b.)Sample training dataset for the Machine Learning for Kids (Lane, 2021) environment, (c.) Annabel's card suite image recognition game



a. b. c.

Data were collected from two different undergraduate courses within two design-based research studies (Cobb et al., 2003;) The first course is an introductory engineering course for educators—a science content course for beginning students in the College of Education who aspire to become elementary grades teachers. This course focused on the interaction among physical science concepts and engineering design principles and was designed to foster Figueiredo's (2008) four epistemic dimensions of engineering, which position engineering as a social science, basic science, process of design, and a problem-solving process. It included three science content modules (structures, simple machines, and electricity), each of which had an associated engineering design project. All 23 students who completed the class consented to participate in the study. The second course is a science teaching methods course. The methods course is for teacher candidates in their 7th semester of study who are seeking professional teaching certificates for middle level grades and are non-science majors. Data sources include artifacts and assignments teacher candidates produced as part of their coursework and instructor/researcher field notes. The analysis began with the student responses to within key assignments, which were coded using open and axial coding (Strauss & Corbin, 1990) and triangulated with other assignments and researcher notes. We constructed themes from the codes, in relation to the research question and established knowledge (Vaismoradi et al., 2016) related to affective dimensions of learning in engineering contexts.

Thematic analysis

We focus on two outcomes of mechanistic explanations in engineering contexts and their potential entailments for preservice teachers' orientation toward ethics of care as aspects of engineering education:

Theme 1: Participation in iterative engineering design gives rise to empathy

Theme 1 is concerned with empathy for youth's feelings of failure in sustained engineering design projects. In the introductory class bridge design unit, we focus on Natalie, a member of a four-person team that had a particularly challenging time designing a bridge that met the minimum stability criteria. An early iteration of the bridge is shown in Figure 1a. The entire team often stayed after class to continue working on their bridge. In Natalie's bridge design report, she explained that the way her bridge snapped "almost upward when it broke," informed her about the compressive forces acting at the point of failure. She wrote, "Our bridge held half of the necessary weight without bending, so we were very optimistic. We decided that if we added more support to the middle of the bridge (where the force would be pulling it down), we would have a better chance of being able to hold the full amount of weight." Natalie and her teammates were paying attention to the bridge as a system of balanced forces and eventually designed a bridge that met minimum criteria. In her end-of-term reflection, Natalie wrote about how her experiences in the course would become helpful in her future teaching: "I went through the processes that I will be asking them to when I am teaching. I learned the hardships that come out of designing and creating the things we did in this class and I feel as if working through them myself will help me better be able to understand my students or assist them when they face similar issues" [Natalie, Week 15 Reflection]. Across the course, Natalie thinking shifted from an initial emphasis on content knowledge alone (e.g., "... If I could answer some of these questions for children" [Natalie, Week 1 Reflection]) to perceptions of engineering that include supporting students' design process as an emotive process and learning and teaching engineering as emotionally entangled (Farris & Tosun, 2020). This is important in relation to our research question because Natalie made connections between learning explanatory mechanisms in (for example, in stable truss bridge design) though immersion in the design process, and this experience influenced on her thinking about her teaching practice towards understanding and attending to elementary children's emotions about engineering design.

Theme 2: A mechanistic view of training data situates criticality about the social impacts of AI

Theme 2 addresses the teacher candidates' development of a critical consciousness of how bias arises in machine learning systems and the need to design more equitable systems. In the 7th-semester science methods course, several members of the class built an image recognition game called Snap! using an environment called *Machine Learning for Kids* (Lane, 2021, Figure 1b). To create the game, students made hand drawn playing cards based on standard suites (hearts, diamonds, clubs, spades), then used their own drawings as the training data. The game flashes a card for the player to match and times the player as they search for correct card to hold up in front of their computer camera (Figure 1c). Across the students' work, we observed that first-hand experience training a simple image recognition model was very important for understanding how the model recognizes images. Here, we focus on Annabel, who selected this game to use in a lesson planning assignment.

Annabel wrote about the importance of students' experience in trying out their own training data for students' evaluation of their own computational models. She explained that students will be training their models "to guess [the meanings of drawings] based off of their/their partners' drawings. Hopefully, through this process and our discussion, students will be able to understand how computers can learn and be trained to interpret and make guesses [about image data]." She explicitly connected her own experience of reasoning about the system, explaining that she will support students the think about "why some [models] worked better than others" and will "show the positive and negative effects in other aspects of life where computer guessing can be good or harmful."

In her reflection, Annabel wrote that applications of science and technology can be important to students' life and teachers' work because, "Recognizing the potential for models and systems to be better, and diagnosing those problems, is important in the lives of students. I see this concept being used in this activity as they get experience with code, machine learning, and modifying their projects for improvement." [Annabel, Lesson Plan]. In sum, in Annabel's work, her mechanistic reasoning about training in image recognition AI supports her emergent criticality about the impacts of AI and her desire to support students to reason about training processes. She considers how modeling machine learning can support students to better make sense of the biases in machine learning and the broader impacts to sociotechnical and sociopolitical systems in which those systems operate.

Discussion and implications

The university students in our studies encountered their first formal experiences in engineering education in the contexts of teacher preparation. Similar to engineering courses for engineers (Gupta et al., 2019; Philip et al., 2018) students in the College of Education had disciplinarily meaningful affective responses to the technical and sociotechnical implications of engineering, for example, the teacher candidates' own recognition of how machine learning systems perpetuate injustices, and the frustration of balancing unknown compressive and tensile forces in bridge design.

Furthermore, our paper expands existing conceptions of engineering as emotional practice in two ways for contexts of teaching children and youth: Preservice teachers' responses were deeply connected to educational contexts and the work of teaching, and these were emergent from their own intellectual engagement with mechanistic sensemaking processes. Specifically, teacher candidates in the cases reflected on pedagogical impacts of emotive dimensions of engineering: Natalie, while involved in engineering work that had minimal direct implications for society, reflected on how deep participation and frustration in the engineering design process motivated a different kind of empathy for young learners in the process of designing engineered systems. Annabel started from reasoning about patterns in training data as mechanisms that give rise to image recognition in machine learning. She identified how patterns in data inform biases that are built into machine learning systems. In both cases, teacher candidates' experiences within the mechanistic and sociotechnical complexities of engineering—alongside their considerations of the pedagogical dimensions of teaching engineering content—led to expressions of engineering education that were entangled in care for others.

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Examining Mathematical Questioning During Math Walks

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Abstract: This qualitative study examines the use of math walks with middle grade students and adult facilitators at a local zoo. Drawing on situated learning and participation frameworks, we used interaction and stance analysis to compare two contrasting cases: In the first case, the adult chaperone asked more questions and evaluated student responses. In the second case, the adult chaperone intervened less frequently, leaving more room for student discourse. Findings support efforts to design informal math learning activities which amplify student voices, towards increased mathematical interest and learning.

Introduction

Despite the growing popularity of informal STEM learning environments, there is little research about how students learn mathematics in these spaces (Pattison et al., 2017). Additionally, facilitating mathematics learning in informal STEM environments can be challenging. Many adult facilitators do not have formal pedagogical training (Hmelo-Silver & Barrows, 2008) or may have difficulties with recognizing mathematics in informal settings (Peck et al., 2022). Therefore, we aim to investigate how adult facilitators and students collaborate to recognize and discuss mathematics in informal learning environments. To address this, we analyzed video footage of adults and students participating in math walks (Wang et al., 2021) at the City Zoo (a pseudonym). Our research question was: *What are different dynamics for adult-student interactions during informal math activities and what implications do these dynamics have for student learning?* Drawing on interaction analysis (Jordan & Henderson, 1995) and stance analysis (Goodwin, 2007), we identified and analyzed two contrasting cases (Schwartz & Bransford, 1998) to highlight how context and student-adult dynamics shaped the mathematical discussions.

Theoretical and analytical framework

This study is theoretically grounded in situated perspectives on learning, which recognizes that all learning is the development of participation structures specific to the setting, (Greeno, 2006). When considering mathematics, it is important to note that learned participation structures may not be especially useful or appropriate in other settings For example, based on their participation in “school math” students may come to believe that participation in a mathematical activity is constituted by obtaining answers to short, self-contained problems requiring repetitive calculations, with no larger goal or purpose for which the answers have meaning. Authentic participation practices in mathematical activities in real contexts (like designing an animal enclosure for a zoo) may bear little resemblance to how students are used to seeing mathematics in school. We believe the difficulty for students and adults to ‘see’ mathematics and negotiate mathematical meaning together in informal settings stems from this tension. To analytically map this tension, we draw on Goodwin’s (2007) construct of participation frameworks which describe how participants publicly organize conversations through a series of stances. Goodwin describes five stances: instrumental, epistemic, cooperative, affective, and moral. We use Goodwin’s stances to trace how adults and students together recognize and discuss mathematical ideas while participating in math walks. Here we only use the first three stances (instrumental, epistemic, and cooperative), because conversations in our dataset rarely involved affective and moral stances.

Table 1
Interactional Sequences

Stance	Definition	Example
Instrumental	Drawing attention to entities (objects, materials, etc.) that are necessary to complete the in-progress activity	Referring to an object (i.e., video) when posing a question
Epistemic	Positioning in a way that promotes the experience through perceiving or understanding the activity	When students discuss mathematical or science content
Cooperative	Organizing one’s body in the direction toward others, as well as the environment, to sustain the activity	Involving other members in the group during a discussion

Context, data sources, and analysis

We partnered with informal educators from the City Zoo to design three math walks, in various locations within the zoo. These math walks highlighted the mathematics of animal behavior, enclosure size, and coat patterns. We demoed the math walks with 20 middle grade students enrolled in a three-day City Zoo camp. Students were in six groups and paired with one adult. Students explored the City Zoo, participated in math walks, completed worksheets to summarize their thinking, and created their own math walks. Each small group was video recorded by the adult participant, using a hand-held video recording device. We began analyzing the video recordings by creating content logs (Jordan & Henderson, 1995). This allowed us to explore the data at a high-level to scope out patterns in interactions and mathematical questions. We created minute-by-minute content logs which documented the turn taking patterns between adults and students, the artifacts used or things referenced in the physical space (e.g., the worksheet, animals in the zoo), and the types of mathematical questions being asked and answered. At this point, we discovered the prevalence of some adult-driven small group discussions. We marked the content logs where adult questioning was most pronounced and compared the set of interactional sequences. For this manuscript, we selected two interaction sequences from the first day to transcribe, compare, and further analyze. With the two cases in hand, we turned to Goodwin's participation framework (2007) to describe how adults and students go about engaging in the math walk stops. Working line-by-line, we annotated each turn-at-talk as to whether it was an instrumental, epistemic, or cooperative stance. Our annotations described *how* a particular sequence of talk achieved a particular stance. In many cases, participant's talk functioned as more than one of the interactional stances (ex. a turn at talk could be coded as both instrumental and epistemic). In the sections ahead, we synthesize our annotations in order to 're-tell' these conversations, with an eye towards the contextual and interactional features that made these cases different.

Case a: Exploring animal walking patterns

Our first case demonstrates how adults and students reproduced canonical mathematical classroom dynamics. This case involved three students and one adult. All three students were middle grade girls, two of the students were Latina (112 and 111) and one of the students was African American (116). The group of students was led by an adult member of the research team (RR) who was a South Asian man. At the start of the recording, the group was seated in a circle on the floor. The group had just watched a short video which explained the walking pattern of all quadrupedal mammals. The video recording began with RR asking the students what they found interesting about the video. Students 116 and 112 briefly mentioned "the walking patterns" and recalled the numerical code '3-1-4-2' which described the order in which legs strike the ground. RR prompted 116 - who was holding the clipboard - to record her group mates' answers. After a short silence from the group, RR began questioning the students to clarify what was interesting about animal walking patterns (below).

Table 2
Transcript from Case A

Line	Participant	Talk
A.1	RR	So for this one you could - like how else would you describe what's being answered though? The video is about walking patterns but
A.2	116	Like how the walking patterns work
A.3	RR	But we're trying to find a pattern between which animals
A.4	112	All of them?
A.5	RR	or not all animals, but what type of animals?
A.6	112/111	(simultaneously) mammals
A.7	RR	Mammals, but
A.8	112	It's called something I remember at the beginning.
A.9	RR	So, I know it's a complicated word.
A.10	112	(It is)
A.11	RR	(But) what is it? What's like a dumb like definition of that word?
A.12	111	Animals that walk on four legs
A.13	RR	Yeah, yeah, there you go. four legged animals.
A.14	116	Quad - quad - quadra
A.15	RR	quadrupeds

RR breaks the silence by asking the students "how else would you describe what's being answered though" (line A.1). Instrumentally, he drew students' attention back to the video. Cooperatively he faced the entire group, panning the camera back and forth to see all the students. Epistemically he signaled that students' initial interest in 'animal walking patterns' was not enough. Then, RR and the students engaged in a series of back-and-forth questions and responses until they had reached the correct answer - one that RR determined was sufficient. Student 116 took up RR's cooperative and epistemic stance, responded first, and said "like how the walking patterns *work*" (Line A.2). RR ignored her epistemic clarification (work), and instead posed a new question: "but we're trying to find a pattern between which animals?" (Line A.3). We interpreted this new question as both an epistemic stance (redirecting what types of mathematical questions should be asked) and a new cooperative stance (continuing to ask students to provide him answers - just not the one 116 had provided). RR led the students, through iterative questioning, to the scientific term 'quadruped.' The discussion ended when RR made two final statements. First, he made an epistemic stance by summarizing their conversation: "So it's trying to find a walking pattern between quadrupeds right - and then we we figured out that they all walked the same across - every single animal." Then, he made an instrumental stance by instructing student 111 to complete the worksheet: "you can - you can just write that - what are walking patterns? Or how do you - how do four legged animals walk - right?"

We interpreted this sequence as a reproduction of canonical mathematical classroom dynamics. The mathematical discussion was epistemically and cooperatively led by RR. Students participated only by taking up RR's cooperative stance and attempting to provide correct answers. When students did not provide correct answers, they were either ignored (as with 116) or redirected with a new question (as with A.10). Furthermore, instrumental stances were limited to references to either the worksheet or the video.

Case b: Exploring giraffe coat patterns

Our second case demonstrated how adults and students engage in a more distributed dynamics relations and student-led talk. This case involved three students and one adult. All three students were middle grade boys, two of the students identified as multi-racial (117 and 118) and one identified as Latino (120). The group was led by an adult member of the research team (AM) who was a white man. The students watched a short video about giraffe's coat patterns. The recording began with the AM asking the students to recall the mathematical content from the video. Student 118 mentions that "you can measure the patterns of a giraffe." From there, Student 117 poses a question after observing the giraffe's behavior (Table 3).

Table 3
Transcript from Case B

Line	Participant	Talk
B.1	AM	okay, we can make a question or that hold that thought okay, let's think about that. So, what else from the video part?
B.2	118	Um that oh that you can make pattern that you can make pattern that well that you can **measure** the patterns of a giraffe
B.3	117	Why are their tongues so long?
B.4	AM	Why do you think so
B.5	118	to get the grass from the trees to get from the high trees (jump)
B.6	AM	What did you? What can you summarize what the video is saying?
B.7	117	Basically, that giraffes' patterns are math mathematical that you can solve them
B.8	120	They have different types of patterns.
B.9	117	Yeah, they have big patterns and small patterns
B.10	120	and different types of shapes
B.11	AM	OK
B.12	117	like squares, triangles, circles.
B.13	AM	Yeah
B.14	117	they can come in different sizes and different shapes.
B.15	AM	OK
B.16	117	Like that one has a lighter in different colors. There's a lighter one and that one has a darker one
B.17	AM	Yeah,
B.18	117	and she has hers a little bit more space a little bit more smaller. Like we're closing, like closer, like not so far away.
B.19	AM	Yeah, that's a good observation

The sequence this case follows is the progression of the conversation related to math patterns. AM begins the discussion in line B.1 by taking an instrumental stance by referring back to the video, epistemic stance by indirectly considering the mathematical concepts from the video, and a cooperative stance by encouraging all of the students to consider the question. Unlike in the first case, the adult facilitator allows the students to pose their own questions based on their observations from the giraffe exhibit and responds in an open-ended manner. In line B.3, student 117 notices the giraffes eating a lettuce leaf from zoo patrons, and poses the epistemic question, "why are their tongues so long?". Immediately, AM answers using a question, which instrumentally indicates that AM took up the students' idea, and epistemically places the agency and ownership on the student. However, AM also took a cooperative stance, based on his positioning toward all of the group members, which led another student (118) to take an epistemic stance and provide an answer to the group (B.5). After allowing the space for the students to consider their observations, AM again, takes instrumental, epistemic, and cooperative stances to have the students recall and summarize the video (B.6). The remaining conversation within this sequence is guided by the students. The students take an epistemic and cooperative stance by building on each other's responses. AM only contributes to the conversation using an instrumental stance, to affirm each students' contribution to the discussion around giraffe's coat patterns. This interaction sequence ends with student 117 taking an instrumental, epistemic, and cooperative stance, by facing and pointing to the giraffes and describing the pattern differences between the giraffes within the exhibit (B.16 and B.18). Finally, it concludes with AM taking an instrumental stance by saying, "Yeah, that's a good observation" (B.19) by acknowledging 117's epistemic stances. We interpreted this sequence as a more equal distribution of power between the adult facilitator and the students. The majority of the discussion was epistemically and cooperatively led by the students. AM's participation during the discussion was taking an instrumental stance to affirm each students' contribution.

Discussion

Our analysis traced the importance of adult facilitators in mediating student mathematical discussions in informal settings. In case A, we found that mathematical discussions were epistemically and cooperatively led by the adult facilitator, thus limiting the students' contributions. In case B, we found that mathematical discussions were epistemically and cooperatively driven by the students, thus enhancing the variety of mathematical questions which were posed. Furthermore, the environmental context differed greatly between the two cases. In case A, the adult facilitator and students were seated in a room away from the rest of the zoo exhibits. This provided a narrower field of possibilities for the students to reference when ideating possible mathematical questions. In contrast, in case B the adult facilitator and students were standing along the giraffe exhibit as they watched associated videos and discussed possible mathematical questions. This provided a broader range of possibilities for the students to explore their natural curiosities through observations, as well as from the videos. Implications for this initial analysis, suggest supporting the adult facilitators so they can better prompt open-ended and student-led mathematical discussions to connect the mathematical content to the present sites. It also suggests that the physical location in which informal mathematics learning discussions take place has important implications for the mathematical discussions that ensue. Finally, it highlights how tensions between academic and everyday mathematics can arise for facilitators in informal learning environments, and suggests that strategies should be developed to explicitly address these differenting participation structures.

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Play as a Site for Children's Construction of Internally Persuasive Mathematical Discourses

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Abstract: This study explores the relationship between play and authoritative discourses (Bakhtin, 1981) in a kindergarten mathematics classroom. Drawing on interpretive methodological traditions, the research team video recorded and took field notes on a week of geometry lessons following a professional development session in which teachers co-designed playful geometry lessons with the researchers. Our findings demonstrated that engaging in play allowed children to construct their own internally persuasive discourses about mathematics.

Introduction

When children experience mathematics as a set of rules to memorize, they come to see mathematics as something they do not have the authority to question or create, such as when children execute procedures like "borrowing and carrying" without conceptual understanding of place value (Laupa, 2000). In contrast, mathematical play can allow children to engage in mathematics in ways that allow them to explore, reason, and rely on their own authority (Wager & Parks, 2014). In this study, we were interested in identifying qualities of mathematical play in a kindergarten classroom that made it possible for children to challenge authoritative discourses about mathematics. For example, rather than seeing mathematics as primarily requiring the memorization and recitation of correct answers, we hypothesized that certain kinds of mathematical play might allow children to raise mathematical questions of their own, form and test mathematical conjectures, and engage other children and even teachers in mathematical arguments. In defining play, we drew on definitions that emphasized play as providing opportunities for pleasure, chosen repetition, creativity, social engagement, and use of attractive materials, whether or not individual children took up these opportunities (Burghardt, 2011). To guide our study, we asked the following research question: What qualities of play-based tasks support children's meaningful sense-making about mathematics and to engage with mathematics as more than an authoritative discourse circulated by the teacher?

Theoretical frame

In exploring the potential of play in a kindergarten classroom during mathematics, we adopted a discursive perspective on authority, heavily informed by the work of Bakhtin (1981). Bakhtin (1981) differentiated between authoritative and internally persuasive discourses. He called authoritative discourses "acknowledged truths," and "the word of a father, of adults and of teachers" (Bakhtin, 1981, p. 342), while he defined internally persuasive discourses as those we believe to be true even though they are "backed up by no authority at all" (Bakhtin, 1981, pp. 342-344). In mathematics classrooms, authoritative discourses circulate around appropriate behavior—for example, sit criss-cross applesauce, raise hands before speaking, obey the teacher—and around mathematics—use proper vocabulary, perform procedures correctly, memorize rules. An authoritative discourse "demands that we acknowledge it, that we make it our own; it binds us, quite independent of any power it might have to persuade us internally" (Bakhtin, 1981, p. 343). In contrast, we hypothesized that play could provide a site for children to develop their own internally persuasive discourses about mathematics.

Methods

This study, which is part of a larger project, draws on interpretive ethnographic traditions (Erickson, 2004). The site of the study was a school serving a racially and socio-economically diverse population. Kindergarten teachers at the school participated in a week of professional development (PD) on mathematical play during the summer as well as four daylong sessions focused on adapting lessons from the mandated mathematics curriculum throughout the school year. This smaller study focuses on one kindergarten classroom with two co-teachers and 26 students during the week of geometry lessons planned during PD. Data collection included video of the week's lessons with four video cameras. In addition, at least one member of the research team observed each lesson. In the weeks before the play-based lessons, a member of the research team observed typical mathematics lessons one or two times each week and took written fieldnotes. For this analysis, the research team viewed video from four recorded lessons in one classroom to identify moments of mathematical play. Additional viewing of the videos focused on identifying authoritative mathematical discourses and moments when children challenged these discourses. These moments were then analyzed to identify differences in children's and teachers' participation in playful mathematics activities as well as to differences in the quality of play and the content of the mathematics (e.g., social engagement, creativity, open and closed problems, etc.) across the playful activities implemented during the week.

Findings

In the weeks leading up to the play-based geometry lessons, children's engagement in mathematics was largely directed by Ms. Lane, who provided explicit instruction and typically assigned independent tasks to children. For example, after first introducing an activity to students in which they counted objects on cards and recorded their counts on a number line, referred to as a "game board," Ms. Lane and her students had the following exchange:

Ms. Lane: Is it time to play?
Students: (*loudly and in unison)* No!
Ms. Lane: Is it time to work?
Students: Yes!
Ms. Lane: "Is it time to learn?
Students: Yes!
Ms. Lane: Is it time to talk to your neighbor?
Students: No!

In typical lessons like this one, Ms. Lane reinforced authoritative discourses about mathematics by focusing on the production of correct answers, acting as the authority in determining correctness, and giving explicit directions about tasks. During these lessons, children typically worked independently after the whole-group introduction. During the week of play-based instruction, Ms. Lane added in group activities co-developed during the PD by the research team and the kindergarten teachers, such as pattern block puzzles, shape sorts, and making shapes on geoboards. During the exploration, children rotated through centers chosen by Ms. Lane.

Authoritative task, authoritative discourse

On the first day of the geometry unit, in addition to using the play-based tasks developed in the PD, Ms. Lane provided the children with a a game that they had played during the previous unit. This game challenged children to unlock a toy by correctly matching a picture with a numeral. The task of the game was relatively closed, supporting only one kind of play with not many opportunities for improvisation. When Ms. Lane engaged with children at this center, she focused their attention on the production of correct answers, as in the episode below:

Layla: *(Counts to 14).* Fourteen! Where's fourteen? (*Picks up a key and smiles at Ms. Lane*).
Ms. Lane: Is that fourteen on the key?... I can't see the number.
(Layla shows Ms. Lane the number 15 key she is holding. Ms. Lane smiles.)
Ms. Lane: FOURRRteeeen, is that FOUUURRRRteeeen? Find FOURRRteeen
(Layla shows key number 13.)
Ms. Lane: FOURteen? Is that FOURteen?
Layla: (*searching for the correct key)* Four....teen

Even though this moment was playful for both Ms. Lane and Layla—they both smiled, Ms. Lane's voice was teasing, and Layla seemed to find pleasure in handling the locking toys—Ms. Lane focused her questions on getting Layla to repeat that the numeral was fourteen and not fifteen rather than exploring Layla's thinking.

Opportunities for improvisation and internal persuasiveness

A center where children used stencils to draw polygons and then mark vertices with dot paints seemed to provide more opportunities for children develop internally persuasive discourses about mathematics. Children could make choices about which shapes to draw and how to mark the vertices, and the blank paper used for the activity supported children in going beyond the authoritative directions for the task. For example, Will and Nicholas wrote numerals inside of a circle they traced, making a connection between the number and geometry. In addition, Ms. Lane's interactions in this center also seemed less focused on reinforcing the authoritative mathematical discourse. For example, when Ms. Lane saw the children writing numerals, Ms. Lane asked the children to explain:

Ms. Lane: What are y'all doing? What's that? *(Points at Will's paper.)*
(Will and Nicholas look at Ms. Lane silently.)
Ms. Lane: Why are you putting those numbers in the circle?
(Will and Nicholas look down at papers, look at each-other, and then smile at Ms. Lane, still silently.)
Tiana: (*Interjecting.)* I didn't put numbers in the circle, but I put a smiley face.
Ms. Lane: No, I am talking to these two. What is that? What are you making?
Will: I'm making a clock.
Ms. Lane: You're making a clock?
Nicholas: Yeah.
Will: Out of the circle.
Nicholas: We are making a clock.

In this episode, the two boys played with the rules of the activity by not just identifying vertices, but also creating pictures out of the shapes. This improvisation allowed them not only to connect shapes and numerals but also to make a connection to a mathematical tool in their ordinary lives. The more open task and the playful social context, which allowed the children to talk freely and build off each other's ideas, supported the children to engage with mathematics as something they had the power to manipulate. In addition, Ms. Lane seemed to adopt a slightly more playful stance in this interaction than in the matching lock interaction, perhaps because the drawing of the clocks inside a shape was both not incorrect and was mathematically relevant.

Authoritative discourse, internally persuasive discourse

Beyond the importance of open activities (e.g., those that supported choice, exploration, and multiple answers), spaces where children could interact outside of the watchful eye of the teacher provided important opportunities for children to develop internally persuasive discourses about mathematics.

One morning before centers, Ms. Lane led a whole group discussion about the orientation of triangles, asking the children to decide if triangles of various shapes and orientations were still triangles. Some children said no, and she talked about how orientation did not determine if shapes were triangles. She prompted children to count all the sides and vertices to determine if a shape was a triangle.

Following this discussion, Will, Nicholas, and Tiana were assigned to a geoboard activity during centers. Each child had a geoboard, stack of shape cards, and some rubber bands. Ms. Lane had asked children to choose a card that had a shape on it and to recreate that shape with rubber bands on their geoboards. As Will, Nicholas, and Tiana begin the geoboard activity, Ms. Lane joined the group to continue the conversation about orientation. She presented the group with a square shape card turned so the square stood on a vertex. Will and Nicholas both claimed that the shape was a diamond while Tiana was insistent that the shape remained square, regardless of its orientation:

Ms. Lane: *(Addressing Nicholas.)* What is it this way?
(Ms. Lane turns the card three different ways and repeats her question. Nicholas continues to call the shape a square only when a side was parallel to the table; otherwise, he calls it a diamond.)
Ms. Lane: *(Addressing Nicholas and Will.)* How does it change from a square to a diamond? It's still the same shape.

In this exchange, Ms. Lane maintained her commitment to reinforcing the authoritative discourse about shapes—orientation does not matter—even though Nicholas disagreed. Ms. Lane continued to press her point by grabbing a board eraser and turning it in multiple directions, asking what it was at each turn. The children agreed it was always an eraser, but when Ms. Lane returned to the square example, both Nicholas and Will still insisted it was a diamond. Throughout this interaction, even in the play-based context, Ms. Lane maintained a commitment to guiding children toward authoritatively correct answers. However, the playful context of the center and Ms. Lane's own smiles seemed to have made Will feel comfortable in reiterating his own position— the square is a diamond—even though it was backed up by "no authority at all." Ms. Lane left the group before she convinced Will and Nicholas to adopt her position. Not long after Ms. Lane left, Will, looking at a square, exclaimed, "It's a diamond! I know it is!" Then, after about a minute of individual work, Tiana reintroduced the orientation conversation:

Tiana: (*showing the square card to the group)* What is this everyone?

Both boys: *(without really looking)* A square.
Tiana: *(changing the orientation of the card)* If I flip it over like this, what it is? *(looking frustrated)* How does this change, but... what if you had a triangle? When you flip it over it still looks like a triangle because all of the sides are the same. *(shows Will a triangle card)*
(Will repeatedly affirms the shape is a triangle as Tiana turns it.)
Tiana: *(shows two different square cards turning them to be different and then matching orientations)* Then how does this one change? They are both the same thing!
Tiana: *(attempting to build a hexagon on her geoboard by making two trapezoids)* I'm making the same shape you teached me.
Will: *(making a square on his geoboard)* I got a diamond. Did you know, if it's a square sideways or diagonal then it's a diamond. Do you see the difference? Nicholas, do you see the difference? *(Taking a breath and pointing to his square turned on a vertex)* This is actually a square! Look! It's just facing diagonally.
Tiana: That's what I just told you.

In this independent interaction Tiana advanced an idea she seemed to find internally persuasive—that the orientation of the shape did not change how it was identified. No doubt, hearing this argument from both Tiana and Ms. Lane helped Will reach a similar conclusion. However, it was his own play with the geoboard that brought his own internally persuasive discourse about shapes in line with the authoritative discourse. The atmosphere of play, where children were able to make shapes on their own, to talk as they worked, to argue and disagree with the teacher supported their exploration of mathematical ideas.

Discussion

As with previous research, introducing playful spaces into the kindergarten provided opportunities for children to construct their own internally persuasive discourses about mathematics; however, some characteristics of play seemed more important to children's sense-making than others. While children found the matching numeral and quantity locking game pleasurable and talked with each other and the teacher while playing with it, the play did not allow them to do their own sense-making, but rather pushed them toward accepting authoritative discourse. In contrast, the tracing shapes and geoboard activities allowed children to alter the tasks in ways that let them explore questions of interest to them and to develop their own understandings. This suggests that closed playful tasks—even if they are pleasurable, social, and low-stress—may not provide the kind of support necessary for children to do their own sense-making around mathematics.

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“I Guess My Question is Like”: Problematizing in an Introductory College Physics Lab

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Abstract: There are beginnings of research studying how college students manage the experience of not-knowing in instructional laboratories. Previous work in introductory physics focused on student problematizing has had mixed results in activities designed to guide students to recognize and address an apparent discrepancy. Here, we study an instance of a student’s successful problematizing, starting from her initial puzzlement during her group’s exploration of a Newton’s Cradle. We highlight the idiosyncrasy of the instance and suggest it raises questions for curriculum design.

Doing science in lab entails being puzzled by natural phenomena

For more than a century, physics educators have called for reforms in instructional labs to encourage students to observe and interpret natural phenomena, rather than to confirm known results (Otero & Meltzer, 2017). Recent work has provided new motivation for these reforms, finding confirmatory labs do not result in any measurable gains in students’ conceptual understanding (Smith et al., 2020). As well, the shift toward objectives of students’ *doing science* has had support in national standards (National Research Council, 2012) and in strands of research on how students learn to appreciate and engage with experiences of *not-knowing* (Watkins et al., 2018).

A number of researchers (Chen & Qiao, 2020; Manz, 2018) have focused on feelings of uncertainty, “the uneasy sense that something is missing or amiss” (Phillips et al., 2017, p. 1), as the beginnings of scientific inquiry. While much research has focused on student learning about *measurement* uncertainty, we consider the broader construct of *epistemic* uncertainty: the feeling and assessment that there is some gap or inconsistency in one’s understanding. Taking that sense seriously entails the often-difficult work of *problematizing*: “identifying, articulating, and motivating a problem or clear question” (Phillips et al., 2018, p. 983).

Recent lab reforms have designed activities guiding students to experience a planned surprise or discrepancy—their data in conflict with their expected results. Part of the goal of these activities is students taking up the opportunity to problematize and construct their own knowledge. These efforts have sometimes led to success (Sundstrom et al., 2020), but the outcomes are highly variable (Descamps et al., 2022; Phillips et al., 2021). The diversity of findings in previous research motivates further study of how students come to problematize in lab. Here we examine an instance of successful student problematizing in a context of an open-ended lab activity.

The students were enrolled in an introductory physics lab as part of a course taught by the third author. There were four lab activities in the course, each lasting 2 or 3 weeks with progressively reduced structure, designed to encourage students to problematize. The lab activity presented in this study was the final and most open-ended of the semester.

We collected video data as a part of a larger project that studies what shifts or sustains undergraduate students’ framing in physics labs (Descamps et al., 2022; Phillips et al., 2021). Here, we studied an episode of one group’s exploration of a Newton’s Cradle and selected it as an instance of successful student problematizing. This clip interested us because of the sudden onset of confusion that a student expresses in the activity. Our analysis of this clip followed Derry et al. (2010)’s video research methods and had iterations of the following process: we viewed the clip, gathered multiple interpretations, and watched it again to refine our initial interpretations. The first author wrote the interpretations and revised them after discussing with the other two authors. Here we present a moment-to-moment analysis of an emergence of student problematizing.

A student problematizing in a physics lab

There were three students in the lab group, Esther, Abby, and Anita (pseudonyms), all first-year undergraduates in the school of engineering. Demographic course data informed us that all three students identified as women, Esther and Anita as Asian, and Abby as White. Leading up to the episode in this paper, the students start their final activity of the semester, with the assignment to arrange some form of collision and study it, and the students were free to ask whatever empirical question they choose. After some initial exploration, this group decides to build and study a simplified Newton’s Cradle comprised of three pendula.

Anita and Abby try to make it work the way it is "supposed to": an outer ball hits the middle ball, which does not move but hits the other outer ball up in the air, which falls back to make the first ball go up again and so on. Esther is with them at first and then retreats to her laptop. When Anita and Abby finish setting up the apparatus, they see that all three pendula swing after the first collision—they do not behave as they are "supposed to."

Anita proposes adding more mass to the middle ball, and explaining, "if it's more massive then it'll have more inertia, will be more resistant to acceleration." Neither Abby nor Esther takes up this bid; Anita decides to do it herself. She hangs a hook with masses on the string that holds up the middle ball, and she watches the first couple of collisions: The middle ball stays relatively still after it gets hit by the first outer ball, and the other outer ball swings up farther than before. Abby and Anita see this, and Anita immediately expresses her confusion, the moment at which the transcript begins. The entire episode occurs over two minutes.

01 Anita: Why does it do that? I don't get that. [looks at the setup]
02 Esther: What?
03 Abby: What?
04 Anita: Why it, why it {[unclear]} [points at the middle ball]
05 Esther: {'Cause it's} harder to, to resist. [releases the left ball] It's
06 harder — {It can resist}
07 Anita: [Points at the middle ball, left ball, and back to the middle ball]
08 {But wait these,} wait, it [left ball] went all the way back up. Right?
09 Wait wait wait.
10 Abby: It should. {It should.}
11 Anita: {It [unclear].} But why? [in a whisper, looking to Abby]

Anita becomes puzzled by how the outer ball bounces off a stationary middle ball. She points at the middle and left balls and articulates the source of her confusion, that the outer ball goes "all the way back up" (line 08). Keeping her eyes on the apparatus, she is struck by the outer ball's clear bounce that happens after she adds mass to the middle ball to make it more stationary.

We are struck ourselves that Anita expresses confusion about the phenomenon that she has been trying for some time to arrange. Seeing it happen seems to shift her into wondering: Why does the outer ball bounce up in the air when the middle ball is stationary? While Anita has focused on adding mass to the middle ball until this moment, she now notices the phenomenon is puzzling, which she tries to identify and articulate. Esther and Abby ask Anita to clarify (lines 02 and 03), and they try to answer her questions (lines 05, 06, and 10). Their responses, however, do not seem to address Anita's confusion, as she points at the left ball (line 07) and emphasizes "why" (line 11) in a whispering tone. Their efforts to respond apparently supports Anita to articulate her question further, perhaps because they do not seem to understand what troubles her.

Anita's efforts to problematize continue

About thirty seconds pass, during which Anita suggests making the middle ball even more massive. Abby points the group's attention to the first collision, and Esther and Anita raise questions about its underlying mechanism.

12 Abby: 'Cause like, it, although because it's, it's not perfect, it's not perfect,
13 but like, [releases the right ball] we have the first one.
14 Esther: But why is it, why is it working?
15 Anita: [Leans in closer toward the apparatus, remaining in her kneeling
16 position] Yeah, I don't know why that the ball is [unclear]
17 Abby: 'Cause it's supposed to be
18 Esther: But why put an extra mass there?
19 Abby: 'Cause it makes it not move. Just because of our error and have it
20 [unclear] collision
21 Anita: I don't understand why
22 Abby: 'Cause the energy
23 Anita: How like, how the – the energy is being transferred
24 Abby: I wanna see if it works. [releases the right ball]
25 Esther: The energy is transferred.
26 Abby: The, the only thing it does is make sure it stays still. It stays in the
27 middle.

Esther's question (line 14) seems to support Anita's confusion, as Anita agrees and continues (line 16). She reiterates her uncertainty (line 21) and revises her question in terms of energy transfer (line 23). In the group's earlier discussion with the TA, Esther explained that she expects full transfer of energy between the balls, which may be what Abby and Anita recall at this moment. What remains unclear for Anita, though, is *how* the energy transfers. She refines her question from wondering about why the outer ball bounces up in the air (lines 07-11) to wondering about how energy transfers (line 23).

In this way, Anita formulates her question in a collaborative effort with her peers: She reiterates Esther's question (line 14), and she asks about energy after Abby mentions it (line 22). Throughout this interaction, Anita is kneeling on the floor, at eye level with the apparatus, and pointing at different features. The materiality of the phenomenon drives her curiosity.

Anita further refines her question

Still thinking about energy transfer, Anita clarifies her question further.

28 Anita: But I guess my question is like [takes hold of the middle ball], when
29 this stays still how does the energy
30 Esther: Transfer?
31 Anita: Yeah. Do you know? [points at Esther with her finger]
32 Esther: Yeah. It [left ball] hits this [middle ball] and it goes through, hits
33 that [right ball]. Passes through.
34 Anita: But, but what if this. What if this [middle ball] is, this [middle ball]
35 stays completely still. It [middle ball] won't do anything?

Anita takes hold of the middle ball, and she asks, how does the energy transfer when the middle ball "stays completely still" (line 35)? That the middle ball stays still, and the outer ball bounces, does not make sense: How can the middle ball transfer energy if it stays still?

She begins her question with the words, "But I guess my question is like" (line 28), which show her effort to arrive at a question. She is still crouched on the floor with her eyes on the apparatus, holding the middle ball in her hands. Anita's physical handling of the apparatus continues to drive her wondering about it. Esther also contributes to Anita's problematizing, as she helps to finish the question (line 30) and offers the idea that "it goes through" (line 32)—probably to mean the energy goes through, or "passes through", the middle ball (line 33). Esther's explanation does not satisfy Anita, who articulates her question again: If the middle ball "stays completely still" would the phenomenon still happen (line 35)? Anita and Esther's different understandings of the mechanisms that underlie energy transfer afford Anita an opportunity to further refine her question.

Contextual dynamics of a student problematizing

To review, Anita's wondering begins with her seeing the very phenomenon that she has tried to make happen. The physicality of the event—the clear bounce of the outer ball off the middle ball, which she watches closely—is the initial trigger. Her effort to articulate what troubles her is supported by her peers, although they do not seem troubled themselves. This suggests social features of the context also played a role (Appleby et al., 2021): The three students have worked together for months and developed a social rapport, evident in their frequent banter and laughter, that supported their attention to and caring about each other's thinking. Of course it also matters that the students were working within instructional labs designed to encourage sensemaking (Etkina et al., 2010). There is evidence here of Esther's framing lab as about their making sense of their data, and in other moments, it is Esther who presses the group with questions.

This moment, in sum, was idiosyncratic. No one could have anticipated these particular dynamics. It is also difficult to imagine a lab design that could have guided Anita to her question. So, what if idiosyncrasy is an ordinary feature of students' problematizing? Perhaps the mixed results in prior accounts of when and how undergraduate students problematize in physics labs reflects the complexity of the dynamics (Descamps et al., 2022; Phillips et al., 2021; Sundstrom et al., 2020). This case, with others, motivates that consideration. Many efforts to support problematizing in the literature involve designing a specific experience of discrepancy into the phenomenon students are to explore. It is clear that these approaches can be successful; we do not propose abandoning them. We suggest, however, that many instances of students' problematizing will arise outside of such specific plans. One implication is that the guided-discovery approach to *problems* has similar challenges to those of the guided-discovery approach to concepts (Hammer, 1997), and so enactments of such curricula should leave room for instructors' discovery of students' productive thinking the designs did not anticipate.

More broadly, instructional labs to support student problematizing would benefit from diversity of approach, including designs to engender idiosyncrasy. This of course argues for student projects, although within introductory courses there may be tension between the various ideas that students want to explore and the shared features of experience in their thinking about similar topics. At another level, labs can pay more attention to student framing of laboratory experiences, including their expectations for how they may be agentive in their learning within the activities. In that regard, Cherbow & McNeill (2022) introduced the possibility that curricula may be *too successful* at anticipating students' thinking, if students come to expect that of the materials: if the course already knows what they are going to ask, why should students bother asking? For instructors and researchers working to prioritize students' agency, the challenge is to designing labs that create space for students' emergent ideas and idiosyncratic questions. Students need opportunities to experience and take up puzzlement of their own.

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WearableLearning: Developing Computational Thinking Through Modeling, Simulation, and Computational Problem Solving

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Abstract: Computational Thinking (CT) is a vital and multi-dimensional skill for all learners. Understanding the development of CT's different dimensions is essential to refining educational experiences that best support it. In this study, we investigated the development of three aspects of CT: Self-Perception of Computational Ability, Modeling and Simulation, and Computational Problem Solving, as students engaged in collaborative game design and programming practices within a game-design platform, *WearableLearning* (WL). Through their engagement with WL and its accompanying curriculum, we show preliminary evidence for developing two CT dimensions, Modeling and Simulation and Computational Problem Solving, and discuss the challenge of developing Self-Perception of Computational Ability. We found an increase in students' ability to understand machines and their processes and an improved capacity to think algorithmically as they constructed models, debugged, and iterated through their designs. Student Self-Perceptions of Computational Ability, however, did not change significantly.

Introduction

Educators recognize that Computational thinking (CT) is an essential skill to master within STEM fields (Wing, 2006). Considered a key aspect of Computer Science (Grover & Pea, 2018), CT is now understood to more broadly encompass the thought processes and practices necessary for systematic problem-solving, such as iterative testing, algorithmic thinking, and troubleshooting, among others (Weintrop et al., 2016; Shute et al., 2017; Resnick et al., 2009). In particular, there is limited work that explores CT within environments that leverage game design to teach critical CT skills and concepts. Our work describes the results of engaging students in a six-stage curriculum (the WearableLearning curriculum) that teaches CT through programming and playing games on a web-based game design platform.

The *WearableLearning* Platform (WL) aims to develop students' CT skills by having K-12 students and teachers create, administer, and play multiplayer games using mobile devices (Arroyo et al., 2022). In this work, we sought to understand the impact of the WL curriculum that involves gameplay, game design, programming, and testing. We thus explore the following research question in this work: *what aspects of Computational Thinking does the process of game playing, game ideation, and programming/implementation impact*? We hypothesized that the aforementioned processes would yield an increase in students' CT abilities, in particular: how students see their abilities to solve problems (self-perception of computational ability), their understanding of machines and models that represent their functioning (modeling and simulation), and their capability to generate correct solutions that use logical reasoning (computational problem solving).

Background

Computational Thinking has become an umbrella term that refers to a broad set of early Computer Science skills essential to thrive in our increasingly digital world (Wing, 2006). Many scholars have grappled with the different definitions of CT and have contributed different, highly context-driven answers. Most definitions include the aspects of problem decomposition, pattern recognition, data representation, generalization and abstraction, systems thinking, and algorithm-building (Grover & Pea, 2018). Another one of the most thorough analyses of CT at the K-12 level (Weintrop et al., 2016) suggested the following practices within CT: analyzing and logically organizing data; data modeling, abstractions, and simulations; formulating problems so computers may assist; identifying, testing, and implementing possible solutions; automating solutions via algorithmic thinking; and generalizing this process to other problems. We agree with the reflection by Román-González et al. (2019), which suggests that the term *Computational Thinking* has helped to extend Computer Science Education beyond computer programming, and helped to lower the barriers to entry for learning computer programming, in part, due to an increase in the number of visual block-based programming languages. In addition to developing cognitive skills, engaging in CT offers the opportunity to develop noncognitive aspects related to attitudes and 21st-century skills such as persistence, self-confidence, tolerance to ambiguity, creativity, and teamwork (van Laar et al., 2017).

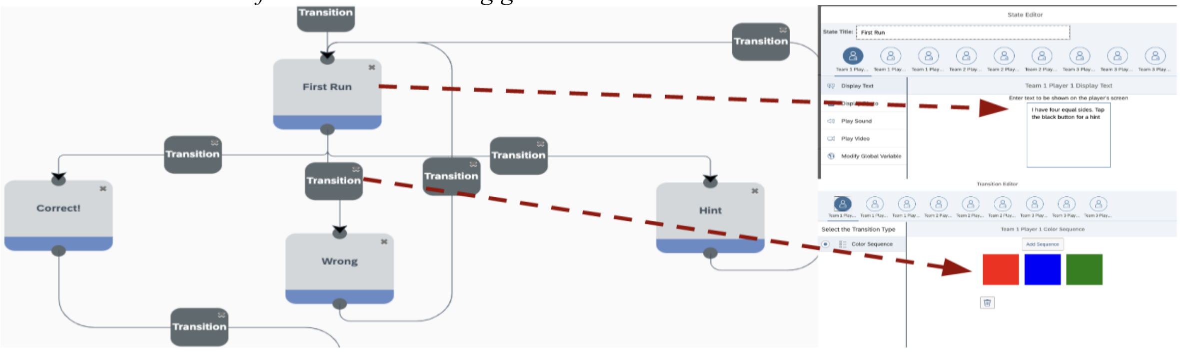
Thus, the uses and applications of CT have evolved and grown beyond strictly CS education (Kalelioglu et al., 2016).

Exploring the different dimensions of CT enables us to identify distinct mental processes during problem-solving tasks in contexts within and beyond coding and programming. Game design emerges as a context that is rich with opportunity to develop CT because students are tasked with creating a sequence of interfaces while keeping scale, difficulty, individual differentiation, and complexity in mind (Kafai et al., 2015). Engaging in CT often results in a logic-based computational solution to a problem that is defined at various levels of abstraction. CT involves a cyclical process where a problem is explored at a high level of detail and precision, with multiple possible solutions. These solutions need to be articulated and implemented to varying degrees, tested according to a success criterion, and revised or redefined.

The WearableLearning platform

The WL Platform is a browser-based platform that enables users to create and deploy active math games without prior programming experience (Castro, 2022). The programming interface (see Figure 1) consists of *states* and *transitions* that users drag and drop onto a canvas on the screen to create a game flow. *States* contain specific game content that are displayed to a game player, such as text (e.g., questions, prompts), images, sound, and videos. Movement from one state to the next depends on the *transitions* that connect states. A player can enter text, color codes, or press buttons corresponding to choices to transition from one state to the next. WL's Game Creator functionality includes a debugger, which runs a simulated game instance to show what a Game Player would see on their screen as they progress through the game, allowing users to troubleshoot, debug, and fix errors as they develop their game.

Figure 1
The Game Editor view of a WearableLearning game.



State Title: First Run

I have four equal sides. Tap the black button for a hint

The WearableLearning curriculum

The WL curriculum consists of a series of guidelines and materials to support teachers in guiding their students through a six-stage process of playing, creating, and modifying games. The overarching goal is to design an active, educational, collaborative math game aided by mobile devices for learners to play, learn, and practice math skills. Students work through an iterative design process and engage in designing, prototyping, and testing/evaluating their game designs, and redesigning after feedback from other students. Students follow a six-stage design process: (1) playing games, (2) brainstorming and designing a game on paper, (3) drawing finite state machine diagrams, (4) programming the games on the WL platform, (5) playing a math game made by peers, and (6) observing others play their math game and iterating on their game based on these observations.

Methodology

To address our research question, we conducted a study with 47 students (11–13 years old), across two after-school programs in Eastern and Western Massachusetts in the United States, where students experienced the six-stage WL curriculum over 8-10 hours of contact time. Across both programs, 22 (46.8%) of students self-identified as male, 18 (38.3%) self-identified as female, and 7 (14.9%) preferred not to answer.

Instruments

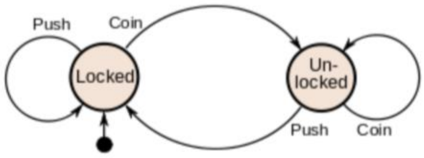
We designed pre- and post-tests to measure three different aspects of CT: Self-Perception of Ability, Modeling and Simulation, and Computational Problem Solving, before and after students engaged in the WL curriculum. The full curriculum and instruments are at https://osf.io/tx9ab/. The first section of each test gleaned students' self-concept of how adept they considered themselves at computational tasks and the use of computers. This section was adapted from Angeli et al.'s (2016) work on CT perspectives where they describe what students at different grade levels should know to have CT. We created a test of CT self-concept by adapting these notions to feelings of knowing CT skills into seven 5-point Likert scale questions (5="Strongly Agree" to 1="Strongly Disagree").

The second part of the test posed questions related to modeling a machine (Figure 2 shows sample items on a finite state machines assessment). According to Wilensky et al. (2016), CT activities in various capacities include learners designing, constructing, and evaluating models as part of their educational activities. We thus assessed students' modeling and simulation ability by assessing their ability to interpret abstract models of finite state machines, what kinds of machines they represent, and how they function, especially given the heavy focus of the WL curriculum and platform on finite-state machines. We created items on Finite State Machines from beginner material given to students in tertiary education as part of Computer Science classes.

Figure 2

The three items that assessed students' knowledge of Finite State Machines

This is a visual model of how a machine works.



1. Can you tell what kind of machine this could be? What does it remind you of and why?
2. According to this model, what would happen if you put three (3) coins in?
3. The machine is currently locked. What would you have to do to get this machine to go "unlocked" and then back to "locked"?

The final part of the test had multiple-choice items from the Computational Thinking test (CTt) by Roman Gonzalez et al. (2019) relevant to algorithmic thinking concepts, such as sequencing and loops, to measure computational problem-solving skills. According to Wilensky (2016), this involves a variety of skills, such as preparing problems for computational solutions, choosing tools, assessing approaches/solutions to a problem, and debugging. The CTt addresses some of these aspects; we adapted from the CTt and included only the preliminary concepts of algorithmic thinking, excluding the more complex nested loops and conditionals, as those were not part of the topics covered in the instruction for the after-school programs.

Results

We computed a total score for each student for the pre-/post-tests, with the score for self-perception as an average of the Likert scale scores for each student and the FSM and CTt components being sums to indicate correctness. We computed descriptive statistics for the collected data and analyzed the difference between pre- and post-test scores using a two-tailed paired-samples t-test (significance compared to an alpha level of 0.05).

We found a statistical significance in the CT measures for Modeling & Simulation (t=2.01, p=0.05) and Computational Problem Solving (t=2.62, p=0.01) from pre to post-test. Modeling & Simulation showed a small to medium effect size, suggesting that exposure to the WL curriculum activities positively impacted students' skills in creating models and understanding finite state machine concepts. The Computational Problem Solving section showed a small to medium effect size, suggesting that students' engagement with the content and process positively impacted their problem-solving skills. We found no statistical significance for average scores on Self-Perception (t=0.74, p =0.46).

Discussion and conclusion

Students showed improvement in two out of three different measurements of Computational Thinking after being exposed to the WL curriculum and platform for 8-10 hours of contact time. They improved in Algorithmic Thinking/Computational Problem Solving Practices and Modeling/Simulation practices, as reflected in their learning gain. They also developed complex models for their games and debugged those models as they built their games, which had branching and distinct levels of difficulty, using concepts such as loops and parallelism.

Students did not improve in their Self-Perceptions of their CT abilities, which probed students to think about the level of comfort and ease with which they can engage in computational practices and use digital media for problem-solving. There are multiple possibilities why there was no significant improvement in their self-perceptions of their CT abilities. This might be because of the steep learning curve experienced during the 8-hour curriculum or because it was their first experience as active creators of complex games. This experience might have challenged their self-perception of their technology/digital skills. These findings reflect similar results in active vs. passive STEM learning that suggest novice learners are inaccurate in their judgments of how much they learned; this "feeling of learning" can be negatively correlated with actual learning (Deslauriersa et al., 2019). Future work may include increasing student exposure or contact hours with the curriculum, which could make students more comfortable with the learning curve. Another possibility would be to add specific reflection prompts that encourage students to think about what skills they have developed as they participate in this game design and creation process, thereby deliberately building their awareness of the skills they are developing.

The results of our study show that a curriculum based on game design and play can impact the development of different dimensions of CT. Our findings invite discussion for a more granular analysis of our curriculum activities and their impact. Different measurements and instruments of Computational Thinking, focusing on different aspects, could yield different results, as they capture only a portion of what constitutes thinking computationally. Therefore, assessing CT through a multi-dimensional assessment that looks at CT skill development holistically will lead to a clearer understanding of where our students stand and what remains to be improved upon.

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Supporting Mathematical Problem Posing Through Representations

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Abstract: In this paper we show how problem posing can be organized in the classroom. The decisions were made in a team of teachers and researchers: to use mathematical representations, to choose worked examples and to elaborate a tool called repertoire-instrument. Thus problem posing can be based on concrete representations, on the one hand, and on worked examples on the other. This case study focuses on a dialogue between a teacher and a student. The results concern the potentialities and effects of this device in the implementation in a class. The study is intended to be continued, with statistical analyses of the students' performance and qualitative analyses of the practices implemented.

Purpose of the study

Mathematics and representations

When considering elementary school mathematics, we often find that students see mathematics as a collection of rules and procedures that must be remembered (Richland *et al.,* 2012). However, the essential purpose of mathematical activity, both in the classroom and for mathematicians, is to understand mathematics.

We argue that the construction of mathematical knowledge is a cultural process. In saying so, we hypothesize that we need to understand patterns of culture (Benedict, 2019). These patterns institute certain ways of seeing-as, of doing, certain practices as specific ways of doing things, with a specific jargon. We argue that culture is embedded in representations, that are ways of concretizing culture. Goldin (2020, p. 556) developed these ideas in mathematics education: « *mathematical representations* are visible or tangible productions – such as diagrams, number lines, graphs, arrangements of concrete objects or manipulative, physical models, written words, mathematical expressions, formulas and equations, or depictions on the screen of a computer or calculator – » . These different representations embody mathematical ideas or relationships. In our perspective, the fundamental means of becoming familiar with culture is becoming familiar with representations. This work on representations is based on a national research project DEEC (Determining the Effectiveness of Experiments which are Controlled in teaching and learning), in France. It is devoted to build a set of mathematics lessons at first, second and third grades (6, 7 and 8 years old students). This project is grounded in a cooperative work between teachers and researchers (Sensevy & Bloor, 2020).

Problem posing

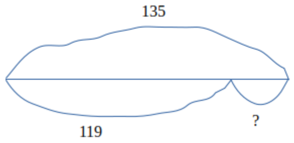
Among mathematical and scientific activities, problem posing is one fundamental part, more important, in fact, than problem solving itself (Kilpatrick, 1987). The most crucial thing for doing science is to know how to pose a problem before trying to solve it. Thus, familiarizing students in the process of problem posing is an essential goal for teaching. Problem posing has been recognized as an important intellectual activity in mathematics education (Cai *et al.,* 2015). By giving students the power to pose their own problems the teacher has to share mathematical authority in the classroom. Problem posing work in mathematics has been studied in different classrooms. For example, Singer & Moscovici (2008) described a learning cycle that includes problem posing as an extension of problem solving. Ellerton (2013) proposed a theoretical framework that situates the process of problem posing in a broader process. Zhang and Cai (2021) analyzed specific problem posing teaching cases. They tried to understand the nature of problem posing tasks used by the teachers. They were interested by the ways teachers led students to pose their own problems. These different studies aim to a better understanding of what teaching through problem posing entails for the teacher and the students. In other words, it means that there are two kinds of practice: the practice of the teachers (what they do in the classrooms) and the practice of the researchers (how they analyze it).

Based on Cai's perspectives (Cai *et al.*, 2015), we define problem posing as the following specific intellectual activities. Students pose mathematical problems based on given problem situations which may include mathematical expressions or diagrams. Teachers generate mathematical problem posing situations for students to pose problems. Teachers are able to predict the kinds of problems that students can pose based on a given problem situation.

Problem posing through a work between teachers and researchers

Teachers and researchers work together to understand what is problem posing and what is the practice of problem posing.. The purpose of this paper is to provide an understanding of what teaching mathematics through problem posing could look like. Students have to write mathematics thanks to representations and problem-posing (Richland et al., 2012). For example, they use symbolic writing (135 – 119= 16) and at the same time the number line, a box of numbers (see table 1).

Table 1
Different representations

119 + **16**= 135 135 – 119= **16**		135 119 **16**

In the classroom teacher and students study problems in a problem posing activity. They keep track of these problems. These problems are considered as emblematic examples, they are categorized according to their mathematical structure : change, combine, compare (Riley *et al.*, 1983). These emblematic examples of the practice can be seen progressively as exemplars, in Kuhn's sense (Kuhn, 1977).

The repertoire-instrument for problem posing

We focus on the fundamental fact, in the teaching-learning process, that students learn by relying on a previous set of meanings, that we may call a "*déjà-là*" (*already-there,* Sensevy **2014)**. In order to teach, a teacher has to gain a deep understanding of this *already-there*. For doing that, we argue that a promising avenue consists of organizing the teaching-learning process on the basis of specific examples of the way problems are posed and solved. The use of analogy is common in the posing/solving problem activity. Thus, the teacher works on problems with students, have them study solved problems, which can be understood as worked examples (Sweller, 2006). The set of these studied problems constitutes a repertoire-instrument for the class. Its "repertoire" function consists of the institution of a memory of emblematic problems of the class which will be considered as *exemplars* (Kuhn, 1977). Another function "instrument" corresponds to the use that students make of it to solve or pose new problems. This repertoire-instrument is a notebook available at each moment. The teachers and researchers team has developed the idea of this notebook as a way to support problem posing sessions. Teachers and researchers share this idea: a repertoire-instrument must contain problems that each student can solve.

Research question

Grounded on the previous analyses, our research question is the following: in the classroom, how the repertoire-instrument that the teachers and researchers team designed can help students pose problems and solve them ?

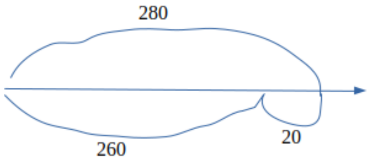
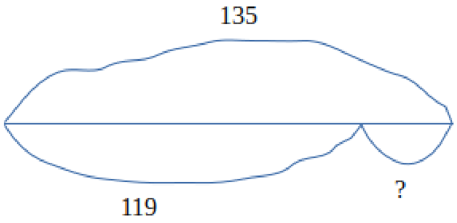
Methods

To try to answer this question we rely on various data collected during the implementation of the problem posing phases and in particular on classroom videos. In this paper we have chosen to describe and analyze what happens in the classroom of one of the teachers who is part of the team of teachers and researchers. This class, while being specific, is part of the team's culture and the culture of posing/ solving problem based on representations. The teacher and his students worked on posing problems early in the year. For example, they developed an example of each category (Riley et al., 1983). These categories were named by the team of teachers and researchers and these names were repeated within the class. We will focus on two categories, comparison and combine. This jargon captures a part of thinking in the classroom: each student is able to say what they are doing, thanks to the repertoire-instrument. In the classroom the teacher organized the same process during problem-posing session. The students are on their own to pose problems: they use a slate, on which one can easily erase and rewrite. The teacher is there but he doesn't help. The specific session was video-recorded and transcribed. We have identified three phases: reading the repertoire-instrument together in the classroom, individual work on the slate, intervention by the teacher with different students. We look at the exchanges between one student and the teacher. We selected this moment in particular since the teacher's role in this discussion exemplifies some central principles for using the repertoire-instrument and mathematical representations.

Results

As a result we will focus on the place of the repertoire-instrument during the exchanges between the teacher and a student called Andreas. Andreas wrote a problem: "I've got 260 marbles. Chloe has got 20 marbles. How many marbles are there altogether?" and made a number line (see table1). He explained that he wanted to compare the number of Chloe's marbles and the number of his own. The teacher asks the student to look at his number line. The teacher then brings up the page of the repertoire-instrument (see table 1), which he places next to the number line produced by Andreas.

Table 1
Both number lines

The Andreas'number line	The number line on the repertoire-instrument
	

He then explains to the student that in his problem, he was looking for what was "at the top" of the number line (280). He then adds that it is not the same thing in the comparison problem, without specifying further. After these exchanges around the number line, the teacher rereads the student's statement aloud. The teacher then asks the student about the meaning of the question in the student's problem: "What are you looking for in the problem? ". Without hesitation, Andreas answers that he is looking for the whole and names the problem category (combine). He has now correctly identified the type of problem he has posed. The teacher confirms, but he does not stop there: "Yes, but you wanted to write a comparison problem. He rereads the beginning of the problem: "I have 260 marbles. Chloe has 20." He asks again about the type of questions to ask for a comparison problem. The student then asks: "How many marbles does Chloe need to have the same number of marbles?"

Let's analyze this particular moment. The student has correctly posed and solved a problem that he finally recognized as a combination problem. But as the student indicates that he wants to pose a comparison problem, the teacher helps him to investigate. The teacher's expertise here can be understood in the following way. The teacher does not accept this problem, even if it is correctly recognized, now by the student as a combination problem. He encourages the student to start from his initial choice: the student wanted to compare the number of his marbles to Chloe's - not to know the total number of marbles. It is a question of posing and solving a problem that the student poses to himself; and not of posing and solving "mechanically" a problem by imitating the representation that appears in the repertoire-instrument. The teacher helps the student in this sense, by comparing the representations used by the student (the number line) and the one of the exemplar of the repertoire-instrument. He wants the student to compare the place of the number sought in the two number lines. In Andreas's number line, the teacher simply states that it is the number "at the top" (280) that is being sought. He does not say that in a comparison problem, the number to look for is "down" In the classroom, the number being sought is usually represented by the question mark. Then the teacher directs the student's attention to the problem question. Andreas's quick responses show his knowledge of the problem categories (combine and compare), responding to the teacher's prompts. We know that the repertoire-instrument is next to the student, with the question, "How many centimeters does Chris need to be as tall as Hana?". We cannot determine whether the proximity of the question of the repertoire-instrument is an aid or not.

Discussion & conclusion

The problem posing requires that the students be able to pose and represent a problem, and to solve it by relying on relevant habits. We tried to show the crucial role of the teacher. He is able to lead the student thanks to these habits, the *already-there*. His help focuses on the exemplar of the repertoire-instrument, a shared exemplar that students can imitate and can build on, only after a sufficient study of it. Through this case study, we can see that the teacher leads the student to understand the problem posing task and the role of the exemplar to pose himself new mathematical problems thanks to the repertoire-instrument. On one hand, student succeeds in designing concrete word problems he is able to solve. On the other hand, an abstract theoretical thinking enables the student to move beyond the words and numbers presented in the problem. The student becomes familiar with an appropriate mathematical structure. For example, the student is able to say that he had written a combine problem when he wanted to write a comparison problem. At the same time, the teacher does not let him in posing a "simple" mathematical problem, which answers a problem posing task. But he leads him to pose a problem that matters to this student. The students involved in this sequence seem to do better on the problems in the national assessments, because they know how to represent problems (Fischer *et al*., 2019). To go further, we want to combine two types of analyses: on the one hand, statistical analyses to identify what is effective in these classroom practices on the basis of students' performances (Evidence Based Practice); on the other hand, a documented joint analysis of these practices, by the members of the team, which determines the reasons for the effectiveness of these practices (Practice Based Evidence, PBE).

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Unpacking the Complexity in Video Artifacts: Visible and Audible Dimensions of Teachers' Noticing

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Abstract: Video artifacts can support teachers in learning to notice phenomena like students' mathematical thinking (van Es & Sherin, 2002) and participation (Wager, 2014). Less is known about the physically visible and audible dimensions that teachers attend to while viewing video. Here, I characterize what teachers noticed in videos of classroom interaction in terms of the visible and audible features of their noticings. Teachers noticed four dimensions in video: *Talk, physical artifacts, time* and *bodies*. Teachers noticed seven dimensions of talk in video: *Students' words, teachers' words, interactions, prosody, distribution of talk, background talk,* and *silence*. I argue that these dimensions can add to our understanding of the affordances of video for supporting teachers' noticing. Further, mapping the physically visible and audible dimensions that teachers attend to when viewing video can contribute to our understanding of the conceptual contours of what teachers notice when viewing video.

Introduction

Video has been shown to support veteran and pre-service teachers' (PSTs') noticing and learning to notice (Amador et al., 2021; Santagata et al., 2021), or their attention to and interpretations of facets of classroom interaction (Sherin et al., 2011). Video artifacts uniquely afford teachers the opportunity to examine the complexity of authentic classroom interaction while providing time for careful examination (Sherin, 2004). How video supports that examination has been less explored. One related question is, what do we mean by *complexity* when we describe what is available to be noticed by teachers via video? While the field has begun mapping the conceptual contours of what teachers notice when they notice via video, we know less about the physically visible and audible dimensions of video to which teachers attend.

Research on teacher noticing via video has explored how teachers notice different phenomena such as students' thinking (van Es & Sherin, 2002), strengths in students' thinking (Jilk, 2016), students' ways of knowing that may differ from normative conceptions of "smartness" (Roth McDuffie et al., 2014), and their participation (Wager, 2014). One study, for instance, characterized what teachers noticed about students' thinking along teachers' interpretive dimensions, finding that teachers noticed things like "indicators of learning" and "problems to be addressed" (Colestock & Sherin, 2015). Teachers often attend to what students say as evidence of their thinking (e.g. Sherin & Han, 2004; Goldsmith & Seago, 2013). But what about students' talk do they *see* (e.g. facial expressions or accompanying gestures) and *hear* (e.g. prosody or volume)? What interpretations do teachers draw related to those dimensions? And based on their interpretations about what they saw and heard, how do teachers decide whether a student "learned" or that there is a "problem to be addressed?" These are open questions related to how teachers notice students' thinking. The same questions can be asked about other phenomena that teachers notice, like students' participation.

Exploring what teachers notice in terms of what they physically see and hear via video is important theoretically and practically. Theoretically, beginning to index what teachers notice in terms of what they see and hear can contribute to the field's unpacking what it means or can mean to notice a given phenomenon, or the range of phenomena teachers notice. Practically, we can begin to develop criteria from which teacher educators and teachers can draw to more purposefully record, choose, or segment video for learning purposes, key to the work of facilitating video-based learning opportunities (Kang & van Es, 2019) and itself fertile ground teacher for learning (Richards et al., 2021). As a foray into exploring what we mean by *complexity* (Sherin, 2004) when we describe what is available for teachers to notice via video, I ask: When discussing video of classroom interactions, what did PSTs notice, in terms of what they physically saw and heard?

Methods

These data are part of a larger study designed to explore how first-year elementary mathematics teachers make sense of video artifacts together *without* heavily structured facilitation. Seven PSTs, all recent graduates of the same master's degree program at a mid-sized university in the Midwestern U.S., participated in the meetings. All PSTs intended to teach mathematics in an elementary or middle school setting in the U.S. in the 2022-2023 SY. All PSTs identified as women. Six identified as white and one as biracial: Black and Caucasian. I facilitated two meetings for participants to get comfortable viewing and discussing video together, asking, "What did you notice?" and "What implications can you draw for your practice?" Data sources include the transcripts of the two meetings in which teachers discussed video clips after viewing them together. In total, teachers discussed classroom video for ~42.5 minutes. All videos teachers viewed were publicly available on Teachingchannel.org. I selected videos that showed raw footage of classroom interaction, and chose each clip based on what I imagined might encourage varied interpretations. I did not contribute my own thinking to teachers' discussions about the video, only occasionally interjecting to ask teachers to clarify their thinking.

Phase 1 of analysis included segmenting teachers' talk turns (n=55) by idea unit (Jacobs & Morita, 2002), or the topic of their talk (n=158), and then again by whether teachers were noticing, or attending to and interpreting moments from the video, rather than ideas or experiences outside of the video (e.g. Sherin et al., 2011). Phase 2 of analysis included coding noticing segments (n=90) along the lines of the visible and audible dimensions of video teachers' noticing, using the constant comparison method (Charmaz, 2005). Phase 3 of analysis included coding for dimensions of the category of talk (n=52), one dimension of video that emerged in Phase 3, using the constant comparison method (Charmaz, 2005).

Findings

Teachers noticed four visible or audible dimensions of video: Talk, physical artifacts, time, and bodies

When discussing clips of classroom interaction, teachers talked about what they noticed in the video in about 57% of their total talk turn segments (90 of 158). Across their noticings, they made explicit the physically visible and audible dimensions to which they attended about 84% of the time (76 of 90 noticing segments). Each of these segments were characterized as either talk, physical artifacts, time, or bodies. In these data, teachers attended to talk more often than all of the other visible or audible dimensions of video they attended to combined, ~58% (n=52) of the time. I will further unpack the dimension of talk in Finding 2. Following talk, teachers noticed physical artifacts most often (n=12). They discussed pattern blocks and a ten frame with magnets, as well as papers and whiteboards showcasing student work. When teachers noticed time (n=7) they noticed teachers' wait time, the allotment of time, and the fleeting nature of moments. When teachers noticed bodies (n=5) they noticed gesture and the physical arrangement or physical movement of bodies.

These dimensions of video that teachers noticed can function as an initial framework to explore to what teachers attend, visually and auditorily, when they interpret moments of classroom interaction. We can use these dimensions to explicate what we mean, in physically visible and audible terms, when we describe phenomena that teachers notice, like students' thinking or their participation. We can also explore these dimensions of video that captured teachers' attention to construct and define the range of phenomena that teachers notice via video.

Teachers noticed seven dimensions of talk in video: Students' words, teachers' words, interactions, prosody, distribution of talk, background talk, and silence

Within the category of talk, teachers attended to seven dimensions: Students' words, teachers' words, interactions, prosody, distribution of talk, background talk, and silence or the absence of words (Table 1). While research on teachers' noticing students' thinking has discussed that teachers notice students' talk (e.g. Sherin & Han, 2004; Goldsmith & Seago, 2013), less work has explored the particulars of talk to which teachers attend. We can use these dimensions to explicate what we mean, in physically visible and audible terms, when we describe what teachers notice about students' thinking. Notably, students' thinking is not all that teachers made interpretations about. They made interpretations about pedagogy and relational issues in the classroom, as well. Drawing from the physically visible and audible dimensions of video and talk in video to which teachers attended, we can construct and define the range of conceptually-defined phenomena that teachers notice via video, contributing to the body of research that has begun to map the conceptual contours of teachers' noticing via video.

Table 1
Visible and audible dimensions of talk teachers attended to on video.

Dimension	Description	Example Segment
Students' words	Words, phrases, and questions students used to make their thinking public.	One student saw the equivalent fraction as being like a smaller division of the same amount sort of. *Because she said small triangles would make up the bigger ones.*
Teachers' words	Words, phrases, and questions teachers used to	I really appreciated…the way the teacher affirmed students' sensemaking especially at the end when *he like told the girl, "wow I didn't think about it that way."*

	frame tasks and respond to students.	
Interactions	The order or amalgamation of different speakers' talk turns.	*She's (the teacher) like, "Does anyone think it's false?" and he (a student) wasn't afraid to be like "Yeah I think it's false," even though no one else seemingly felt that answer… and none of the other students were like "How would you think it's false?"*
Prosody	The stress and intonation audible in students' and teachers' words, phrases, and questions.	*I didn't hear in her tone any kind of like shame, you know what I mean? Like it was very much just, "Where'd you make that mistake?"*
Distribution of talk	The amount of words, phrases, and questions offered by different students and teachers.	*I'm still kind of thinking about how much the one girl kind of over here in the video like directly across from the one kid didn't talk as much.*
Background talk	Overlapping and quieter words, phrases, and questions made audible while others were speaking.	*Other kids were immediately like, "Yeah yeah," there is that sense of camaraderie or understanding… a sense of communal understanding without a sense of shame or "you're wrong," you know.*
Silence	The length of pauses between talk turns, and moments without words, phrases, or questions.	*She left a lot of silence while the student was explaining their thinking… until she understood, without asking more questions.*

Discussion and implications

This study contributes to our understanding of how video supports teachers' noticing. By characterizing what teachers noticed along physically visible and audible dimensions, I have begun to unpack how video is uniquely suited to support teachers' noticing and map what we mean by *complexity* (Sherin, 2004) when we refer to the affordances of video for noticing. This study also contributes to our understanding of teachers' noticing via video. The dimensions presented here begin to unpack, in physically visible and audible terms, what teachers attended to in video. These dimensions can be used to further explore what teachers notice when they notice students' thinking (e.g. Colestock & Sherin, 2015) or other phenomena. They can also support the field in continuing to map the conceptual contours of what teachers notice when viewing video, by using the physically visible and audible dimensions of video to which teachers attend as a novel starting point.

Future research can enumerate and refine these dimensions to work toward outlining a more comprehensive framework to represent to what teachers notice via video, and in turn, the unique affordances of video for supporting teachers' learning to notice. Practically, I hope this framework can be expanded and used to further develop criteria from which teacher educators and teachers can draw to more purposefully record, choose, and/or segment video for teacher learning purposes.

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The Black Love Framework: How Remembering Leads to Reimagining STEM Pedagogy

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Abstract: STEM learning spaces have necessitated assimilation for students from minoritized communities. Humanizing pedagogies within STEM learning spaces can serve as an opportunity to broaden participation for historically marginalized youth. Attending to the racialized and gendered intersections of Black students, researchers, and educators, the Black Love Framework provides an opportunity to remember and reconnect cultural ways of knowing and doing within STEM learning. The focus of this research is to highlight the ways Black Love can serve as a pedagogical frame for STEM learning. We argue that community and relationship-building should take precedence beyond the content as the authority within the STEM learning space. Remembering such racial and cultural experiences cultivate a space within education that celebrates and affirms various identities rather than separates or isolates.

Introduction

STEM learning spaces reflect larger aspects of American society such that who is identified as a scientist and science doing is informed by settled hierarchies that privilege Whiteness (Calabrese Barton & Yang, 2000). Students are expected to simultaneously assimilate to cultures of power and thrive in spaces that do not celebrate, encourage, or affirm their culture including language, clothing, and ways of doing (Bang, Warren, Rosebery, & Medin, 2012; Brown, 2006). Science education supports "historically privileged ways of knowing, talking, seeing, and acting shaped by European American practices and values" (Rosebery, Warren, & Tucker-Raymond, 2016, p. 1574). Sense-making and cultural processes are severely undervalued, inaccurately assessed, and overlooked within STEM education. Specifically, minoritized students and teachers such as Black women and girls within science learning spaces contend with assimilation and perforation of who they are and cultures they represent. Collins (2002) theorizes these intersections as a "matrix of domination" (p. 18), due to the multitude of organized structures and systems operating across racial, classed, and gendered boundaries. Particular to STEM, these matrices have been conceptualized as a "double-bind" (Ong et. al., 2011), where women of color experience matrices of domination within STEM workplaces and educational settings because of perpetuated Whiteness (Morton & Parsons, 2018). Therefore, Black girls in STEM at times experience othering and separation, erasure, disinterest, isolation, and irrelevance (Keller, 1985; Ireland, et. al, 2018; Rosa & Mensah, 2016; Roth & Lee, 2004.).

Literature review

STEM tends to be taught from a westernized perspective directly making these spaces rooted in anti-Blackness. Jenkins (2021) defines anti-Blackness as "the socially constructed notion that Black people are non-human, inherently problematic, and disposable, structures the spatial arrangement and social imaginaries of every facet of American society" (p. 111). Ultimately, we consider the question "What does it mean to reimagine the ways in which youth are provided opportunities to engage in science" (Wright, 2016, p. 25)? Considering the call for additional research focused on "integrating the experiences, beliefs, and cultural awareness of Black teachers within spaces of professional learning" (Watkins et. al, 2020, p. 2185), we are presenting a pedagogical framework developed by a Black woman tinkerer and educator while working with Black youth in an informal STEM community-based program. This framework utilizes students' and teachers' experiences inside and outside of the classroom for pedagogical strategies for STEM learning. Essentially, the framework operationalizes experiences in the community and at home for learning (Ladson-Billings, 1992). The act of remembering "refers to the process of bringing to mind a particular event, feeling, or action from one's past experiences and the process of actually putting those memories back together in the present" (Dillard, 2008, p. 91). Remembering and connecting these intimate, deeply complex racialized, gendered, and cultural experiences can support expansive learning experiences and pedagogical practices in STEM. The guiding research question for this work is: *What are humanizing pedagogical practices that affirm (celebrate and recognize) Black students in STEM?* To answer this question, the authors turned to radical remembering to support the development of the Black Love Framework.

Methods

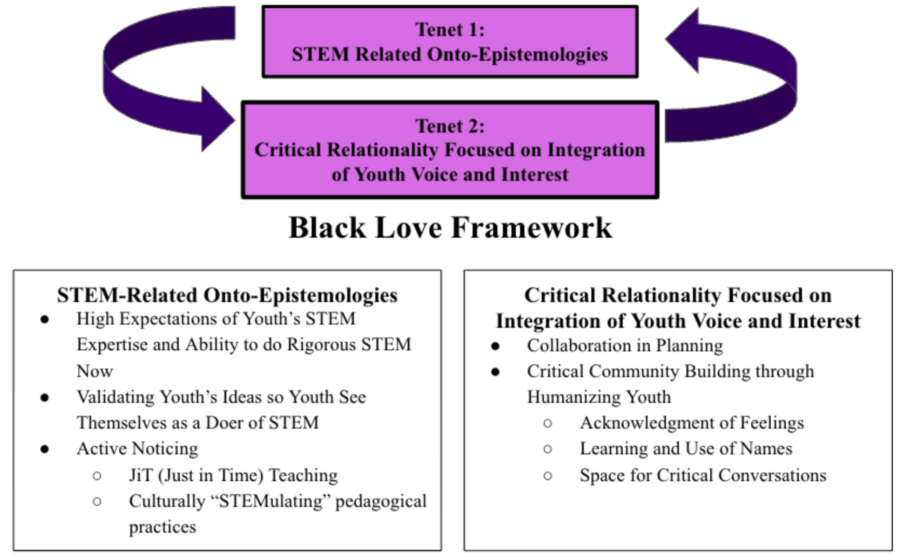
The focus of this paper is to highlight the ways Black Love as a pedagogical frame intentionally attends to the racialized and gendered experiences of Black women in STEM. In an effort to avoid further proliferating and separating deeply woven together experiences that are capable of informing science learning curriculum and instruction, this project makes an attempt to move toward considering whole experiences of Black women and their pedagogies. Crenshaw (1991) argues that "the intersection of racism and sexism factors into Black women's lives in ways that cannot be captured wholly by looking at the race or gender dimensions of those experiences separately" (p. 1244). The authors are two self-identified Black women with undergraduate and graduate degrees in biological sciences and agricultural engineering and currently hold doctorate degrees in STEM education. Previous STEM experiences for both of them have suggested separating these very complex and intertwined identities as a part of science teaching and learning. Worsley reflected on STEM experiences such that "I wondered what the possibilities could have been if I had educators who created spaces for me to engage in STEM in the ways that I wanted" (Worsley, 2022, p. 124). Likely expressed "I wanted [science learning] that could be more applicable to daily scenarios and reflective of cultural practices. But how was I to do that when I had not experienced it?" (Likely & Wright, 2022, p. 149). Reconnecting racial and cultural memories associated with being a Black woman, who self-identifies as a tinker, and science education researcher informed the choices made in the development of the Black Love Framework.

Findings: Development of Black Love

Black Love (Figure 1) pushes against canonical norms that are embedded in science/STEM spaces by fostering, restoring, and humanizing of Blackness within STEM spaces. Black Love is emergent from lived experiences within formal and informal STEM settings, on the ground work within the community, and current facilitation of STEM to Black youth. The framework follows two tenets that are in dynamic relationship with each other: STEM-related onto-epistemologies (Tenet 1) and critical relationality focused on the integration of youth voice and interest (Tenet 2). Black Love is a pedagogical frame that supports the interaction between disciplinary content and relationships between the students and teachers. Each tenet is further expanded in the next sections.

Figure 1

Black Love Framework consists of two tenets that dynamically interact.



Black Love Tenet 1: STEM-related onto-epistemologies

The focus of Tenet 1 is on content through actively engaging in the doing of science and activities. Using an asset-based approach to students' capacity to engage in the STEM doing and learning provides the opportunity for youth to participate in disciplinary learning. SROE are the intersections of who someone is (ontology) and how they develop STEM-related knowledge (epistemology) (Barajas-López & Bang, 2018). When engaging in STEM there are multiple ways to reach solutions and they are informed by youth's SROE. High expectations set a norm that youth put forth the effort and take pride in their work because it is an extension of themselves and follows their interests. Through utilizing various methods. youth begin to see themselves as a doer of STEM.

Black Love Tenet 2: Critical relationality focused on youth voice and interest

Critical relationality means that "my humanity, my integrity, and my dignity are rooted in my willingness to safeguard your humanity, secure your integrity, and protect your dignity" (Olivares & Tucker-Raymond, 2020). This reduces power dynamics and gives youth the agency and confidence to speak up and advocate for their learning (Bettez & Hytten, 2010). Pedagogical practices to support youth interests are collaboration in planning and critical community. Collaboration in planning requires being flexible and also includes receiving feedback from youth, and using it to improve programming (Escudé et al., 2020). Within the learning space, the educator acknowledges feelings, learns and uses names, and makes space for critical conversations that are informed by students' livelihood (Calabrese Barton & Tan, 2020; King & Pringle, 2018).

Implications

Settled hierarchies within science point toward the content being the authority within the learning space. We argue that community and relationship should take precedence beyond the content as the authority within the STEM learning space. By connecting STEM learning with critical community, we remember and reconnect practices to "help us create more affirming and loving spaces of education and personhood for our students, especially Black and Brown students" (Dillard, 2022, p.32). Implications for such radical remembering by people within the margins who have been required to assimilate could serve as the catalyst for change needed in STEM education. The Black Love Framework honors the wisdom in creating learning opportunities, sustained engagement to reimagine possibilities, and developing politicized trust and critical relationality through remembering what science learning has tried to proliferate. The pedagogical strategies supported by Black Love support the wholeness and vulnerability needed for effective teaching (hooks, 2014). Instead of separating identities for specific learning goals, we argue that it is imperative to incorporate a more holistic approach to teaching and learning in STEM pedagogy using strategies such as the Black Love Framework.

Conclusion

Reconnecting racial and cultural experiences within STEM education can cultivate a learning space that celebrates and affirms rather than separates or isolates. "We have to learn to remember the things we have learned to forget" (Dillard, 2022, p.5). When seeking to integrate and leverage students' cultural wealth as a part of learning, we must make it a practice to engage with our memories beyond the classroom to support "expertise as they live and narrate life from their perspectives without censorship or apology" (King, 2021, p. 3). Ultimately, focusing on the intertwined knowledge that is experienced and expressed through culture plus content knowledge are instrumental and necessary for good teaching. Black Love suggests that instructors be prepared to do the active work to support students' learning experiences and build a trusting community. Black Love provides support for Black youth to find joy in STEM-rich making while loving themselves, especially their Blackness, throughout the process (Love, 2019; Worsley & Roby, 2021). Black Love persists beyond the written text of the curriculum and is evident through the pedagogy and assessment to support students' interests in content, scientific vocabulary, phenomenon, and process.

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Identifying Transitions Between Self-Regulated Learning Operations During Game-Based Learning

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Abstract: Self-regulated learning (SRL) is essential while learning with a game-based learning environment (GBLE) to effectively interact with instructional materials, monitor and regulate SRL strategy use, and increase domain knowledge. The field of SRL has had little progress in understanding how learners temporally deploy SRL operations, including Searching, Monitoring, Assembling, Rehearsing, and Translating (SMART; Winne, 2018) , during game-based learning. This study recruited 56 undergraduate students to play Crystal Island, a GBLE focused on increasing microbiology domain knowledge. Using both log-file and eye-tracking data, learners' SMART operations were captured as they completed the game. Results found that learners engaged in Searching and Assembling/Rehearsing significantly more than any other operations. Transition matrices revealed that while some transition sequences were detrimental to learning, directly monitoring after assembling/rehearsing information were positively related to learning gains. These results have implications for designing GBLEs whose features simultaneously promote and discourage the sequential deployment of SMART operations.

Introduction

Given continued developments in advanced learning technologies (ALTs) accompanied by dramatic changes in learning environments over the last decade, researchers and practitioners have increasingly turned to game-based learning environments (GBLEs) as an approach for increasing learner engagement and improving learning outcomes, with generally positive results (Taub et al., 2019). Despite the growing acceptance of GBLEs in the classroom, few studies have examined how learners' interactions with GBLEs are related to their self-regulated learning (SRL) and deployment of SRL strategies within GBLEs (Dever et al., 2021; 2022). Self-regulated learning (SRL) may be viewed as an ability (Dever et al., 2022), a complex system of recursive events (Taub et al., 2017), and a phenomenon (Winne, 2018; Winne & Azevedo, 2022) in which learners implicitly and/or explicitly monitor and regulate by enacting strategies to control their own cognitive, affective, metacognitive, and motivational (CAMM) processes during a goal-directed learning activity (Azevedo et al., 2019; Molenaar et al., 2023; Winne, 2018). Specifically in this study, we operationalize SRL as learners' behaviors within the GBLE (e.g., opening/closing instructional materials) aligned with Winne's (2018) **c**onditions, **o**perations, **p**roducts, **e**valuations, and **s**tandards (COPES) model. The focus of the current work is on the function of SRL SMART operations – searching, monitoring, assembling, rehearsing, and translating – learners' cognitive processes (i.e., searching, monitoring, assembling, rehearsing, translating) that facilitate SRL strategy use and on how learners deploy these SMART operations during learning with a GBLE and their relationship to learning gains.

Prior research with GBLEs in the context of SRL has focused on the use of multimodal data, including both log-file and eye-tracking data, to develop models predictive of learning outcomes (Cloude et al., in press; Dever et al., 2020; Geden et al., 2021). However, there have been calls for a broader application of interdisciplinary methodological approaches and analytical techniques toward understanding learners' deployment of SRL strategies during gameplay (Taub et al., 2017), and specifically, a need to use multichannel data to identify when and how learners enact specific SRL processes within GBLEs. Therefore, in this work, we collected eye-tracking and log-file data to examine the frequency of and transitions between learners' SRL processes while using a GBLE (i.e., Crystal Island) to provide actionable insights for the design of adaptive interventions to induce better learning outcomes through supporting learners' SRL.

Current study

Current SRL literature does not examine how learners deploy the specific SRL operations during learning with GBLEs. Specifically, it is not studied how learners transition between Searching, Monitoring, Assembling, Rehearsing, and Translating operations as they learn with a GBLE. Within the current study, we aim to use multimodal data to examine the frequency with which learners use SRL SMART operations and the transitional relationships between these operations during learning with a GBLE. To begin addressing this gap, we ask three research questions: (1) Are there differences between the frequencies in which participants deploy SMART operations with a GBLE?; (2) How do learners generally transition from one SMART operation to another?; and (3) To what extent do the probabilities of learners' SRL operation transitions relate to learning gains?

Method

Participants and experimental procedure

Undergraduate students ($N = 56$) aged 18 to 26 ($M = 20.1$, $SD = 1.54$) were recruited to play Crystal Island, a GBLE focused on increasing microbiology knowledge. Prior to the start of the experimental session, participants provided informed consent and were calibrated to an eye tracker. Participants then completed a series of questionnaires including a microbiology content knowledge pre-test. Afterwards, participants started Crystal Island in which eye-tracking and log-filed data were collected as learners interacted with non-player characters (NPCs), read instructional materials, moved around the environment, scanned food items for diseases, completed concept matrices, and filled out a diagnostic worksheet. Upon completion of the game, participants were asked to fill out post-test questionnaires including several self-reports and a microbiology content knowledge post-test similar to the pretest. Participants were thanked and compensated for their time $10 an hour up to $30.

Coding and scoring

SMART operations consisted of one or more activities that were directly related to and captured by the Crystal Island environment (see Table 1). These operations were recorded using both log-file and eye-tracking methods where the order in which participants engaged in activities were captured. All participants engaged in each activity and SMART operation.

Table 1
Activities Captured in Crystal Island and their SMART Operation Classification

Activity	Capture Method	SMART Operation Classification
Movement across Pre-Defined Areas	Log File	Searching
Completing Concept Matrices	Eye Tracking	Monitoring
Viewing Posters	Log File	
Filling out Worksheet	Log File	
Reading Books and Research Articles	Eye Tracking	Assembling/Rehearsing
Conversing with NPCs	Log File	
Scanning Food Items & Hypothesizing	Log File	
Submitting Final Diagnosis	Log File	Translating

Learning Gains were calculated using normalized change scores developed by Marx and Cummings (2007). The set of equations calculated the differences in participants' pre- and post-test scores on microbiology content knowledge while controlling for their prior knowledge.

Results

Research question 1: Are there differences between the frequencies in which participants deploy SMART operations?

A within-subjects ANOVA was conducted to examine the differences in the frequency of participants' use of SMART operations. There was an overall significant difference between the four groups, i.e., Searching, Monitoring, Assembling/Rehearsing, and Translating, where participants engaged in Searching and Assembling/Rehearsing operations the most followed by Monitoring and Translating ($F(1.86, 102.22) = 169.9$, $p < .001$). A pairwise t-test with a Bonferroni correction found that all groups were significantly different except for Searching and Assembling/Rehearsing. Participants engaged in Searching and Assembling/Rehearsing more often than any other SMART operation. This is followed by Monitoring and then Translating. For descriptive statistics, refer to Table 2.

Table 2
Means, Standard Deviations, and Pairwise T-Test Scores

Variable	*M*	*SD*	Searching	Monitoring	Assembling/ Rehearsing

Searching	132.5	56.42			
Monitoring	95.8	43.5	-4.54**		
Assembling/Rehearsing	137.91	48.1	0.70	23.2**	
Translating	8.8	4.4	17.3**	15.2**	20.8**

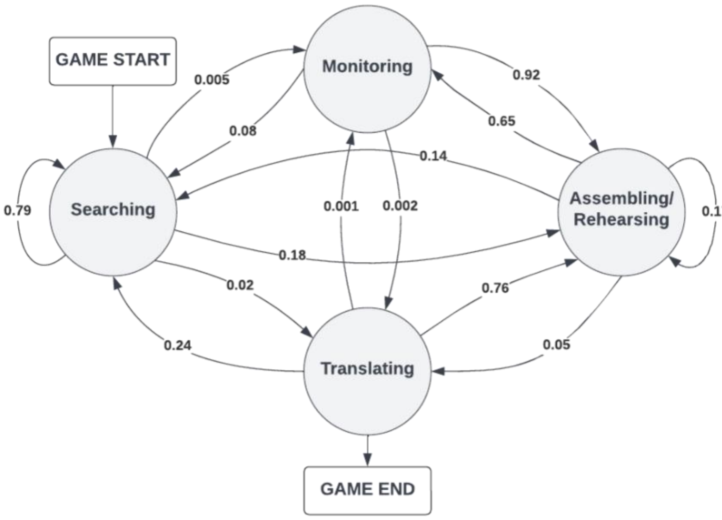
Note. * indicates $p < .05$; ** indicates $p < .01$.

Research question 2: How do learners generally transition from one SMART operation to another?

A transition matrix was calculated to identify the probability each participant would transition from one SMART operation to another. Each participant received a probability across 16 possible transition states. Each transition probability was averaged across participants to create Figure 2, a diagram depicting the average probability that specific state transitions could occur. From the transition probabilities, participants are most likely to transition from Searching to Searching, Monitoring to Assembling/Rehearsing, Assembling/Rehearsing to Monitoring, and Translating to Assembling/Rehearsing. However, it is essential to contextualize the meaning of these transition probabilities in relation to their effectiveness for learning outcomes to fully understand how to better promote learning through participants' deployment of SMART operations.

Figure 2

Diagram showing the average probability a participant would transition from one SMART operation to the next



Research question 3: To what extent do the probabilities of learners' SRL operation transitions relate to learning gains?

Multiple linear regressions were conducted to examine each transitions' relationship to learning gains. Results found that the greater the likelihood a participant had of transitioning from Assembling/Rehearsing to Assembling/Rehearsing ($t = -2.16$, $p < .05$; $\beta = -1.44$) as well as Translating ($t = -2.35$, $p < .05$; $\beta = -3.58$), the lower the learning gains. Conversely, the greater the likelihood a participant had of transition from Assembling/Rehearsing to Monitoring the greater their learning gains ($t = 2.15$, $p<.05$; $\beta = 0.54$). In sum, sequential and recurrent engagement in an Assembling/Rehearsing operation during game-based learning had a detrimental effect on learning gains along with transitioning directly from Assembling/Rehearsing into a Translating operation. However, when participants engage in a Monitoring operation directly after Assembling/Rehearsing more often, learning gains increase.

Discussion and future directions

The purpose of the current study was to examine how learners deploy SMART operations during game-based learning using multimodal data. Findings from this study support the assumptions of SRL models while enhancing Winne's (2018) SMART operations model. Specifically, this study examined how learners temporally engage in SMART operations and how transitions from one type of operation to the next support learning. This study serves as the baseline for future studies to examine the relationships between SMART operations across different GBLEs and domains. From the results, we identify a need to expand this study regarding learners' more detailed use of the SMART operations as well as GBLE design implications. For example, does the duration of each SMART operation influence which operation is next initiated, its quality, and is this related to learning outcomes? Can we identify accurate versus inaccurate SMART operations and does the transition between these (in)accurate SMART operations use relate to learning outcomes or reveal learners' lack of SRL skills? Does the spatial layout of the GBLE influence how SRL SMART operations are deployed through an embedded cognition perspective? Could an analysis of transitions between observed SRL strategies provide more insight than an analysis of observed SRL operations? These questions and future directions elicited by the current study have the potential to better support our understanding of SRL and how GBLEs can be used as a tool to detect, measure, and support SRL processes.

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Supporting Students' Epistemic Agency to Revise a Class Criteria List for Scientific Models

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Abstract: Reforms in science education have called for students to engage in scientific practices. A scientific practice that has received increased attention is modeling. Part of the practice of modeling is the development, use, and evaluation of epistemic criteria which are the standards scientists use to evaluate the validity and accuracy of scientific models. For students to effectively engage with epistemic criteria, they need to be given collective cognitive responsibility, or epistemic agency. This study investigates how the design and implementation of a fifth-grade model-based inquiry unit supported students' epistemic agency to revise an initial class criteria list for scientific models. The findings indicate that reflecting upon peer critique of their scientific models in a written task, and the ways that teachers engaged students in a class discussion to revise the initial class list, supported students' epistemic agency to revise an initial class criteria list for scientific models.

Introduction

Current standards in science education emphasize students learning core scientific ideas through engagement in scientific practices (NGSS, 2013). A part of the practice of scientific modeling is the development, use, and evaluation of epistemic criteria which are the standards that scientists use to evaluate the validity and accuracy of scientific models (Pluta et al., 2011). Examples of epistemic criteria for good scientific models include models should fit the evidence, be conceptually coherent, fit with other established theories, and be parsimonious (Kuhn, 1977). Engaging with epistemic criteria (as an aspect of modeling) provides several benefits to students. First, students will be involved in the analogous scientific reasoning and evaluative processes that are part of the development of scientific models (Chinn & Buckland, 2012). Second, class criteria lists can be scaffolds for communities of learners (Pluta et al., 2011). Third, engaging students with epistemic criteria and understanding how they guide the practice of scientific modeling can build trust and commitment to them.

For students to authentically engage with epistemic criteria in scientific inquiry environments, it is helpful to have collective cognitive responsibility, or *epistemic agency*, which is the responsibility to shape knowledge and practices of a community (Damsa et al., 2010; Stroupe, 2014). Epistemic agency is an emergent characteristic of a group which enables the group to make progress on a shared knowledge object (Damsa et al., 2010). Epistemic agency is visible in the ways that the members of a group jointly negotiate the collective collaboration of a shared knowledge object. Fostering epistemic agency in students is important because, "…we assume, both individual learners and groups with a higher sense of agency should have a greater potential to engage in productive collaborative activities that generate new knowledge" (Damsa et al., 2010, pp. 146). The purpose of this study is to show how students were afforded epistemic agency to revise an initial class criteria list for scientific models through reflecting on peer critique in a written task and teachers' supportive discursive moves in a class discussion.

Theoretical framework

Epistemic criteria

Pluta et al. (2011) found that students *generated* a range of normative criteria for scientific models that were categorized as goals of models (i.e., models explain or describe), model constituents (i.e., pictures, words, diagrams etc.), communicative elements (i.e., clarity, focus, organization, etc.), evidential criteria (i.e., explicitly references evidence), and epistemic elements (i.e., accuracy, interest, realism etc.). However, prior research has not focused on students' revision of a class criteria list which can reflect students' valuing of criteria by which criteria they choose to add, revise, or remove from the initial class criteria list.

Epistemic agency

Prior educational research has shown ways that students' have been afforded epistemic agency in science classrooms. Teachers can position students as epistemic agents with effective discursive moves such as an epistemic press which is a public statement about a scientific idea, for example, requesting evidence; asking questions to clarify a point, solicit information, encourage participation, or probe metacognitive understanding; publicizing private ideas by revoicing or summarizing students' statements; dismissing or extracting students' science ideas during discussion; and providing space for tangential talk (Stroupe et al, 2014). Stroupe et al. (2018) positioned students as epistemic agents by inviting them to cocreate the space therefore attributing value to their ideas. Students suggested areas of research, and designed methods and knowledge products, therefore using their epistemic agency to guide the unit in new directions.

Prior studies have made gains in promoting students' epistemic agency in science classrooms, but they have focused on students' agency in terms of what to study, which methods to use, and which questions to ask (Stroupe et al., 2018). There had not yet been an investigation into students' epistemic agency regarding students' considerations about a good explanation or necessary evidence, or how to facilitate students' development of robust criteria. A study of this kind would be significant because students' valuation of criteria can affect how they engage in scientific modeling (Ryu & Sandoval, 2012). The aim of this study is to extend prior research by asking *how does the design and facilitation of a model-based inquiry unit support students' epistemic agency to revise a class criteria list for scientific models?*

Methods

Participants and context

The unit was taught in a public charter school in the Northeast of the United States. The school performs above average on standardized state tests on Mathematics, Language Arts and Science. The demographics of the school were 60% White, 22% Asian, 9% African American, 7% Latinx, and 2% other; 5% of students were eligible for free and reduced lunch. The study was conducted in a fifth-grade classroom, Class A, during a five-week model-based inquiry unit with 25 students. Students made models in a new modeling software called MEME (Model and Evidence Mapping Environment) (Danish et al., 2019) that enabled them to create components and link them with arrows (mechanisms) to provide a causal account of why fish were dying in a local pond (a eutrophication phenomenon). Students reviewed evidence in the form of reports and simulations to develop the model and linked the evidence to support the various parts of the model.

At the start of the unit, each class developed an initial class list of criteria for scientific models which scaffolded model development, evaluation, and revision. At a mid-point in the unit, students provided critique to each other's models in a gallery walk. Students displayed their models in MEME and used the "comment" box to give feedback to peers. The gallery walk was positioned to occur before the revision of the initial class criteria list to inspire students to think about criteria. By providing critiques, students assessed how well the models met the class criteria and how useful the criteria were in evaluating the models. After the gallery walk, students reflected on the critique in a written task in which they wrote down with a partner which criteria they thought should be added, revised, or removed from the initial class criteria list. In a class discussion immediately following the written task, teachers drew on students' suggestions to revise the class criteria list. The class ended up with a final class criteria list composed of five shared and agreed-upon criteria for good models.

Data collection and analysis

The data for this study are from the written task and class discussion. The written data was categorized into which criteria students thought should be added, revised, or removed, and then by the type of criteria they referred to. For example, whether the statement suggested a revision to a criterion about evidence or understandability. We then counted the frequencies of statements that referred to each type of criteria. The class discussions were audio and video recorded from multiple angles and there were microphones on students in two focus groups in each class. The videos of the class discussions were viewed multiple times to identify the kinds of suggestions students gave for what criteria should be added, revised, and removed, and how classroom discourse between students, and between students and the teacher, shaped the final class criteria list. We used content analysis to code the class discussions (Schreier, 2012). A students' suggestion marked the start of an episode. We coded the discussion moves as supporting students' epistemic agency if there was uptake of students' ideas that preserved and built upon the meaning in the students' statements. For example, a teacher asked a clarifying question to ensure she properly understood what the student said and thus retained the meaning of the students' statement. A discussion move was coded as not supporting students' agency if it diverted away from the meaning of the students' statement. For example, a teacher reframed a students' contribution which introduced new language and took attention away from the meaning in the students' contribution.

Results and discussion

The written task, in which students reflected upon peer critique, and the class discussion, in which students' suggestions were supported in various ways, prepared students to revise the initial class criteria lists (Table 1).

Table 1
The initial and final class criteria lists in Class A

Class A: Initial Class Criteria List	Class A: Final Class Criteria List
1. Be on topic with accurate information	1. Model should *make sense*
2. Include a main focus supported with reasons and evidence	2. Components and mechanisms should be *clearly* ordered and labeled to show a start to finish
3. Be neat and organized	3. Each component and mechanism should have a *clear* explanation supported with reasons and evidence
4. Use a specific order	4. The mechanisms should be *understandable* sentences
5. Have labels within a visual representation of data	5. Model should have a main focus that includes all components and mechanisms

Students' written data reveals a theme: models being understandable. 11/14 students' statements about which criteria should be added and 12/19 statements about which criteria should be revised were about models being understandable. Four students suggested adding a criterion about a clear start and three students stated to add a criterion about models making sense. Five students wanted to combine "*neat and organized*" with "*use a specific order*" and four students suggested replacing both these criteria with "*models should make sense.*" Students' ideas, that models should be understandable, are shown in the final class criteria list in the language "make sense," "clear," and "understandable" in the following criteria: "*models should make sense,*" "*components and mechanisms should be clearly ordered and labeled,*" "*each component and mechanism should have a clear explanation,*" and "*mechanisms should be understandable sentences*" (Table 1). The written task supported students' epistemic agency because students reflected on which criteria they valued. They developed good quality knowledge (criteria) which shows they had the responsibility to shape knowledge and knowledge products in their classroom community. Students had agency over their lists because they generated the criteria based on their own (and not the teacher's) ideas and they held each other accountable by their critiques.

The teacher facilitated the class discussion in ways that supported students' epistemic agency to revise the initial class criteria lists. The teacher supported Lily's epistemic agency to include a criterion termed, "*fully evidenced.*" Lily's reason for suggesting this criterion was that one group had included a mechanism in their model that said, "which makes this" (e.g., nutrients "makes this" algal bloom). Lily's explanation (line 3) shows that she did not think the label on the mechanism, "which makes this" adequately explained how the two components were connected. Note: square brackets provide clarification.

1 Lily: Like, I think it [the class criteria list] should also have one that says, like, "*fully evidenced*" because, like, some… one of the groups, they wrote, like, something… they didn't really write anything, but… they wrote something, but they didn't write anything that related to the mechanism.
2 Teacher: Like clear explanations?
3 Lily: For mechanism, they wrote umm… "which makes this" and then had a component and it didn't really say anything like how they [the components] connected to each other.
4 Teacher: So, was the explanation not clear or was the evidence not linked? I feel like you're saying two different things. Or was it both?
5 Lily: Both.
6 Teacher: So, we have "include a main focus supported with reasons and evidence". Do you want to revise that? [Lily nods.] What do you want it to say?
7 Lily: That it should have like understandable evidence that makes sense.
8 Teacher: So, each component and mechanism should have a clear explanation with appropriate evidence? What do you guys think? Does that make sense? Is that a little more specific? Okay. So, each component and mechanism should have a clear explanation- Lily, is that what you want to say?
9 Lily: Yeah.
10 Teacher: Supported by reasons and evidence [end of episode].

The teacher in Class A interacted with Lily in specific ways which supported Lily's agency when revising the class criteria list. The teacher asked Lily a clarifying question, "Like clear explanations?" to better understand Lily's suggestion (line 2). Lily explained that the mechanism did not explain how the components were connected (line 3). The teacher followed up with another clarifying question (line 4) in which the teacher rephrased what she thought Lily said to identify multiple aspects of Lily's statement and bring attention to each. The teacher then draws attention to an existing criterion and asks Lily if she wants to revise it (line 6). Here, the teacher highlights that Lily's suggestion is like an existing criterion, but she asks Lily if she wants to revise the existing criterion and what she wants it to say, thus preserving Lily's agency to direct the way her suggestion will alter the initial class list. Finally, the teacher asked what the class thought and asked Lily what she thought of the criterion, thus seeking confirmation from Lily and consensus from the class (line 8). This episode resulted in the criterion, "*each component and mechanisms should have a clear explanation supported by reasons and evidence.*"

Conclusion and implications

This study shows how the design and implementation of a fifth grade MBI unit supported students' epistemic agency to revise a class criteria list for scientific models. The findings build on prior research by showing not only which kinds of criteria students develop (Pluta et al., 2011), but the criteria they value by how they revise an initial class criteria list, and how to afford students with epistemic agency, not only by asking questions, selecting what to study, or designing methods (Stroupe et al., 2018), but by building a knowledge product that reflects students values about the standards (criteria) for scientific models. Providing students with the opportunity to reflect upon critique in a written task, and the ways that the teacher engaged students in a class discussion, supported students' epistemic agency to revise a class criteria list for scientific models. Teachers can support students' epistemic agency in class discussions by asking clarifying questions, paraphrasing in a way that retains the student's meaning, checking with the student to ensure the meaning has been adequately captured, seeking class consensus, and giving students choice on how they want their suggestion to alter the initial list (by being added as an additional criterion or revising an existing criterion). The findings have implications for design research because they suggest ways that students' epistemic agency can be supported to develop criteria for epistemic products such as scientific models. The findings have implications for teacher practice because they show ways that teachers can support students' epistemic agency during class discussions to revise a criteria list.

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Studying Whether Expansive Framing and Authorship Impact Transfer Using Statistical Discourse Analysis

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Abstract: We analyzed the relationship between the engagement strategies of expansive framing and authorial positioning with the transfer of online learning. Mixed methods were used to analyze 1154 discussion posts and 156 ePortfolios in a semi-synchronous graduate course on educational assessment. Open qualitative coding and statistical discourse analysis modeled the influence of peer and instructor interactions on the display of authorship, accountability, and transfer strategies. We found evidence of sustained roles of authoritative and accountable positioning by participants and the use of strategies presumed to foster generative learning that transfers readily and widely. These findings are discussed in light of the theoretical explanations of why expansive framing should support transfer.

Introduction

The engagement strategy known as *expansive framing* assumes that broader social and linguistic connections within learning activities can promote the development of learners' capacity to generate and adapt disciplinary knowledge in subsequent engagements (i.e., transfer, Engle, 2006; Engle et al., 2012). Engle et al. (2011) conducted a one-on-one tutoring experiment where tutoring interactions used expansive framing or bounded framing. The expansive condition pushed students to make numerous connections with outside people, places, topics, and times and positioned learners as "authors" who were respondents to the texts. The bounded condition did not push learners to make connections beyond the tutoring context. Students in the expansively framed tutoring condition were more likely to transfer and adapt learned concepts and knowledge to new problems. More recently, Tierney et al. (2020) conducted several studies in a design-based research project on developing students' connected identities within an environmental sciences course. Their initial study examined a detailed case analysis of students and their teacher's development of agency and connected identities. Two follow-up studies used comparative analyses of expansively framed activities across course design iterations. Their findings indicated initial support for the relevance of expansive framing in developing broader, more connected disciplinary identities for learners.

A systematic review by Hickey, et al. (2021) confirmed that expansive framing has been employed in dozens of interventions. But expansively framed engagement remains largely unexplored and has yet to be examined using learning analytics. For example, the actual processes by which expansively framed engagement promotes transfer remain unproven. This study seeks to explore these connections in relation to proposed explanations linking authorship and expansive framing in Engle et al. (2012).

Expansive framing, accountability, and authorship

Engle et al. (2012) proposed five explanations for how expansively framing engagement might support the transfer of knowledge. The first two explanations deal with how connecting settings within learning tasks promotes the expectations of transfer and prioritizing previous knowledge as relevant to current and future learning tasks. The third explanation focuses on the links between authorship and prior settings in promoting the transfer-in of knowledge. The fourth and fifth explanations, however, center on how authorship promotes accountability to disciplinary knowledge and promotes the generation and adaptation of knowledge in new contexts.

These last two explanations are the focus of the current study. The development of authorship should be recognized by peers and instructors in collaboration with a student. This recognition of authorship should lead to further authoritative positioning by students. This authoritative positioning also enables participants to hold each other accountable to disciplinary practices, thereby leading to social "pressure" for participants to regularly hold themselves accountable as authors of disciplinary knowledge. Here, we explore these two explanations in the context of an online course on educational assessment. Specifically, we seek to answer the following question: does peer and instructor collaboration enable students to position themselves as authors accountable to disciplinary standards? If so, does this continued positioning support the development of transfer strategies such as generating examples, making generalizations, and making comparisons?

Course design, context, and hypotheses

This course has been iteratively refined and developed as part of a decade-long ongoing design-based research project (Hickey & Rehak, 2013; Hickey et al., 2020). The course design facilitates learners' development of disciplinary knowledge and practices in educational assessment through agentic engagement. This is accomplished through students regularly responding to prompts that guide them in problematizing course content from the perspective of a personally relevant curricular aim and context. These responses are shared on public (to the class) ePortfolios where peers and the instructor comment on a student's engagement in the assignment. We posit that if the explanations on authorship and transfer in Engle et al. (2012) are viable, then links between previous authoritative engagements should occur and such engagements should contribute to enhanced transfer.

Participants, data, and methods

Fifteen students who completed the course in 2020 were asked to participate or opt-out of having their data used in this study. No students opted out. This study examined 162 distinct ePortfolio assignments and their corresponding threaded discussion posts (n = 1475) by peers, the instructor, and the ePortfolio author.

Methods & analysis

This study occurred in two stages and incorporated a mixed-method design. In the first stage, we conducted qualitative coding of students' ePortfolio responses and discussion posts. Next, we used statistical discourse analysis (Chiu & Fujita, 2014) to model relations between these coded posts.

Coding procedures

Codes for expansive framing, authorship, and accountability were adopted from Andrews et al., (2019). Codes for transfer strategies were developed from general transfer processes (i.e., generating examples, making generalizations, and making comparisons) that are widely assumed to promote transfer (National Research Council, 2000). The transfer codes were attributed as evidence of a post's author adapting or generating knowledge across contexts. All codes assigned were binary indicators for whether a participant's response exhibited a coding category. Coding was conducted transparently and openly by the first author through three audit sessions (Cresswell & Miller, 2000).

Statistical discourse analysis

Statistical models of conversations present several challenges to the assumptions of independence of observations and the homogeneity of variance in standard regression techniques. Chiu & Fujita (2014) developed procedures under the umbrella of statistical discourse analysis to mitigate these issues. First, talk is clustered in terms of specific conversational instances through multi-level models (i.e., models that include fixed and random effects to contend with clustered or repeated data). Second, lagged variables are included through vector autoregression, which deals with the sequenced dependency of conversational turns. Following Chiu & Fujita, sequencing posts in terms of their threaded replies rather than temporal order in the discussion is also required for asynchronous discussion forums. This reduced the modeled data to 1145 posts that were replies to prior comments in 156 ePortfolio assignment responses. Codes from the t-1 variables (i.e., the immediately prior posts) were used in the model along with codes from the ePortfolios (as t-2) variables. All code variables were binary. Post-authorship (i.e., peer and instructor roles) were also used as regressors.

Using ePortfolio discussion posts as units of analysis, we constructed multi-level logistic regression models with codes for authorship, accountability, and transfer strategies as dependent variables. Models were fitted in R using mixed effect and Bayesian mixed effect models where evidence of partial to complete separation (see Heinze & Schemper, 2002) was observed in parameter standard errors or indicated by issues in model convergence. All R cleaning and analysis scripts are available within an OSF repository (https://osf.io/w4rnv) for replication.

Results

Table 1 presents the exponentiated model parameters for the relationship between previous displays of expansive framing, authorship & accountability, and a given post's display of authorship and accountability. While no statistically significant relations were generally observed in the expansive framing variables, the presence of authorship and accountability within the ePortfolios increased the odds that a comment would display authorship and accountability by an average of 1.86 and 2.11, respectively. The prior comment's display of expansively framed participants (i.e., individuals outside the class context) was also borderline significant within an alpha level of 0.05, though these results should be considered in relation to type-1 errors. Additionally, if the previous comment displayed evidence of accountability, the next comment had an average increase in the odds of it displaying accountability by a factor of 2.24. It also seems that comments made by the instructor were much more likely to display authoritative positioning. When a comment was made by an instructor, it increased the odds of authoritative positioning in a comment by a factor of 4.15 relative to comments made by peers with a factor of 2.59, both significant. These observations suggest evidence for authorship and accountability as being promoted socially, thereby providing support for Engle et al's (2012) fourth explanation.

Table 1
Statistical Discourse Analysis of Authorship & Accountability

	authorship			**accountability**		
Predictors	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*
(Intercept)	0.21	0.09 – 0.46	**<0.001**	0.02	0.00 – 0.08	**<0.001**
author role [instructor]	4.15	2.61 – 6.60	**<0.001**	0.95	0.44 – 2.07	0.906
author role [peer]	2.59	1.72 – 3.92	**<0.001**	1.02	0.52 – 2.00	0.960
ePortfolio time past	1.00	0.71 – 1.41	0.988	0.76	0.43 – 1.33	0.332
ePortfolio time future	0.91	0.64 – 1.29	0.592	0.60	0.33 – 1.12	0.111
ePortfolio participants	1.32	0.89 – 1.96	0.170	1.78	0.93 – 3.44	0.084
ePortfolio places	0.96	0.66 – 1.39	0.831	0.81	0.43 – 1.55	0.527
ePortfolio topics	0.74	0.50 – 1.09	0.125	1.46	0.71 – 3.02	0.306
ePortfolio authorship	1.86	1.05 – 3.28	**0.033**	2.61	0.72 – 9.46	0.144
ePortfolio accountability	1.08	0.73 – 1.59	0.714	2.11	1.12 – 3.96	**0.020**
time past lag1	0.63	0.34 – 1.17	0.144	0.90	0.36 – 2.27	0.829
time future lag1	0.31	0.08 – 1.21	0.092	0.29	0.03 – 2.90	0.291
participants lag1	1.28	0.79 – 2.08	0.316	2.02	1.00 – 4.09	**0.050**
places lag1	1.36	0.79 – 2.34	0.270	1.54	0.72 – 3.27	0.265
topics lag1	1.12	0.55 – 2.28	0.758	0.99	0.35 – 2.81	0.979
authorship lag1	0.98	0.68 – 1.41	0.903	0.96	0.54 – 1.68	0.877
accountability lag1	1.16	0.70 – 1.90	0.572	2.24	1.17 – 4.31	**0.016**
author role lag1 [instructor]	0.96	0.52 – 1.77	0.903	1.34	0.54 – 3.30	0.525
author role lag1 [peer]	0.70	0.48 – 1.02	0.061	0.92	0.48 – 1.77	0.794
Random Effects						
σ^2	3.29			3.29		
τ_{00}	0.27 $_{\text{discussion\_topic\_id}}$			0.43 $_{\text{discussion\_topic\_id}}$		
ICC	0.07			0.12		
N	156 $_{\text{discussion\_topic\_id}}$			156 $_{\text{discussion\_topic\_id}}$		
Observations	1145			1145		
Marginal R^2 / Conditional R^2	0.134 / 0.199			0.150 / 0.249		

Table 2 presents the exponentiated parameters for each transfer strategy model. Given the lack of influence of expansive framing in prior posts in the previous models, only authorship and accountability in previous comments were used as lag variables along with the ePortfolios' display of expansive framing codes. No statistically significant relationships between expansively framed engagement and transfer strategies were observed. However, the ePortfolios' display of experiences prior (times past) to the course reduced the odds of a post displaying generalizations. ePortfolios' display of expansively framed participants was borderline significant for a post's likelihood to display generalizations with an average increase in the odds of 2.8. Prior comments from the instructor also increased the odds that the subsequent post would display generalizations by a factor of 4.33. These results, therefore, present a somewhat mixed account of the explanation of positioning students as accountable authors enabling them to adapt or generate new knowledge.

Table 2
Statistical Discourse Analysis of Transfer Strategies

	generates_example			**generalizations**			**comparisons**		
Predictors	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*
(Intercept)	0.16	0.06 – 0.39	**<0.001**	0.00	0.00 – 0.02	**<0.001**	0.03	0.00 – 0.21	**0.001**
author role [instructor]	1.20	0.63 – 2.30	0.578	1.58	0.40 – 6.26	0.515	0.32	0.09 – 1.14	0.078
author role [peer]	1.85	1.07 – 3.20	**0.027**	3.83	1.31 – 11.23	**0.014**	1.03	0.41 – 2.57	0.950
ePortfolio time past	1.21	0.82 – 1.79	0.339	0.41	0.17 – 0.98	**0.046**	0.76	0.30 – 1.89	0.551
ePortfolio time future	0.89	0.59 – 1.34	0.569	0.69	0.27 – 1.78	0.447	0.97	0.39 – 2.42	0.941
ePortfolio participants	0.92	0.58 – 1.46	0.728	1.73	0.68 – 4.45	0.252	0.86	0.30 – 2.42	0.770
ePortfolio places	1.29	0.84 – 1.99	0.252	2.80	1.00 – 7.86	**0.050**	1.47	0.55 – 3.92	0.444
ePortfolio topics	0.82	0.52 – 1.29	0.380	2.81	0.82 – 9.58	0.100	0.67	0.25 – 1.78	0.418
ePortfolio authorship	0.78	0.43 – 1.42	0.424	1.49	0.33 – 6.66	0.604	1.63	0.37 – 7.22	0.519
ePortfolio accountability	1.03	0.66 – 1.62	0.896	1.32	0.52 – 3.36	0.564	0.72	0.25 – 2.06	0.537
authorship lag1	0.73	0.46 – 1.18	0.197	0.92	0.38 – 2.22	0.857	0.69	0.30 – 1.59	0.383
accountability lag1	1.17	0.61 – 2.23	0.637	1.10	0.36 – 3.33	0.865	1.64	0.59 – 4.56	0.344
author role lag1 [instructor]	0.83	0.37 – 1.88	0.661	4.33	1.27 – 14.83	**0.020**	0.18	0.02 – 1.60	0.125
author role lag1 [peer]	0.75	0.46 – 1.23	0.251	1.23	0.46 – 3.27	0.677	0.89	0.36 – 2.19	0.797
Random Effects									
σ^2	3.29			3.29			3.29		
τ_{00}	0.16 $_{\text{discussion\_topic\_id}}$			0.84 $_{\text{discussion\_topic\_id}}$			2.11 $_{\text{discussion\_topic\_id}}$		
ICC	0.05			0.20			0.39		
N	156 $_{\text{discussion\_topic\_id}}$			156 $_{\text{discussion\_topic\_id}}$			156 $_{\text{discussion\_topic\_id}}$		
Observations	1145			1145			1145		
Marginal R^2 / Conditional R^2	0.065 / 0.108			0.226 / 0.384			0.082 / 0.441		

Discussion

These initial findings provide some evidence of the explanations of the importance of authorship and accountability in Engle et al. (2012) contributing to participants' sustained authoritative positioning. However, the presence of accountability and authorship was not directly observed to contribute to the display of transfer strategies. Furthermore, we observed few relationships between the use of expansive framing and transfer, as evidenced by the use of transfer strategies. Importantly, Engle et al. noted that positioning learners as authors need not involve expansively framed activities to encourage the transfer of knowledge. However, we found little indication from these observations that such adaptations occurred, at least in terms of the codes used in this study.

These outcomes suggest several possibilities. First, modifications to the coding analysis may be called for. Specifically, modification of the coding scheme to reflect more nuanced descriptions of both expansive framing, authorship & accountability, and transfer rather than simple binary indicators may reveal more insights. Alternatively, it is possible that the explanation of linking authorship and expansive framing may be incorrect. Alternative mechanisms of transfer, such as concreteness fading (see Goldstone & Son, 2005), posit that increased use of concrete representations may interfere with the later transfer of knowledge. In such a framework, expansive framing may present complications in the ability of students to adapt knowledge due to an increase in information a learner needs to engage with. While such a perspective presents alternative theoretical and epistemological commitments to knowing and learning, comparing these frameworks' utility in learners' transference of knowledge may reveal further clarification on what is being transferred and how such adaptations occur. Future work, then, will seek to make these modifications and extend these comparative analyses through experimental designs.

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Giving Voice to Kosovar Teachers: Experience and Reflections on Play-Based Math Learning in the Classroom

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Abstract: According to PISA results, Kosovo students performed worst in Europe and in the bottom three out of all 77 participating countries. It may be due to the discrepancy between PISA's focus on problem-solving and Kosovo's explicit pedagogical mode of instruction. Here, we present initial findings from an ongoing project, which aims to support educators in fostering students' active participation and more play-based learning in early childhood math education. We conducted an interview study in three schools to evaluate what active and playful learning looks like to Kosovar teachers, considering the specific challenges and affordances of the local educational context, as well as unique challenges posed by COVID in a developing European country. Student-driven, playful learning is welcomed but rarely implemented digitally. Lack of resources and skepticism about digitization were major barriers to broader implementation.

Context and background: Kosovo

In this short report, we present a part of an ongoing project with Kosovar teachers exploring challenges and opportunities in transforming early math education in a developing European country. Kosovo, once an autonomous region in former Yugoslavia, experienced drastic transitions since the 1990s. After recent civil wars and armed conflicts, Kosovo now ranks among the poorest countries in Eastern Europe (World Bank, 2022). These events had a devastating effect on the educational system, with closings of state-funded early childhood education institutions and a sharp decline in enrollment (Ibra-Zariqi, 2019). There are now numerous systemic challenges to providing high-quality early education, including a lack of teacher training, difficulties in recruiting qualified teachers, high workloads, and underpayment (Haxhikadrija, 2019). Unfortunately, government expenditures on education are low, with only 0.1% of GDP allocated to early education (Ibra-Zariqi, 2019).

According to the 2018 Programme for International Student Assessment (PISA) test results, Kosovo ranked well below average overall, and below all participating European countries—ranking 75th out of 77 surveyed countries (OECD, 2019). Math was the subject in which Kosovo performed lowest. Because mathematics is a particularly good predictor of later life prospects (Ricthie & Bates, 2013), there is an evident need for more effective math instruction. Indeed, research indicates that instructional approaches in Kosovar schools are typically limited to explicit instruction, often based on learning by rote memorization. Researchers previously noted a lack of awareness and knowledge of more child-centered pedagogical approaches in Kosovo (Kadriu & Gougeon, 2014; OECD, 2017). Unfortunately, recent evidence indicated no progress in educational quality, despite this being an area requiring significant improvement (EU Progress Report, 2020).

A major impediment to educational progress in Kosovo is the challenge of digitizing its educational system (Government of Kosovo, 2016). No national distance learning system existed at the start of the COVID19 pandemic in 2020. Moreover, internet access is not widespread. Consequently, the pandemic caused severe disruptions to education with some children left without schooling for several months (UNICEF Kosovo Programme, 2022). UNICEF supported Kosovo in setting up the e-learning platform shkollat.org; other existing platforms have also been used to ensure learning continuity, such as public television and YouTube, yet, among teachers, there is an overall sense of this being "too little, too late."

Within the math context, the best predictor for future achievement are basic mathematical skills that underlie early numerical learning (Gashaj, Oberer, Mast, & Roebers, 2019). Despite a lack of agreement on the best pedagogy, one promising direction comes from play-based instructional approaches, which come with strong scientific support (e.g., Ginsburg, 2006; Hirsh-Pasek, Golinkoff, Berk, & Singer, 2009). There, scaffolding through appropriate materials coupled with expert guidance appears to increase learning and foster a more positive attitude towards learning. A fundamental step towards enhancing early math education in Kosovo is to better understand its current state. The present study focused on understanding the current use of play-based instruction in math learning. Preschool teachers in Kosovo seemed interested in play-based activities but preferred nondigital over digitally supported ones (Gjelaj, Buza, Shatri, & Zabeli, 2020). As this was pre-COVID, we were interested in whether and how Kosovar teachers embraced digitization after pandemic-related educational disruptions.

Method

Participants were teachers in primary schools instructing children from kindergarten to 5th grade. By design, the schools differed in terms of resources. One of the schools was a private institution (commonplace in Kosovo), and two were public. The schools were selected due to their willingness to participate. When writing this article, 12 teachers were interviewed by the first author in their native language. The semi-structured interviews (average length of 90 minutes) explored teachers' beliefs, practices, and challenges in implementing play-based mathematics learning. Questions were taken from Russo, Bragg, and Russo (2021), Allsop and Jessel (2015), and Jesmin and Ley (2020). All questions were adapted and translated into one of Kosovo's official languages by the first and senior author. These preliminary results reflect Albanian-speaking schools.

We report on survey responses complemented by a discussion of selected teacher responses. The selected excerpts, identified through inductive analysis of the interview data and discussion among the authors, reflect three distinct viewpoints on play-based learning. The names of contributing teachers were anonymized. Ermond is a male teacher in his early forties in a rural area with two years of teaching experience. Zanfina is a female teacher in her early twenties, teaching in a private institution in the capital, with one year of experience. Finally, Anduena is a female teacher in her fifties with three decades of teaching experience in rural areas.

Results and discussion

All participants reported using play-based activities "all the time" or "often" during math instruction. The teachers agreed on when play-based activities should be used, stating they would "use play-based activities mostly to introduce new math concepts, to consolidate learning, and add variety to their classes." When asked about the effectiveness of these play-based activities, teachers agreed that they are "effective for engagement and on-task behavior, but also to acquire general skills." Additionally, play-based activities were generally perceived as "supporting the understanding of and connections between math concepts, as well as facilitating problem-solving skills." Despite this, the teachers disagreed on a number of important points, as seen below.

Use of play-based activities

When we asked teachers "How frequently do you play math games in your classroom, and what materials do you mostly use?" The following answers were given. According to Ermond, there were few opportunities to employ play-based activities, and he practiced more direct instruction than he would like to:

> I lack materials and time… All materials must be bought by the teacher, that's why I usually use verbal quizzes and let one student summarize what we learned while the other students can elaborate on it. So, we teach a lot of theory, but it can't be practiced. If our students can't practice what they learn, they can't learn in higher levels. Low salaries and insufficient materials make it very difficult to switch from direct instruction to more child-centered approaches.

The most used materials were blank papers used as pretend money, or cards for card games. Less frequently, teachers also used traditional mathematical manipulatives (such as Cuisinaire rods) and commercial games (such as Ludo). Anduena told us she used "cards for a game for multiplication, Dominos, self-made money from paper, PlayDooh to make the numbers or magnitudes and enhance fine motor skills." Zanfina also reported using "different kinds of dice, cards with numbers, blocks in the form of numbers."

Anduena was undeterred by a lack of available materials. She mentioned:

> I connect math with physical education, use gestures for learning the signs smaller than, greater than, equal, tell the children to build groups of *x* students, so they learn numbers and magnitudes by building groups for a team. For example, a football (soccer) game—when they play football or other known games, they have to count the goals. Sometimes I make them count their steps, estimate how far away their friends are standing, and so on.

Many of the teachers described creative examples of play-based activities. For instance, using hoola hoop rings that were held by some children while another one had to throw a ball through them to be awarded points. As children earned different numbers of points from throwing the ball through different rings, they had to count/calculate to come to their final score. When we asked them "Where do you find ideas for math games in your classroom?" most reported being inspired by colleagues, but also social media, and Anduena's response seems typical: "Nowadays, I use social media; there is nothing you can't find on Instagram and Pinterest!"

The broad trend for surveyed teachers was that they valued play-based activities, and believed that these activities are beneficial and effective, but also perceived a lack of (digital) resources, both in terms of training and materials. This scarcity issue became utterly apparent during the pandemic when digital services were the primary means to ensure at least basic schooling. As such, we also investigated teachers' teachers' attitudes and experiences with digital technologies and as digital games.

Digitization during and after the pandemic

Anduena taught first graders during the pandemic and reflected on the negative consequences due to the lack of digital resources during that time:

> The horror! Most of the students and teachers did not even have a laptop. I did use zoom and wanted to be able to see all my students. I am lucky that my sister [in a more developed country] brought a laptop for me to use; otherwise, I would have done the same as my colleagues did. They left the students watch the educational TV program, where for each subject, there was a ten-minute recording. The recordings were of good quality, but can you imagine first graders learning from a ten-minute TV program? Horrible, there was no active participation of the students, no play or engagement.

To the question of how digital devices and tools like games are or were used before and after the pandemic, we received similar responses expressing skepticism about the benefits of digitization.

> Ermond: There is no IT equipment for digital games. I do not own a private computer either.
> Zafina: We do not use equipment for digital games. It is possible that the children play at home with the parent's phone, but not in kindergarten. We practice imaginative and role play the most.
> Anduena: We have projectors, we have a computer in the school, but we prefer to use books, board and card games, and more social activities.

Such scarcity may well affect educational achievement as reflected in PISA results. Therefore, we explored potential changes in response to PISA in another set of questions described in the following.

PISA response

Because PISA results were shocking, we asked teachers "Have you or your school adapted the educational approach since 2018? If so, please explain." Ermond perceived no change:

> No, not even in theory… The decision-makers do not have any experience with teaching and do not see the reality of the classroom. They do not understand that teachers need materials and students need an appropriate environment to have the possibility to do activities… Action plans are taken from other countries [Scandinavia], but these plans are for whole-day classes and our students only come in the morning or the afternoon. There is only half the time to achieve the same goals. If there were additional classes in the afternoon… the students would get to practice and consolidate their knowledge.

In contrast, Zanfina, who started teaching during the pandemic, perceived positive and effective change in her private institution in the capital:

> Based on multidisciplinary cooperation (educators, psychologists, and speech therapists) within our institution and working within the framework set by the Ministry of Education, the realization of all educational goals has been successfully achieved.

Anduena had a more differentiated perspective that provides some more context:

> No. Maybe in big cities [capital city]. The teachers, if they wanted to deal with logical math, they changed it themselves by finding ideas on their own, searching for PISA-similar tasks to

> practice with. The books we use for education have changed, they support a more active learning approach, but the teachers decide for themselves whether they want to buy new ones or not.

Conclusion

This contribution presents data from an ongoing investigation into challenges and opportunities for integrating play-based activities to support children's early math learning in Kosovo. At this stage, we focused on teacher surveys and interviews to better understand the educational landscape from the practitioners' side.

Kosovo has attempted to reform and improve its educational system by adopting policies and practices from more economically advantaged countries (such as Finland, Shala & Grajcevci, 2018). However, our findings highlight the need to consider the specific local political and economic context when implementing educational reforms. Regarding play-based instruction, it seems crucial to ensure that teachers are trained to implement the required activities, to provide actionable evidence to guide teachers in improving their practices, and not to require resources beyond what is available in the average classroom.

We found that teachers welcome integrating play-based learning into the primary school math curriculum. They believed that play-based learning is more built on enjoyment and that children are more likely to stay engaged when actively involved. Arguably, these perspectives are remarkably progressive—even though their implementation seems to remain a challenge. Teachers tend to use the physical materials in their classrooms as tools for playful learning. At the same time, there appears to be skepticism towards digital games or digital technologies in general. It may be necessary to address this skepticism before further commitments are made regarding digitizing the existing curriculum. Despite this skepticism, teachers reported widely using social media to spark inspiration for play-based activities.

Despite these challenges, there is an eagerness and an opportunity to guide the next steps towards a more modern curriculum in Kosovo. We hope to report these and future findings to a broader audience of learning scientists and gather feedback on what actionable steps may be taken in the near future. Yet, these findings already indicate that play-based learning does not have to be an either-or proposition, even in situations with limited resources. Creating eagerness for math from earliest education may inspire children to see mathematics as mathematicians do: difficult but rewarding and playful.

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Scaffolding Middle School Children's Coding Experiences in an Open-Ended Social Robotics Program

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Abstract: Social robots and collaborative open-ended learning may help expand perceptions of computing and develop computational thinking to build skill and interest in Computer Science. We designed pre-programming activities to scaffold middle school children's learning in a collaborative and open-ended social robotics program. In this work, we report on how this scaffolding influenced children's computational thinking and perceptions of computing by describing children's experiences in the program. We conclude with theoretical and practical implications of these results.

Introduction

Learning computing through robotics, has demonstrated how working with robots reified abstract computing concepts, including *computational thinking*, and increased student interest and enjoyment (Rusk et al., 2008). *Social robotics*, where robot actions intentionally use human social cues and norms to interact with people and its surroundings, may further expand options for connecting youth to computing. Research addressing harmful stereotypes about the nature of computing has shown how learning computing in a collaborative environment can increase their confidence and change perceptions that computing is a solitary activity (Bowman et al., 2021). In our work, we believe there may be a unique benefit to computational thinking and addressing stereotypes by connecting learning in the context of social robotics with an open-ended and collaborative learning environment. Our goal is to investigate how working on open-ended collaborative social robotics projects with pre-programming scaffolds impact children's computational thinking and perceptions of computing.

Background

Perceptions of computing

Research on stereotypes of computing has identified negative perceptions of the discipline as boring, asocial, and disconnected from student's personal interests (Fisher & Margolis, 2003). We have seen an increase in computing programs to address these negative perceptions by utilizing collaborative learning approaches such as pair programming (Bowman et al., 2021) and creating new computational materials such as educational robotic kits (Xia and Zhong 2018). An approach that has been helpful in broadening participation in computing has been promoting computing as a way to help (Ross, 2007). Thus, expanding student's perceptions of computing through *social robotics* can be useful in emphasizing how computing is integrated within our daily lives and can contribute to modern society.

Computational thinking and robotics

Computational thinking (CT) encompasses skills and practices that use the concepts of computer science to formulate and solve problems (Wing, 2006). Computing practices and concepts can be supported through lessons and programs that often use block-based programming tools to support or *scaffold* students with a range of abilities to quickly begin programming projects (Bers et al., 2014). These block-based programming environments have often been combined with robotics as physical representations that may benefit learning (Merkouris & Chorianopoulos, 2015). Robots as physical objects can be personally meaningful to learners and designed to communicate with their environment so are noticeable by others providing opportunities for rich social interactions and collaboration. As such, using *social robotics* for introducing students to computing can be a more effective method compared to traditional programming as it involves students systematically applying computing concepts and practices within complex coding needed to program a robot that interacts with the environment around it.

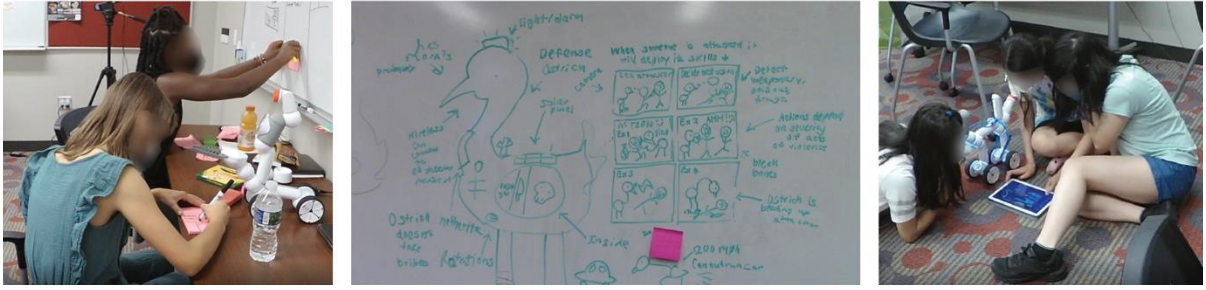
Open-ended learning environments

Supporting open-ended programming projects is challenging as instructors don't know what ideas students will have and what problems they might face (Hannafin et al., 1999). Research has shown that scaffolding around open-ended learning environments can benefit student learning by calibrating an optimal balance of autonomy and support, where students explore their own ideas and receive support to learn and use new programming features to be successful in developing that idea. Pre-programming activities, are designed to support student's conceptual understanding of programming concepts to better apply programming skills later in their project. However, this type of pre-activity support is seldom used in computing education. Well-designed pre-programming activities for social robotics can scaffold students' learning of abstract computational practices, including problem identification, decomposition, problem solving and testing where students are supported through the process from initial idea generation to building and then coding their robots.

Program design

To investigate how working on open-ended collaborative social robotics projects with pre-programming scaffolds impact children's computational thinking and perceptions of computing, the first author co-designed a summer computing camp for middle-school girls with four female undergraduate Computer Science majors. Activities were designed to promote collaboration and included paired participation, facilitated whole group discussions, informal share-outs, gallery walks, scaffolded computational activities, a mentored social environment, and a technology showcase for family and friends (see Figure 1).

Figure 1
Activities in the social robotics program including children working in pairs on their designs(left), a sample storyboard (center), children working across different groups to problem solve (right).



We selected the context of social robotics for program activities as it required children to deeply consider the role of creating and coding computational artifacts that would have impact on society. In this paper, our goal is to understand how students experienced the collaborative open-ended projects, social robots, and pre-programming scaffolds. Specifically, we ask the Research Question: *How does an open-ended and collaborative social robotics program influence computational thinking and perceptions of computing?*

Method

The MyTurn summer camp took place at a large midwestern university. Participants (N = 17) all identified as female, were between the ages of 10 and 14 (*M* = 11.3), and were from a diverse racial and cultural backgrounds including Asian or Asian American (n = 6), Asian or Asian American and White (n = 1), Black or African American (n = 3), Black and Latinx (n = 1), Latinx (n = 1), Mexican and Puerto Rican (n =1), and White (n = 4), were introduced to the topic of social robots and provided a modular social robotics kit, ClicBot (Keyirobot, 2022), to design, build and code their own social robots. We ran two one-week sections of the camp with eight-hour sessions for five days. The first week included rising 5th and 6th graders and the second included rising 7th and 8th graders. In each camp section, students worked in pairs with a mentor to design robot interactions using storyboards and pseudocode and program the robots using block-based programming on a tablet with the ClicBot App. The last day of camp included a Showcase for parents and family members where the campers shared their work and demonstrated their social robots. Campers completed daily surveys and pre/post surveys in computing and completed post-camp interviews. Exit Interviews took place on the last day of camp, followed a semi-structure qualitative interview protocol (Blandford, 2013), and were video recorded and later transcribed verbatim. We conducted a Thematic Analysis (Braun & Clarke, 2022) to analyze the interview transcripts. Data familiarization through notes on videos was followed by a process of open semantic coding on a subset (20%) of the data. The data was then organized within major categories of latent codes based on these semantic codes. All four authors used these codes to iteratively and collaboratively propose and refine themes that developed from the analysis and determined final themes through consensus. The findings below are presented according to these themes.

Results

Our analysis of the interview transcripts revealed two main themes that help us understand the experiences of children in the social robotics program. For clarity in reading quotes, ellipses were added to connect ideas in responses, bracketed words indicate intended objects, and interjections or fillers were removed when not impacting the meaning.

Theme 1: Children related the pre-programming scaffolds to integrate their planning in problem solving with understanding and applying block codes.

Children referred to the pre-programming activities as being very helpful to their process of learning Specifically, children explained how their learning was supported by: (1) storyboards that helped them organize their ideas and sequencing the robot's interactions (2) pseudocode that simplified selecting and planning for block code and built explicit connections between block code and informal descriptions of their function.

First, children explicitly stated that using the block code directly to implement their ideas for the robot would have been challenging for them. For example, P2 said, "I think that [the activities] helped because if we just jumped to the block code, I think we would have a hard time of how its gonna work." Our inclusion of storyboarding activities seemed to address this issue by helping children work out their ideas as they could "piece it together into what we're doing," where if they, "didn't do[the storyboard]…I think that would be very challenging" (P2). Specifically, the storyboard assisted in planning the robot's actions as they had to "brainstorm with the storyboard, what it was gonna be able to say and do since we couldn't speak to it" (P17). Thus, we found that the children were able to use storyboards to engage in procedural thinking to plan a successful program for the robot by sequencing the actions they wanted the robot to perform.

Second, the pseudocode activity reduced the complexity of using the block code by helping students select code blocks for the actions they want their robot to do. one student shared "[the pseudocode] was beneficial because if they just took us straight to the block coding, we would be like, oh, what are we making the robot for? Or, oh, what does the robot do? How do we use these blocks and code?" (P11). The pseudocode guided students in making a connection between what they planned for the robot to do, from the storyboards, and how they were going to implement that plan in their code. Pseudocode also seemed to help children make explicit connections between their daily or natural language use and the verbiage and nomenclature in the block code they needed to program the robot. Children were able to connect the pseudocode activity to the design of the algorithm to be used by the robot by seeing it as a simplification of the actual coding. Children felt that implementing their ideas for the robots and subsequently programming them was supported through the progression of these scaffolded activities. P17 commented on this process, "helped us simplify it [their ideas] into almost block code".

Theme 2: Open-ended and collaborative learning supported creativity, problem solving, iteration, and expanded perceptions of computing.

Students described instances where they were engaged in key CT practices such as, creativity, problem solving, testing/iteration, and related them to the open-ended and collaborative nature of the program.

First, the open-ended learning environment let children practice computing as a creative discipline by incorporating their personal interest into defining the problems and solution paths that they work on. This freedom to make choices in the problems to work on enabled students to include their own interests into their work that demonstrates how computing requires creativity. P10 said, "I mean that we get to really be creative of what we do and kind of choose, we get to choose what we want to create." The diversity of concerns and approaches that students could take and the creativity they were able to experience impacted their perceptions of computing as a discipline. Comments about figuring things out were frequent and demonstrated that children were actively engaged in problem solving through a process of iteration. P4 reflected that, "if you get something wrong you have to problem solve to figure it out and try different methods."

Second, the collaborative nature of the program allowed children to exchange ideas and knowledge within and across groups to help them build on each other's programming solutions. For example, collaborating lead to children making improvements in their work, "it was a lot of fun to implement other people's ideas and use them to create the robot and make the robot better"(P17) or assisting in issues with coding, "we could talk about each other's work and also give each other ideas or help them out with the code" (P13). Children attributed across groups interactions as helping them in the generation of ideas. P19 shared, "I got to look at other people's robots and sometimes it would give us ideas or I'd be like, 'oh, hey, this is a nice way to write their code." Children were continuously seeking help, sharing ideas and communicating around computing with each other and the mentors and this prompted a shift in perceptions of computing from a solitary endeavor in front of a computer screen to a more collaborative image of the discipline that requires interacting with people to generate ideas for problem solving.

Discussion and conclusion

Our results demonstrate that (1) children felt to be successful they needed scaffolds as a bridge between conceptualizing the interactions in their project and coding with block code and (2) practicing computing as an open-ended and collaborative activity broadened students' perceptions of computing disciplines.

First, we found that children felt their learning was supported through the pre-programming scaffolds in ways that helped them connect conceptualizing, planning, and programming the social robot interactions. The progression of activities let students convert their initial, unorganized thoughts for their social robot designs into a concrete set of instructions that they could then implement with the block code. Children in our study benefitted from the additional scaffolds in pre-planning their code to make the block code more interpretable and help structure interconnected block programs. Our findings indicate that the designed scaffolds seemed to help reduce the complexity and that allowed learners to write more complex and sophisticated robot programming. In this way, our scaffolds supported CT concepts involved in creating specific elements of their programming as well as higher order CT practices where children learned to decompose problems and iterate on solutions.

Second, the open-ended activities approach may provide students a perspective of computing that is not just focused on programming but problem-solving. Social robotics helps with this perception shift as children problem solve in a social context, related to their everyday lives, that requires considering how the robot interacts with its environment. The collaboration students engaged in also may have helped to change their perspectives about computing to demonstrate how interactive problems solving can be in the field (Bowman et al., 2021). Thus, integrating social robotics in the collaborative open-ended learning environment may be an effective way to support key CT practices where students' problem-solve in creative ways and in doing so provide an expansive understanding of computing.

In summary, we found that children related their learning of coding and computational practices to the pre-programming scaffolds where the positive experiences changed their perceptions of computing as a creative and collaborative discipline. We found social robotics to be a powerful context for learning CT.

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Comparing Virtual and Augmented Reality: Learning and Interaction Effects in Astronomy Classrooms

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Abstract: There is growing interest in the educational applications of immersive virtual reality (VR) and augmented reality (AR). However, there have been scarce empirical studies that directly compare the learning affordances of AR and VR. This study examines how AR and VR versions of the same astronomy simulation affected learning and collaborative behavior in undergraduate astronomy classrooms. Results showed that both environments were effective for supporting student understanding of key astronomy ideas and problem-solving strategies (e.g., determining one's latitude and longitude). Students who used AR had stronger learning gains on the more challenging assessment items compared to the groups of students who used VR. Additionally, students who used AR made explicit attempts to reconcile their viewpoint with their group members' viewpoints through gesture and referencing each other's perspectives, whereas VR users relied more on verbal coordination.

Introduction

Immersive technologies like virtual reality (VR) and augmented reality (AR) have attracted attention because they have the potential to engage students in active learning by allowing for direct manipulation of virtual objects and altering their perspectives in ways that can potentially enhance their understanding of complex phenomena (e.g., Checa & Bustillo, 2019; Papanastasiou et al., 2019). While both VR and AR technologies show promise for collaborative activities, more research is needed to understand their respective affordances and tradeoffs in small group contexts. AR allows students to engage with real-world problems in familiar contexts (e.g., in-class group work around a table) while experiencing augmented digital information (Klopfer & Sheldon, 2010), whereas VR provides full immersion (Bowman & McMahan, 2007), a sense of presence (Slater, 2009), and embodiment (Johnson-Glenberg 2018) in a simulated environment, enabling natural interaction without real-world distractions. Both types of immersive technologies have potential to enhance student perspectives in ways that may benefit group learning and problem-solving practices, but efforts to understand the effects of these technologies on collaborative learning processes are still limited and the results so far are inconclusive (Ke & Carafano, 2016).

A multi-year research project on collaborative learning with undergraduate astronomy students presented the opportunity to compare the relative affordances of AR and VR technologies for supporting learning on the same task, addressing questions related to learning effectiveness, collaboration experiences, and differences in usage between the two technologies.

- *RQ1*. How effectively do students in the VR and AR groups learn the astronomy concepts and procedures?
- *RQ2*. What differences were observed in how students used the VR and AR headsets in the context of small group problem solving?

Methods

Participants & design

A total of 68 students (39 in the VR groups, 29 in the AR groups) from a midwestern community college introductory astronomy course participated in this quasi-experimental study. The software system and task outlined below were integrated into the course's existing 120-minute lab time. Leading up to their engagement with the system, students were introduced to both the AR or VR headset as well as the features of the software across immersive and tablet platforms during portions of their lab time leading up to the study session.

Software design, VR, and AR environments

The software environment, designed to facilitate sharing night sky perspectives and stellar information across immersive devices and tablet interfaces, provides users with three main perspectives shown in Figure 1. As groups explore the sky, they can share star selections, draw annotations, and viewing locations on both immersive devices and tablets.

Figure 1
The three main views accessible in the software environment: "star view" (a full celestial sphere accessible without any Earth horizon), "horizon view" (a situated first-person view of the sky as if standing at a location on Earth), and "Earth view" (an orbital perspective facing Earth).

In the VR headset (Oculus Quest), participants access shared interface panels with information about selected stars, networked group members, and controls to manipulate location, date, and time. Figure 2 (Left) shows a group working together within the VR implementation. The AR implementation (HoloLens 2) required interface changes to accommodate hand-tracked gestures, which were also carried over to tablets, as seen in Figure 2 (Right). Data representations were made more visible, buttons enlarged for easier use, and interface panels in AR could be moved in 3D space around the user.

Figure 2
The left image illustrates a VR-based learning environment and the viewpoint of a student using VR, while the right image likewise displays a learning environment utilizing AR.

Task design

For both the VR and AR implementations, a problem-solving multistage task "Lost at Sea" was created in collaboration with the introductory astronomy course educators. The overarching goals addressed by the task were to facilitate students with building on their existing knowledge and apply it in a novel context, as well as provide a foundation to promote collaborative interaction via task goals and distributed resources (each group had one AR headset, two tablets, and assorted paper materials). "Lost at Sea" is a problem-based collaborative task that places students in the role of a space capsule recovery team attempting to determine the location of a splashed-down capsule. Working in groups of 3-4, students are tasked with using observations of the night sky within the software to: 1) Determine the hemisphere of the crash site and support their decision with identified stars or constellations, 2) Identify additional constellations they recognize to orient themselves to the cardinal directions, and 3) Calculate approximate latitude and longitude of the crash site location based on night sky information.

Measures

We conducted pre and post questionnaires for both implementations. The pre-questionnaire was designed to check pre-existing characteristics of each group's students. It asked students to rate their interest, confidence, and knowledge of astronomy on a 5-point scale from "Very Low" to "Very High". The post-questionnaire asked students to make self-ratings on their own group collaboration. In addition to the self-rating items, open-ended questionnaires asked participants what tasks they completed while they were using each device. The first and second authors classified open-ended post-questionnaire items using the coding scheme, which was applied to all device types (VR, AR, and Tablet). Developed coding scheme classifies how students used technology into four levels: Level 0 - not used, where students didn't use the device; Level 1 - adjusting to the technology, where students focused on understanding the device rather than problem-solving; Level 2 - exploring, where students used the device to explore the night sky and interact with stars and constellations; Level 3 - measuring, where students used the device to calculate or measure for task completion, such as changing locations, tracking time, and finding constellations.

Pre and post assessments measured students' knowledge of calculating latitude and longitude after the intervention using an open-response prompt: "Write as much as you know about the steps for calculating latitude/longitude based on the stars visible in a given location." The first and second authors scored students' answers using a co-developed rubric. The rubric classified responses as Basic (1) or Advanced (2); if there was no response, it was scored as a 0. Basic responses included height or distance of a star from the horizon for latitude and time as a calculation component for longitude. Advanced responses added using degrees for measuring the height of a star and identifying Polaris as a target star for latitude, and measuring two time zones and understanding 15 degrees equals one hour of Earth's rotation for longitude.

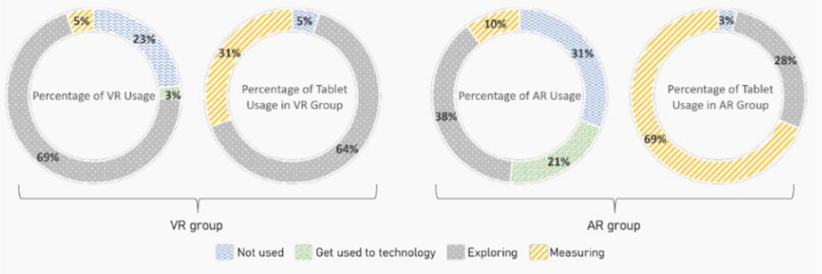
Results

We first examined whether there were any pre-existing differences between the groups in science interest, confidence, and astronomy knowledge. The t-test result shows that the two groups did not differ in the mean scores ($p=0.18$). Furthermore, from the pre-test scoring result, Wilcoxon signed rank test revealed that there were also no significant pre-existing knowledge differences between the two groups (latitude: $p=0.63$; longitude: all students were at 0 points). Therefore, we can conclude that there were no significant pre-existing differences between the two groups.

Our first research question concerns whether students learned the desired content after the intervention. We conducted Wilcoxon signed rank tests for both groups' pre- and post-test scores and the results show that both groups' post-test results were significantly higher than the pre-test for both learning outcomes (VR group latitude: $Z = 4.31$, $p < 0.001$; VR group longitude: $Z = 2.99$, $p = 0.004$; AR group latitude: $Z = 3.78$, $p < 0.001$; AR group longitude: $Z = 3.98$, $p < 0.001$). In addition, we conducted a Mann-Whitney test to compare which group performed better. The results show that there was no difference in latitude calculation between groups. However, the AR group performed significantly better on the determining longitude task ($p = 0.009$).

Our second research question investigates whether students used each device differently. According to students' device usage self-report responses, 69% of the students in the VR group used VR devices to explore the night sky, whereas only 38% of the students in the AR group used AR for exploring (See figure 3). We also found that more students were at the "get used to technology" level while they were using AR devices (VR = 3%; AR = 21%). In addition, both groups' tablet usage also looked different. The VR group mainly used tablets for exploration (64%), while the AR group used tablets mostly for measurement (69%). Interestingly, VR group students used both VR and tablet devices mainly for exploring, whereas AR group students used each device in diverse ways.

Figure 3
Each device usage comparison.



To get a better sense of how each immersive device affected students' approaches to device usage, we picked the group who scored highest on the post-test from each immersive platform and compared their collaborative discourse. Reviewing the video recording data from the two groups, we found that students in the AR group communicate more efficiently in establishing shared knowledge than students in the VR group. For example, there were episodes in which a student wearing an AR device looked at both the AR environment and a tablet screen (used by other group members) simultaneously to make sure they were all on the same page. On the other hand, students using VR devices had to undergo more turn-by-turn verification processes to ensure they were looking at the same object as their group members, since VR users could not see the tablet screen simultaneously and vice versa. However, once shared knowledge was established between students using VR devices and students using tablets, the exchange of related information took place very quickly and efficiently.

Discussion

In this study, we compared two multi-platform collaborative learning environments in astronomy classrooms to investigate students' learning outcomes and device usage. The analysis shows overall positive learning outcomes in both environments measured via pre- and post-knowledge assessments. AR group students performed better on a more difficult and complex task (calculating longitude) compared to VR group students. This may indicate that

AR devices provide a similar immersive perspective as VR devices without completely blocking students from the physical learning environment, facilitating communication between AR and tablet users. However, both groups' self-rated collaboration scores did not differ significantly, warranting examination of how they used each device during collaboration.

We intentionally designed tasks to require different levels of device use: the latitude task focused on exploring, while the longitude task involved measuring. One possible reason AR group students performed better in the longitude task is that they used tablets more for measuring, while most of the VR group students focused on exploring. This suggests that AR devices encourage higher-level tablet usage, and learning outcomes may depend on the combination of device use and collaboration. AR users coordinate their understanding by viewing both AR and tablet displays, while VR users engage in longer discourse exchanges. These technological affordances may impact collaborative discussion, particularly for the longitude task, which requires significant information exchange. However, this does not imply that AR is superior to VR in every situation or tasks. When designing tasks for multi-device immersive learning environments, researchers should consider each device's unique characteristics and how they may impact students' learning.

We expected students to have more difficulties with AR devices due to (bare) hand-tracking interactions and provided a short technology introduction session before the intervention day (not the case for the VR intervention). Nevertheless, many students had difficulty adapting to technology usage. To apply AR devices in classrooms, it is appropriate to consider long-term use instead of single sessions, allowing students enough time to acclimate to the novel technology. We acknowledge that the data analyzed and discussed here came from students' self-reporting and selected video recordings and as a result has limitations on the ability to draw broader conclusions beyond the context of this study. However, the trends toward use across the different immersive platforms uncovered here lays the groundwork for a more structured and targeted qualitative analysis of group discourse and action based on the full data corpus.

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Finding Life in Data: Datafication and Enlivening Data Towards Justice-Oriented Ends

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Abstract: We investigate the process of "enlivening" data and what it entails for youth vis-à-vis its relations, mechanisms, and purposes. Using vignettes, we explore enlivening data and datafication as nested concepts. While enlivening data gives learners agency to take action, datafication affords new ways to collect, analyze and present data about oneself. Educators must be attuned to the socio-political historical aspects of learners' experiences and as informed, be willing to make changes to their shared environments.

Introduction

Data are intentionally manufactured and they act to order and construct the world (Sadowski, 2016). Lupton (2016) characterized "lively data" as how people are "living with and by our data" (p. 709). That is, lively data is personally meaningful and consequential to how one is making decisions in daily life. In this paper, we attempt to map how minoritized youth "enliven data" which we operationalize as a datafication process involving larger data sets, embodied data, and lived data in myriad combinations shaped by historical and contemporary social interactions. We are interested in investigating what happens during the data enlivening process, who it involves, how, when and what justice-oriented trajectories such data enlivening might initiate, including new datafication directions. Using vignettes across our research-practice-partnership work, we explore the following overarching question: What are the relations, mechanisms, and purposes for datafication and enlivening data?

Theoretical framework

Datafication, lively data

A focus on data science education assumes a centrality of datafication in everyday life. That data, and questions of when, how, and why people engage with data, matter in the world. Datafication involves how experiences are rendered in data (most often quantified) and mediated by data with intentionality, purpose, and direction (Beraldo & Milan, 2019). Datafication is always a social, historical, and political project, often geared towards economic and political gain (Sadowski, 2016).

Datafication in society has been given authority in ways that lives/stories do not. And yet, datafication is *contingent on lives and stories*. Processes of datafication often make data lives invisible, as experiences in the world become quantified. However, datafication is not static, it is always enlivened, whether acknowledged or not, with pasts, presents, and futures. We draw upon Lupton's notion of lively data to theorize on the intersections between datafication and enlivening data. Lively data focuses on humanistic entanglements with data, including people's personal data, big data sets, and daily interactions with technology. It involves how people "live with, by, and through data" (Lupton, 2016, p.1) in their everyday lives, practices and decision making. Thus, making sense of how lives are made visible in datafication is an important practice for young people to be engaged in. We view processes youth engage in to *enliven* data as a way of theorizing the possibilities for justice in data science education.

Data justice, data agency

Our work is grounded in theories of data justice as a way to help us to make sense of how youth call attention to how their lives have been datafied in non-neutral ways. These theories remind us that people are made visible, invisible or hypervisible, represented or misrepresented, treated or mistreated in data (Taylor, 2017). Data is always racialized, gendered and related to socioeconomics (Philips et al., 2015). Engagement with data, and data infrastructures is thus always power-mediated (Vakil, 2016). As Acker & Clement (2019) remind us, meaning-making with data is never "innocent work."

Datafication does not impact all people equally. Theories of data justice tell us that engagement with data always takes place in sociohistorical and political contexts, shaping what data is made **visible and makes visible**, who and what is **represented** in data, and the **stories told** with and about data. All of these shape youths processes of coming-to-know and act in the world -- whether it be decisions on how to stay safe during a pandemic or taking action against forms of systemic racism such as environmental injustice, or make decisions related to athletics.

Youth not only act with data, but also act on data –to contest, re-appropriate and transform how datafication shapes their lives. Studies show that youth view data as a powerful force for social transformation and justice, and seek to mobilize more just data arrangements. For example, Kahne & Bower (2018) illustrate how youth have used social media in both the Black Lives Matter and the DREAMer movements to increase visibility, share resources, raise critical awareness, exert pressure, and organize action. How youth curate and distribute data sources can be viewed as a response to systemic asymmetries in data access and knowledge production, shaping what the public is able to know (Lehtiniemi & Haapoja, 2020). Data agency thus extends beyond data fluency by emphasizing youths' understandings of data and their efforts to actively control and manipulate information flows, wisely and ethically.

Research question & methodology

Our overarching research question is: What are the relations, mechanisms, and purposes for enlivening data? Specifically, we focus on these sub-questions: 1) What is the process of enlivening data for youth? 2) How do we know that data has become enlivened for youth? What indicators from youth reveal that data has become enlivened for them?

In a *Community-Based Critical Data Practices (CCDP) Collaborative*, involving researchers from three institutions, we collaboratively analyzed data across three extant projects to study youths' critical data practices (see Calabrese Barton et al., 2021, Tan et al., 2019, Clegg et al., 2022). This study takes an abductive analytic approach, which refers to "an inferential creative process of producing new hypotheses and theories based on surprising research evidence" (Timmermans & Tavory, 2012, p.170). Our approach to abductive analysis sits within an historicized and future-oriented design-based participatory orientation where we give witness to and learn with youth and community (Villenas 2019). Our approach is guided by participatory knowledge building approaches within research practice as we intentionally bring analyses into dialogue with partner youth and adults, as critical to the meaning making process. In monthly workshops we identified and explored data/cases that either intrigued us or challenged our thinking in relation to our framework of data justice and critical data to build possible explanations for enlivening data processes. We looked across these projects, drawing on existing analyses from the three projects noted above. We then used the framing of lively data (Lupton, 2016) and data justice (Taylor, 2017) as a lens to look across the cases specifically with a focus on understanding how data became enlivened for participants in our studies and the indicators for such.

Findings

First, we suggest that the work that it takes to enliven data requires people to be attuned to the social political parts and be willing to make changes based on such sociopolitical data-integrated insights. Enlivening data orders and constructs the world in particular ways and how we understand it with particular consequences and actions. Second, the relationship between enlivening data and datafication is dialogic, nested and "live". These processes are not merely taking existing data and giving it life. A generative outcome of enlivening data is new ways of datafication that lends further insights and a wider stakeholder buy-in to the issue being datafied and enlivened. Third, we propose three practices by which youth enliven data, including: a) Re-performing lived experiences; b) Building hybrid forms of data (e.g., community survey data + personal lived, embodied data, takes place through fleshing out data - with stories, range of examples); and c) Recruiting powered stakeholders for sociopolitical allyship towards a shared justice-oriented purpose.

Vignette 1: Collegiate athletes' enlivened experiences with data on their teams

In interviews with NCAA Division I athletes across sports, focused on critical data practices in their sport, we found that athletes on low-revenue teams collected their own quantitative and qualitative data from their training (e.g., heart rate, distance, pace, video). We conjecture that these data became enlivened for them as they integrated them with their own "felt" data (i.e., sensory-oriented reflections from their experiences). For example, Lei, a middle-distance runner on her university's track and field team mapped her speeds and heart rate to her own sense of "felt" exertion during runs, "Let's say I'm running four miles at a 7:30 pace. I'm feeling good, and my heart rate is 150... By the end of the season let's say I'm running that same four miles, but the 7:30 pace feels like I'm jogging and my heart rate is 130 average. That feels good because you feel like you're improving." However, Lei carefully about how she could and would leverage data on her team with her coaches. While she did not verbally leverage the aforementioned data integrations with her coaches, she and her teammates used them to determine when to collectively speed up or slow down from coach-set paces.

On the other hand, athletes like Omar on high-revenue teams had less agency on these metrics of data collection because of extensive staff set and implemented data practices on the team. However, Omar became animated in interviews when he realized film review counted as a data practice, "Because it's everything. Film shows you how an offense operates, their tendencies, how they line up to tell you if it's a run or a pass." This data, we conjecture, was so enlivened for Omar because this was a data practice that required Omar's agency and because he brought his unique "felt" experience to bear on when, and how, to use insights from film review in games. For example, Omar described the importance of appropriately weighing film review insights with the felt data of reading his key, "*…the most important thing they emphasize is, 'Read our key,' each position has a key. My key is the shoulder of the linemen, if he's turning down, I know it's a run block and then someone else is coming at me, so I got to play differently… It's good to have tendencies but you can't rely on that, you always have to trust and rely on your key.*" These findings suggest that while datafication abounds on Division I athletics teams, these data become *enlivened* for athletes as they integrate it with their unique felt experiences during training and games and as they leverage this data to enact change on their teams (e.g., in training or in game-time decisions). Yet, athletes needed to be socially and politically attuned to navigate the complex power dynamics of athletics (e.g., knowing how they could and could not advocate for and with their data).

Vignette 2: Mood board

In a 6th grade STEM classroom, a group of students engineered "a mood board" to address concerns about classroom morale they documented through surveys and interviews. Sage stated the mood board was important because, "Students normally don't have a way to express their feelings and show how they feel. Normally you can only talk to someone or use your body language. Some people don't feel comfortable doing that. When someone's using the Mood Board, it's easier for them to express their feelings." Layla pointed out that she is sometimes sleepy in class because she stays up late to greet her mom coming home from her night shift. Her sleepiness causes her to feel cranky and get in trouble.

The mood board was a light-up board where students could call attention to how they were feeling that day. As Sage explained: "Students can put their hand in the box and pick a mood that fits how they're feeling. Then they put it on the board. If students want to light up the board, all they have to do is turn the hand crank." Layla further explained that they switched to a parallel circuit instead of a series circuit because they wanted to light up many lights, supporting them in calling attention to their mood because: "if a student sees someone share that they are feeling angry or sad", then "you can practice empathy and try to make them feel better in some way or show you understand." In this way, the students pushed for the importance of recognizing and making visible a range of student feelings as important in school science. Students also handed out "mood board cards" to their peers, school personnel, and family members to encourage use of their design.

These findings suggest that students *enliven* their analyzed survey data through layering their own embodied experiences onto them, such as when Sage described how being sleepy caused her to be cranky and get in trouble. By making visible how their embodied experiences shape their lives in classrooms, they could orient their data towards having consequential impact on their classroom culture. Additionally, the mood board itself offered a process by which students' moods were *datafied*, making them visible and learnable by their teacher and peers through a new communication platform – via the physical operations of the mood board. As students posted their moods, new ways of *datafication* and learning became possible, as the teacher tracked differences in moods across the school day and week, and among student groups. As students *datafied* their experiences, then cranked the lights, they invite others into their experiences. Such *enlivening*, through performance provided spaces for youth to engage agency to do the things they needed to foster better classroom morale, e.g., I want to use this board so that people know how to interact with me in class today.

Vignette 3: Black youth vaccine resistance

As the pandemic unfolded and Black communities were disproportionately impacted by poor health outcomes, the Black youth with whom we work in our weekly community-based STEM programs recalled mental anguish caused by accessing statistics on COVID rates in their cities and states and hospitalization and death rates in the Black community through the CDC and the WHO. Such *datafication* positioned them as a statistic—*hypervisible* in a demographic group with higher infection, hospitalization, and mortality rates. However, when vaccines became available, datafication rendered their lives *invisible* as their experiences were not fully considered in how vaccines were tested or made accessible to the public. Many of the youth articulated their reluctance to get the Covid vaccine when it was finally approved for children 5 to 18 years old. The youth invoked historical abuses on Black bodies in Western Science and medicine, saying that "they experimented on Black people" as ample reason to not trust CDC (Center for Disease Control and Prevention) guidelines. One Black youth, Selena explained why she refused to get the Covid vaccine: "I have sickle cell [anemia] and they did not test the vaccine on people with sickle cell. They think I don't know science, I know science!"

However, even for those youth who wished to be vaccinated, information and access was limited. Fourteen-year-old community member and research participant, Jazmyn, shared her experience as she navigated tensions of a) standing up with her community by leading a Black Lives Matter protest but also b) wanting to avoid COVID-19 exposure: “I had to decide whether to protect myself and my family against injustice by protesting, or to protect myself and my family by not going.” It is because of navigating realities like Jazmyn’s that our participants did not anticipate a vaccine rollout to serve them in a just manner. First, vaccine distribution has been chaotic, and well-known statewide structures to reach communities who need it most are glaringly absent. Jazmyn wondered where were “the televised PSAs and billboards, phone banks, citywide text/email alerts,” along with volunteers, and centralized resource access locations that seem so readily available during “political campaigns”? In both cases youth observed their lives datafied – as statistics in a pandemic.

Implications & tensions

Enlivening data has the potential to lead to new territories and possibilities when youth and young adults experience how particular kinds of data might be salient to their lives now and inform their lives in the future. Sociopolitical allyship with more powerful others is an important element of enlivening data, both in the enlivening process and in the setting into motion new modes of datafication. As we can see from the mood board in vignette 2, Layla and her teammates had the support of their science teacher to pursue and create their engineering project which datafied and enlivened data on students’ moods, with concrete social-relational outcomes in the classroom. There are also tensions that arise out of the data enlivening process, with implications for sociopolitical allyship. For example, Omar’s data agency in vignette 1 with how he enlivened film data is contingent on how he negotiates the information from this data with the data apparatus and coaches within his Division 1 team. In vignette 3, while Selena was wise to consider historical exploitation on Black bodies in western Science, how she then couched current covid vaccine data against that historical backdrop was problematic. Jazmyn was highly insightful when she articulated the tension between prioritizing what kinds of safety for her community, as a Black youth committed to Black lives. Given these insights, how do we move forward in mapping the affordances and constraints of datafication and enlivening data? How might we design more student-agentic, justice-centered learning experiences for youth concerning critical data literacy?

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“The Answer is Your Thinking…:” One Teacher’s Role in Helping Students in Navigating Their Epistemic Vexation

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Abstract: Current understandings of science learning revolve around students’ developing the ability to use science concepts and practices to “figure out” aspects of the natural world. One emerging area of focus in this new vision of learning is the emotional work required in students’ participation science sense making. This research focuses on how one teacher supports student reframing of moments of epistemic vexation. After reviewing classroom video, and interviews, three themes emerged: (1) Productive meta-affect is more likely to occur when students understand why the teacher allows for failure to connect ideas or understand scientific concepts, (2) Without explicit attention from the teacher during moments of epistemic vexation, students can disengage from sense-making and (3) When the teacher does not adequately attend to students’ epistemic vexation, students can build solidarity and reach out to each other for emotional support in developing meta-affect.

Introduction

Science Education has transitioned from a portrait of science learning as one driven by the recognition of “facts" to that of science proficiency--in which students are to gain the ability to engage in sense-making about the natural world (National Research Council [NRC, 2012])- learning to “figure things out” (Passmore, 2014). An emphasis on authentically engaging in the discipline of science asks students to share, discuss, and refine thinking about scientific phenomena in a classroom community (Bamberger & Davis, 2013; Berland & Reiser, 2009; Manz & Suarez, 2018; McNeill et al., 2006).

Many aspects of this disciplinary engagement have been widely studied and continue to be a focus of ongoing investigation. One emerging area of focus is that of the emotional work involved in science sense-making. Davidson, Jaber and Southerland (2020) and others (Arango-Muñoz, 2014; Jaber & Hammer, 2016a, 2016b) argue that epistemic affect-- learning how to *feel* as scientists do when engaged in their work-- should be recognized as a central component of meaningful disciplinary engagement in science. Epistemic affect includes “the emotional responses, feelings, and dispositions that emerge as one participates in the construction of knowledge through figuring things out about the natural world” (Davidson et al., 2020, p. 1009). Additionally, meta-affect (feeling about feelings), also plays an integral role in construction of knowledge and beliefs (Goldin, 2002). There is a growing recognition that these emotions are not just unnecessary by-products of scientific work, but rather they are part-and-parcel of doing science, as these emotions are part of what “instigates and stabilizes disciplinary engagement” in scientific pursuits (Jaber & Hammer, 2016b, p. 189). From this position, epistemic affect is recognized as an essential aspect of scientific research and thus needs to be considered as students are learning to engage in science practices (Davidson et al., 2020; Jaber & Hammer, 2016a). The work presented here is an extension of this line of inquiry, as we examine a teacher’s response to his students' epistemic vexations.

Research question

While this is an emerging area of inquiry, much work remains in terms of understanding how teachers can support their students as they learn to manage the emotions inherent in disciplinary engagement. Toward those ends, this work provides a description of a teacher’s efforts in supporting his students in navigating these emotions. The question at the center of this research is: What is the teacher's role helping students navigate moments of epistemic vexation, so students maintain their engagement in sensemaking?

Study design

Data for this study comes from a larger four-year professional development (PD) project focused on supporting teachers in their work to foster student sense-making through productive science talk (Southerland et al., 2017). Danny was our focal teacher, was intentionally selected because of (1) his teaching approach that focuses on helping students to be agents of their own learning, (2) his focus on students’ reasoning and deepening of this reasoning in his course, and (3) his long-term participation in the PD. For this study we selected to follow his

Advanced Placement (AP) chemistry classes in year one and four of the PD. A diverse group of students' interviews and classroom observations were coded to support initial themes.

Data sources for this study include classroom video and audio recordings, teacher interviews, and student interviews. After analyzing these different data sets in terms of their alignment around epistemic vexations and the ways in which Danny's efforts allowed students to reframe moments of epistemic vexation, the research team conducted final interview to capture Danny's perspective of students' epistemic vexation boundaries.

We employed a constructivist grounded theory approach (Charmaz, 2017) to analyze the data, where patterns were identified in both Danny and his students' perceptions of his teaching. The first author adapted the coding scheme from Radoff et al. (2019) to identify common themes in the student interviews, as well as the themes presented in Danny's final interview. The second author drew out common trends in Danny's four post lesson interviews and two end of year interviews to identify how he framed student emotions when teaching.

Findings

Theme 1: Productive meta-affect is more likely to occur when students understand why the teacher allows for failure to connect ideas or understand scientific concepts.

Danny prioritizes giving his students experiences where they have the responsibility to determine the meaning to be derived from their experience, which may lead to students experiencing emotions similar to those of scientists and create space for student agency of their own learning. Students are given opportunity early on in the course to share their thinking as a way to build resiliency as they reason through their ideas. Danny explained how he set up expectations to support agency and resiliency in his course:

> [L]ike setting the expectation, that regardless of your comfortability level, like you are going to share at some point, but at least having them start off with the experience of sharing in the lower stakes setting of a group of four people is a place to start off, where they don't instantly feel like the entire class is watching and judging…

This goal of providing students experiences, to "be like a scientist", which was necessary for their own sense-making, was not unnoticed by Danny's students. As Candice stated in her end of year interview:

> It definitely felt more like we were the scientists, not the students, I guess, let's put it that way. It felt like we were, we were scientists and not like we were making a discovery, although it was already proven, but like, still felt a lot more interesting.

However, students did not understand why Danny would not answer their questions or give them closure on concepts, and in turn students experienced frustration that in some students became anger. In Candice's understanding she continued:

> You would ask him like, "Well why does this happen?" He'll be like, "I don't know, figure it out" and you're like, "I need help! I am 16 years old! Okay? I am not a chemist. I don't know. Please help!" Um, the [task] just frustrating cause I never got closure on anything...With this one [chemical equilibrium investigation], we weren't getting it so he was frustrated with us and we were mad at him and it was just a really toxic environment because everyone was mad at everyone."

Throughout the year Danny continually pushed his students to rely on their own ideas, and toward deeper sense-making. At times he kept students productively engaged in that effort through careful questions, and in other times those questions push students past their vexation boundaries, causing them to become frustrated and disengage in sensemaking.

Themes 2 & 3: When the teacher does not reframe moments of epistemic vexation, (1) students will disengage from sense-making or (2) students will build solidarity and reach out to each other for emotional support in developing productive meta-affect.

Danny sees questioning as a way to "get [students] onto that train of thought", as he focuses students on the sensemaking portion of a lesson as students grapple with their explanations. Wanting students to "at least attempt to grapple" with ideas as he addresses questions to entire groups but expects students to engage, even if at the very least they are passively engaging. Danny states:

> So, usually I always focus on the "why". My kids will tell you that "Why?" is my favorite question. And if they can't answer that, I'm not gonna let them not, so I'll just keep pressing them until eventually they tell me what they know.

It is evident that Danny's students are also aware of his consistent presses as he questions and probes their thinking. Hannah stated, "Even whenever he's teaching, if someone has a question, he asks them like, okay, well how do you think this will happen?". Likewise, Emily had mentioned in her end of year interview, "He would never give us a direct answer and even when I had like come to him and ask him a specific question, he would make me work myself to the answer."

In one moment during implementation of a lesson, Danny asks one small group member, Kyle, to make a relationship about the elements on the periodic table. While Kyle appears to be confused on the relationship in the periodic table (shuffling papers in his hands while staring at Danny without saying anything), Ryan, another group member, speaks up to address Danny's question and further the train of thought that is being built. Students look to Danny for answers, and while he realizes this he does not comply. Instead, Danny uses the building of ideas within the group to help students make sense of their own observations. Danny knows students become frustrated by his constant questioning instead of answers, as students look to him as an authority in the classroom. He stated in one of his end of year interviews:

> [Students] are probably going to be frustrated. This is what we're going to do in this class. I would advise you to not try to read answers off of my face, because I typically don't change my tonality, and I don't change how my face looks. So just trying to guess if you're right or wrong by looking at my facial reaction, that's not gonna go well for you.

In another classroom moment during a whole class discussion with a student named Carol, Danny asks "Why was green the one with the highest energy?" This question is the turn in conversations that began to lead Carol away from the idea she was initially trying to express. The frustration that Carol exhibits (identified by her flushed face nervous tone to her voice and putting her head in her hands) is observed by others in the classroom This moment provides a common experience which later helped build solidarity amongst students. During student interviews, students were asked to watch this moment and talk through their feelings and recall what was happening with a researcher. Hannah speaks about solidarity in her interview, "During that lesson, I didn't feel as bad cause I think I felt like, okay, like majority of the class isn't getting it either. So it's not just me." This solidarity helped students be more empathetic with each other's sense-making which in turn led them to emotionally supporting each other when they experienced feelings of frustration or confusion. Students expressed their gratitude for their peers throughout the interviews.

> But I always had partners so we could talk about it together. So, it wasn't just me like figuring out the answers. -Emily
>
> Yeah, well I think it's like the whole class having that discussion, it just makes it a lot easier because it's not just you and even if it was just you and your group, you know sometimes you and your group really might not know the answer. Some when it is the whole class. At least one person's bound to get it right or like at least one person at least somewhat understands and can help explain it. -Hannah

While student support and solidarity can build a sense of community, this solidarity is not always enough. In the moment with Carol and Danny, the lack of substantial guidance from the teacher when a student so obviously has been pushed beyond her vexation boundary can have a lasting impact. Rose stated in her end of year interview, "Yeah, I think like, I don't know, I don't know like [Carol] especially like towards the end of the year, like stopped talking as much as she used to."

Contributions

This work offers insight into the case of one teacher and his students' perspectives on moments when students are tittering at their epistemic vexation boundaries. Danny views epistemic vexation as a necessary part of student sensemaking. For sake of disciplinary connections, Danny forgoes attention to students' emotions and his own in order to make space for empirically driven sensemaking. This does not mean that Danny is not aware of these emotions but given his teaching goals he chooses to not forefront in science learning for his students.

While this is only one teacher and his role in helping students navigate epistemic vexations, it speaks to a need to attune teachers to the need to recognize and find techniques to help students navigate students' epistemic vexations. If we are to successfully engage students in the thinking of the discipline, teachers will need to learn to recognize, value, and support students' emotions involved their wrestling with uncertainties (Jaber et al., 2022; Manz, 2015; Manz & Suarez, 2018)

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Designing Science Curricula That Disrupt Disciplinary Boundaries Towards Sociopolitical Change: A Middle School Life Science Unit

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Abstract: Supporting minoritized students' participation in a science requires designing expansive notions of what counts as doing and learning science. We present the design of a middle-school biology unit about stress and body system interactions that challenges the boundaries of disciplined science and promoting social change making through consequential learning. Four core axiological commitments shaped the design of the unit: a) expanding disciplinary practice by entangling mind, body, and environment; b) supporting students' rightful participation and expertise; c) recognizing the environment as politicized across scales; and d) supporting social change through allied political struggle. We describe how we embodied these commitments in the unit design and how they played out in the context of a 7th grade urban science classroom. This work provides another example of consequential learning environments and contributes to the theory and practice underlying their design.

Introduction

Over the past two decades Learning Sciences has increasingly attended to issues of equity and justice by recognizing that all learning environments are inherently political and thereby serve to either maintain the status quo and (re)produce inequities or disrupt historical and ongoing injustices and redress them (Esmonde & Booker, 2017). In the context of science education there have been ongoing efforts to promote a more expansive view of desirable aims that include using science to identify, investigate, and address injustices (Basu et al., 2009; Morales-Doyle, 2017). Such efforts have emphasized the importance of learning that is consequential to students in that allows them to participate in science through knowledge and practices that are relevant and meaningful to them and their communities (Tan et al., 2019). Designing for consequential learning therefore entails attending to and disrupting settled and powered participation structures in order to expand disciplinary boundaries (what counts as science) and allow for new aims and new forms of participation. A core and valued aim of consequential learning is to make visible and address locally meaningful injustices that are, invariably, rooted in broader sociopolitical injustices (Tan et al., 2019).

In consequential learning environments legitimate participation extends beyond being included and supported in sanctioned disciplinary practices and entails rightful presence-- the ability to reauthor rights, make injustices visible, and shift normative power relations and expectations. The *Rightful Presence* framework (Calabrese Barton & Tan, 2020) challenges traditional notions of equity as inclusivity and argues that legitimate participation needs to afford changing those very rules and expectations by challenging guest-host powered relations. Traditionally, students in science classrooms function as guests learning new normative disciplined practices (ways of doing, being, knowing) from the teacher or adult hosts. Given the (still) prevailing view of science practice as relevant to yet unaffected by broader social and political struggles, students' own experiences of historical and ongoing injustices are not made visible as part of science learning nor made welcome in the classroom. Rightful presence therefore entails making sociopolitical struggles visible in the classrooms as a legitimate form of participating in science, and places responsibility on those who hold power in these spaces (e.g., teachers) to leverage their positions, as sociopolitical allies, for change towards more just outcomes.

Examples of consequential learning environments in K-12 science education, while compelling, are rare and the field would benefit from additional efforts (National Academies of Science, Engineering, and Medicine, 2022). Here *we discuss the design of a middle school life science unit aimed at addressing science standards in the U.S. (NGSS Lead States, 2013), while also challenging the boundaries of disciplined science, and promoting* *social change making through consequential learning*. Our aim with the unit was to address science standards through investigation of a health issue that was of concern to the local community through a unit that involved sociopolitical change making at the local level. This design work was guided by commitments to and intentional design towards: a) expanding disciplinary practice by entangling mind, body, and environment; b) supporting students' rightful participation and expertise; c) politicizing the environment across sociopolitcal levels (national to local); and d) supporting social change through allied political struggle.

We present a middle school biology unit-- Bio4Community: *Stressed Out- How our bodies interact with our environments,* as a design case with the hope that it can contribute to the field in three ways. First, as an example of expanding disciplinary practice in the context of life science adding to the small, but growing, collection of exemplars of consequential and justice-oriented science units available for researchers and practitioners. Second, as an example of connecting structural oppressions at the larger sociopolitical level to their local manifestations. Third, and following from the prior point, as an example of student-developed solutions that are, in turn, aimed at transforming inequitable structures and policies at the local level (but that are embedded in the larger sociopolitical context) in ways that will benefit their community.

The Bio4Community design team and the Stressed Out! unit

Our team was engaged with design in multiple configurations, some of which included youth and teachers from the school district with which we collaborated (Krishnamoorthy et. al., 2021). As a research team we hold different positionalities (in terms of racialized and gendered identities, ethnic backgrounds, and their intersections), we have different lived experiences and expertise. Team members also brought experiences and perspectives informed through their identities as immigrants (voluntary and involuntary), settlers on colonized lands, and as members of the queer community. The collaborating teachers who enacted the unit were a Middle-Eastern immigrant woman who has been teaching in the urban district for multiple years and a Black woman who recently joined as a special education teacher in the 7th grade classroom and also had extensive experience teaching in urban and marginalized settings. This district itself serves a majority Hispanic community (85%) with over two thirds of families socioeconomically deprived.

Briefly, the unit included six lesson sets each lasting multiple days. The first lesson set introduced students to the phenomenon of stress grounded in their embodied experiences, through testimony from community members their age, and through quantitative data from their community. In the second lesson students engaged in community ethnography and developed a survey about causes of and solutions to stress in their community. The survey was sent out to the school community. Results from the survey were analyzed later in the unit to inform students own solutions in the stress-in-our-community problem space. The third lesson set engaged students with evidence from, predominantly, Eurocentric scientific research about the short-term stress response (fight-or-flight) to support the construction of a class consensus model of this phenomenon. In the fourth lesson set students investigated long term stress through a set of stories. The fifth lesson set focused on the ways in which injustices structured into the environment act as ongoing stressors. In the sixth and final lesson set students developed "proposals for change" that honed in on a particular cause of stress in their school (based on analysis of the survey done earlier in the unit), identified the existing structure or policy that was at its root, and advocated for a solution at the policy level (e.g., universal bathroom policy). Students presented these to the principal, faculty, and staff.

Axiological commitment I: Expanding disciplinary practice by entangling mind, body, and environment

Much of school science is grounded Eurocentric ways of knowing that separate humans from the environment and mind from body. In the *Stressed Out* unit we learned from Indigenous scholars by taking a more expansive and holistic view of human biology that focuses on the relations between and within the mind, body, and the MTH (Bang et al., 2012; Kimmerer, 2013). Throughout multiple activities were encouraged to express physiological sensations (heart rate, sweating, shaking) and mental sensations (overthinking, anxious, crying) as entangled, legitimating a holistic view of how we define stress in our bodies.

To engage students in exploring the effects of chronic stress on our minds and bodies we used an approach we term story-driven investigations that presents students with a story that includes evidence and that explicitly weaves the sociopolitical. We endorsed an expansive view of evidence that included community-based knowledge from elders and respected community members (along with normative scientific evidence). For example, one of the stories involved a high school student- María- who struggles to focus in class and is frustrated by this. María's abuela (grandmother) suggests that she may be unable to focus due to stress setting María (and the students) on a journey to find out whether stress can actually affect your focus. Throughout this journey María leverages the expertise of multiple individuals including family, teachers, and scientists who provide her with resources that serve as evidence in her quest for an explanation.

María's story was intentionally designed to entangle feelings, thoughts, and the neuronal networks in the brain with her school and home environment. Taking an adaptive, rather than deficit, view of the impact of stress on the brain, in the story María finds out that stress increases connections in the brain's fear networks making the mind constantly "on alert", and reduces connections in the attention network making it hard to focus on cognitively challenging tasks such as taking a math test. Both sides of this response, are adaptive but in the context of schooling become a problem. Entangling feelings, mind, body, and environment was an intentional decision that was embodied and made explicit in all three stories.

Axiological commitment II: Supporting students' rightful participation and expertise

Throughout the unit students' experiences and expertise served as crucial and valued levers in driving the investigation forward. Students' experiences also served as proxies for the experiences of the larger middle school community and informed community ethnographies. In this sense, students' personal experiences informed theoretical construals of the phenomenon—how stress shows up in the community and what are its causes. The proposals for change (Lesson set 6) that were informed by the community ethnography data also intertwined disciplined science knowledge (model of long term stress) and community knowledge. The legitimated presence of local and personal knowledge shaped the problem space and made salient the importance and relevance of that knowledge; students were able to reauthor what kinds of contributions, problems, and solutions were valued.

In an effort to encourage youths' rightful presence through valuing their worlds as consequential to their learning, all three stories featured family and community members as integral to the main character's sense making journey, such as the positioning of elder wisdom (María's abuela) as culturally relevant (Ladson-Billings, 2021) to and explicitly *not* less important than disciplined science knowledge. As this part of the unit unfolded, abuela's role in youths' sensemaking expanded beyond the words on the page. When explaining their model of "stress and focus" to the class through a skit, the youth prominently featured María and her abuela's relationship as central to the model of long-term stress. Acting as a sociopolitical ally, the teacher (host) ceded power to the students (guests) in authoring their rightful presence in the space through legitimating social interactions in which one student began identifying himself as 'abuela' (and was referred to as such by the teacher). Finally, the consensus model-making activity, was led by 'abuela' (the student), who was called on to evaluate the model. 'Abuela'. The class positioned their consensus model as being storied, by abuela - thus weaving disciplined science with culturally valued expertise (abuela) and practices (story telling).

Axiological commitment III: Politicizing the environment across sociopolitical levels

We wanted students to understand that minoritized communities are not at fault for being stressed, and while they are agentive in their own survival, they do not have much control over the stressors in their environment because those are intentionally structured into the environment. Towards this aim, we interrogated our positionalities and ways of knowing (Austin, 2023) with regard to the disproportionate impacts of white supremacy on our lives. This resulted in a more nuanced presentation to the students of data about perceived stress in their town, disaggregated by race and income level, in the very first lesson set, to position health disparities as ultimately caused by the environment. The stories included many details about the characters' environments in terms of the unjust structures and policies. For example, one of the stories featured Felix and Josue a young gay couple living in a segregated and economically disadvantaged neighborhood with limited access to health facilities and robust grocery stores, yet with a culturally vibrant and supportive community.

We have used the language of unfair structures, policies, and procedures to support students in seeing and naming these elements in the environment. This framing helped us illustrate: a) the designed nature of injustice in the environment (i.e., targeted racial policies such as redlining); b) that these environments are not neutral in that different groups of people experience them differently; and c) that these environments are therefore not benign, they cause inordinate harm to some groups of people. Students then applied what they learned about unjust structures, policies, and procedures at the larger societal level to their own local context—i.e., what structures, policies, and procedures in their school stress them and their community of peers.

Axiological commitment IV: Supporting social change through allied political struggle

Social change making requires understanding and disrupting the structures operating to propagate and entrench inequities. Successful efforts depend on the support and allied struggle of others in the community, and in particular those in positions of privilege and power (Calabrese Barton & Tan, 2020). The teachers, a highly regarded elder in the community, and the researchers worked with and alongside the students in their advocacy efforts. Several curricular activities in the last two lesson sets supported this allied political struggle. First, the teachers and the elder created and shared their life-lines of stress depicting stressful events in their lives from middle school to adulthood, making an effort to explicitly connect the stressors they experienced to unfair structures and policies. Second, the students interviewed the elder (another form of community ethnography) about her experiences with racism and her sense of unfair structures in the school environment and what has been done about them. The elder shared advocacy and activism efforts she had participated in the school to allow students to wear hoodies. She emphasized the importance of "being right" and doing due diligence on researching and understanding the inequities and their root causes (structurally) and then intentionally developing allyship and support in activism that aims to disrupt them. Third, the principal was invited to the presentation of students' proposals for change and, in turn, was able to provide the students with an opportunity to present to all the school faculty and staff during a faculty meeting. This was not a trivial opportunity to bring to fruition and required substantial effort on the principal's part- another example of allyship.

Concluding remarks

Here we have attempted to explicate the axiological commitments undergirding our equity conjectures (Lee al., 2022). Centrally, we attempted to take an overt political stance by developing materials that engage students with the historical and political nature of the injustices experienced by marginalized communities. Understandings about racism at the broader sociopolitical context were then leveraged to make sense of and advocate against local institutionalized oppressions and inequities as experienced by the students. The science ideas and explanations students' developed in the unit motivated the urgency and need for the sustainable solutions students proposed. In this sense the disciplined science, local knowledge, and embodied experiences were brought together, consequentially, to problematize and push against the status quo.

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White Faculty Learning Through Co-Design: Building Racial Equity-Centered STEM Courses for Preservice Elementary Teachers

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Abstract: Postsecondary science education has been shaped by Eurocentric ideologies that center science as a set of culturally neutral, color-blind, and meritocratic systems designed to exclude underrepresented groups from positions of power and knowledge production. Nationally, white faculty still predominate senior faculty positions, resulting in few opportunities for students of color to take courses from faculty who share their racial or cultural backgrounds (Haynes & Patton, 2019). At the same time, there is a need to diversify the predominantly female and white elementary teacher workforce as the K12 student population is rapidly diversifying (Januszyk, et al, 2016; NCES 2103). This paper will describe white STEM faculty learning around race, culture, and STEM teaching/learning in a design-based research project in which we are designing science and engineering modules for preservice elementary teachers that deeply integrate scientific concepts and practices, racial equity, and examinations of the history of racist research practices within science itself.

Introduction

Increasingly, the natural sciences are recognizing the need to address social theories in the study of natural systems (Schell, et al, 2020; Graddy-Lovelace, 2017). For example, Schell, et al's review (2020) argued for conceptualizing social inequality as a key driver in the ecological and evolutionary outcomes of more-than-human species in urban environments. Residential segregation and redlining have resulted in a legacy of racially segregated geographies that correlate with decreased biodiversity, canopy cover, and increased heat islands. To understand how these factors affect genetic diversity of species in urban ecosystems, then, racial inequity needs to be taken into account as a driver of these processes. Redlining, comorbidity factors, dense housing, and inequitable access to health care--all stemming from institutional racism--have been implicated in the disproportionate suffering of Black and Latinx people in the current global pandemic. Caplan, et al (2015), argue for the need to consider racial justice implications of CRISPR and gene editing technologies. These considerations include historic distrust of communities of color of the medical community because of studies such as Tuskegee, and because of the underrepresentation of people of African descent and Indigenous peoples in genetic databases, which can differentially affect the types of therapies available to people of color and poses a real threat to the rise of eugenics. In these examples, racial inequity are key variables in the actual doing of the science.

However, postsecondary education–in particular, science learning environments– has been shaped by Eurocentric ideologies that center science as a set of culturally neutral, color-blind, and meritocratic systems that invisibilize eugenicist practices to exclude underrepresented groups from positions of power or from knowledge production (McGee, 2020). Nationally, white faculty still predominate senior faculty positions, resulting in few opportunities for students of color to take courses from faculty who share their racial or cultural backgrounds (Haynes & Patton, 2019). Studies of the development of race consciousness in white faculty have found that they may miss many opportunities to address historicized patterns of racial oppression, or to center culture in their teaching through pedagogical choices they make in micro-interactions with students (Haynes & Patton, 2019). There is a need, therefore, to understand how instructors in higher education develop *political clarity*, or coming to see the teaching of science as an inherently political endeavor (Madkins & MicKinney de Royston, 2019), in order to connect science with the sociopolitical realities of their students.

At the same time, there is a need to diversify the elementary teacher workforce. Elementary school teachers in the United States are predominantly female and white, even though the K12 student population is rapidly diversifying (Januszyk, et al, 2016; NCES 2103). Although a majority of elementary school teachers are over 40 years old, one-third of them report having 5 or fewer years of experience teaching science. Elementary teachers have taken limited college courses in physics, chemistry, and engineering, and only one-third have had coursework in all areas of science recommended by the National Science Teachers Association. Curriculum materials give some guidance in helping teachers learn content but are often not enough to support teachers in teaching complex ideas such as climate change–especially as related to intersecting issues of racial justice.

Teachers feel much more prepared to teach math and literacy than science or social studies. When asked about different aspects of science pedagogy, they do not feel well-prepared to support students engaging in the practices of science, providing science instruction based on students' ideas, or incorporating students' cultural backgrounds into science. In addition, almost 25% of elementary teachers have never attended a professional development focused on science (Plumley, 2019).

Informed by these bodies of scholarship, this paper will describe white STEM faculty learning in a design-based research project in which we are designing science and engineering modules for preservice elementary teachers that deeply integrate scientific concepts and practices, racial equity, contemporary scientific tools, and examine the history of racist research practices within science itself. We are a group of learning scientists and interdisciplinary STEM faculty who are co-designing a 2-quarter undergraduate course sequence that engages preservice elementary school teachers in project-based, interdisciplinary science content that incorporates contemporary issues (ethical engineering and algorithmic justice, gender inclusive biology, socioecological constructs of time, soil contaminants and redlining), science and engineering practices (computational modeling, GIS), and ethics ("should we"? vs "can we"?) of science, situated within the economic, social, and political contexts in which science and science decision-making always live. We are designing anti-racist pedagogies to highlight the ways in which science has been used as both a means of oppression of Black, Indigenous, and other people of color (BIPOC) and as a tool for advancement.

We argue that shifts in preservice elementary teachers' understandings of science begin with the instruction, modeling, and positioning they receive in their undergraduate STEM courses. This portion of our research asks:

(1) *What shifts occur in STEM faculty learning around the connection between their disciplines and racial equity during the design and re-design process? and*
(2) *How do these shifts show up in faculty instruction and course design?*

Framing

The recently released consensus study from the National Academies (NASEM, 2021) outlined a framework for understanding equity in terms of four "discourses" of equity and adopted from Philip & Azevedo (2017). These equity discourses are: (1) increasing opportunity and access to high-quality science education, (2) emphasizing increased representation and identification with science, (3) broadening what counts as science, (4) connecting science and engineering to social justice movements.

We also use Philip's "ideology in pieces" framing (2011) to study how faculty's ideas around racial justice as it pertains to their disciplines evolve over the course of co-design. The "ideology in pieces" framing allows us to track the "naturalized axioms", or commonsense ideas, that faculty have about their students, their disciplines, and their teaching practices. We study how those become articulated, or increasingly connected and systematized within and across contexts of use. This allows us to make sense of how a faculty member might simultaneously hold, for example, the connections between racism and the teaching of stoichiometry when reading and discussing an academic paper, but center dominant chemistry discourses that center whiteness while co-designing instructional sequences in our course, as emerged with one of our case study faculty.

Methods

We use a case study method (Yin, 2017) to understand the learning trajectories of four STEM faculty partnered in a multi-year co-design effort to collaboratively redesign the undergraduate science course sequence for pre-service elementary education majors at a public university in the Pacific Northwest. Data included recordings and transcriptions of bi-weekly design team meetings and quarterly design summits (72 hours), 3 interviews with each faculty member across the first year and a half of project work (14 hours), exit tickets from quarterly design summits (16), and artifacts (such as syllabi and course modules) related to course co-design. We used grounded theory (Straus & Corbin, 1994) to iteratively code data related to science teaching, racial justice, connecting to family/community practices, and course design, and we triangulated our findings across data to find common themes and patterns (or ideologies) that emerged for faculty over time and space. There were a total of 17 emergent codes related to faculty ideological stances.

Findings

A major part of our co-design work has been joint study and reading together around connections between science learning, Indigenous sovereignty, refusing anti-Blackness, power and historicity, ethics, and complex systems theory. We are also using educator frameworks from the Learning in Places project (Learning in Places

Collaborative, 2021) to understand issues of power, historicity, culture, ethical deliberation, and nature-culture relations in science.

Emerging findings indicate that faculty have shifted from processing their understandings about the four equity discourses to thinking about how to operationalize justice-oriented science and engineering design and teaching. In this paper, we will present the shifts in one faculty member's [Leah's] thinking about the connection between racial justice and teaching physics over the course of our first year of co-design work. Outside of our project, Leah has been engaged in a yearlong professional development project in which she supports a cohort of teachers incorporating equity into their physics courses. During our design meetings, Leah would frequently share how she tried out ideas from our co-design with her high school teachers. The shifts in thinking that we noticed in Leah are exemplified in her responses below: The first two responses are from exit tickets after two co-design meetings, and the third is from an interview with her after our first year of co-design.

> January 2022: The Azevedo framework for equity is exciting to me and aligns well with my current work with high school teachers - that was fun to learn about.
>
> May 2022: My thinking about honoring Indigenous presence continues to grow and evolve as a result of this project and others. I'm trying to remind myself of the option to decenter humans, think of humans in the context of plants and animals and lands and waters, think of the more-than-human as also mattering. In my work with high school teachers, I am trying to teach about place-based education, introducing them (and myself...) to the Learning in Places framework.
>
> October 2022:
> It's not my experience so far that, like different demographics of students have different science ideas…I mean, they think all different things. But you know…I feel clear that there must be different things that students are bringing to my class than their science ideas that I am barely um tuned into, if at all. I'm a lawyer's daughter. Argumentation is how you say I love you in my family right like we um spar for fun. So like that translates super easily to a science context for me, and I'm theoretically aware that that's probably not true in everybody's family. But um, I don't really know what's going on with my students about that. I'm just sort of theoretically aware that that is probably a thing that is not the same as me for many of my students.
>
> I'm still in a learning area about like what physics concepts are, can serve social justice and the best area. So far like one of the really good areas, so far, is power plants. Power plants are great [for]understanding the energy transfers and transformations that happen in a power plant [and] can help you engage with the impact the relationships that the power plant has with its environment, with the human communities and the more than human communities, the lands and water and air and plants and animals that um that is in relationship with…there's always some kind of community decision making happening around it… How are they engaging with the tribes? And what should they do about the salmon? I'm planning to make the whole course be about power plants and…maybe have someone from the utility company come and talk to the class to make that more community based. But, like everybody, has a utility company, right? Everybody pays a utility bill right? And so like learning more about that seems like a good idea.

Over the course of 10 months, we see Leah form a gradually more concrete operationalization of ideas connected to her course design and pedagogy. In January, she has just learned about the four equity frames (Philip and Azevedo, 2017) and is connecting it to her work with high school teachers. Her May response shows that she is reflecting on the frameworks that we read around *nature-culture relations* and seeing humans as a part of natural systems (rather than apart from and dominant over natural systems). By October, Leah is starting to articulate these ideas into her course design. She is starting to consider the role that her students' cultural practices might play in the knowledges and practices they bring to physics learning, and that some of those practices may be more aligned to science than others, though, at the same time she dismisses the idea of culturally-based ways of knowing. We also see her beginning to incorporate the "equity and justice" framing and begins seeing humans as part of the physics concept of power by making connections to power plants, human decision making, and more-than-humans. Through these brief episodes, we see the different pieces of Leah's emerging ideology around the connection between race, culture and science and how she applies them to different contexts, including community partnerships, research, and course design.

Significance

Research has found that co-design is a powerful learning mechanism for teachers and researchers to both make sense of scientific knowledge and also gain more clarity on design and pedagogy (Penuel, 2022). In this work, we conceptualize co-design as a set of practices that include reading relevant research, engaging with and re-designing pre-existing tools, data analysis, and designing new materials for student and faculty learning. While research on co-design within K-12/university/community partnership has shown productive shifts in learning for co-designers, more work needs to be done in postsecondary education to understand how university faculty become attuned to issues of racial justice in their STEM teaching. Given findings in the literature about both the reluctance of STEM educators to acknowledge the importance of race and culture in their teaching (Morales-Doyle, 2021) and the structural racism embedded within postsecondary STEM education (McGee, 2020), this work contributes to our understanding of how to support faculty in shifting the design of their courses and their pedagogy towards more culturally sustaining and anti-racist practices.

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Elementary Students' Reasoning About Explanation-Evidence Relationships

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Abstract: Relating evidence to explanations is a critical epistemic practice for productive engagement with evidence in the science classroom and beyond. However, research examining students' reasoning about what makes for stronger and more robust evidence is limited. In this study, we explored students' justifications for their judgements regarding whether evidence supports, contradicts, or is irrelevant to a causal explanation. We worked with 4th-grade students in the context of an after-school virtual science club. Students examined evidence in relation to simple causal explanations using an adapted Model-Evidence Link (MEL) Matrix as a scaffold for coordinating explanations and evidence. Evidence varied in whether it included a mechanism, whether the mechanism was similar to that of the explanation, and whether the entity (organism) involved in the mechanism was similar or not. Analysis of students' choices and justifications revealed a preference for evidence that includes a mechanism, and for similar mechanisms over similar entities.

Introduction

The ability to comprehend and evaluate evidence in terms of its relevance and strength is vital in both science practice, science learning, and for a science literate society (Duncan et al., 2018) and is an explicit aim in science education (NRC, 2012). However, the research examining students' reasoning about what makes for good evidence, is limited. Children can recognize weak explanations (e.g., circular explanations; Mills et al., 2017). However, children may struggle to link evidence with explanations in different contexts (Sandoval et. al., 2014). Typically, reasoning with evidence in the classroom involves evidence that is directly relevant to the explanation, whereas reasoning with evidence outside the classroom is often much messier as evidence is more complex and may not directly support or contradict an explanation (Duncan et al., 2018).

To better understand students' reasoning about evidence relevance and strength, Danovitch and colleagues (2021) examined children's judgments of the helpfulness of different types of evidence in supporting a simple explanation. They presented children with an explanation for an animal's behavior and then provided them with several pieces of evidence that varied along two key dimensions: whether the evidence was about the same organism or a different one (i.e., same organism/different organism), and whether it pertained (and supported) the same causal mechanism postulated in the explanation or was not relevant. Danovitch et al. (2021) found that elementary students recognized when a piece of evidence was clearly relevant to a proposed causal explanation. However, children's ability to recognize that evidence involving the same organism as the explanation is sometimes causally irrelevant was tenuous or inconsistent. Thus, students were better able to recognize relevance in terms of the causal mechanism when it involved the same entity (i.e., same organism).

Danovitch et al. (2021) did not ask students to explain why they found evidence more or less relevant; children were simply asked to rate the evidence's helpfulness. In this study, we further explored students' justifications for their judgements regarding whether evidence supports, contradicts, or is irrelevant to a causal explanation. Specifically, we asked what are students' epistemic considerations when reasoning about the relationship between evidence and a causal explanation?

Grasp of Evidence Framework

We draw on the evidence interpretation dimension of the *Grasp of Evidence* (GoE) framework to inform our analyses of students' justifications of evidence-explanation relationships (Duncan et al., 2018). The GoE framework describes five dimensions of evidentiary practice that addresses the understanding of expert's use of evidence and laypeople's use of evidence. A grasp of scientific evidence involves epistemic knowledge about evidence as well as practical skill in thinking about evidence individually and collaboratively. In this study, we specifically focus on the *evidence interpretation* dimension of the framework, which emphasizes coordination of explanations and evidence. The interpretation dimension of GoE describes the epistemic aims, ideals, and reliable processes involved in relating evidence to one or more explanations. These constructs are drawn from the AIR model of epistemic cognition (Chinn et al., 2014): a) *Aims* are valued goals that individuals and communities set to achieve, b) *Epistemic Ideals* are the criteria used to evaluate the quality of resulting scientific products such as evidence or models; and c) *Reliable epistemic processes* are the diverse methods used to achieve epistemic aims, such as protocols for carrying out observations or conducting experiments. The aim associated with interpretation is to determine explanation validity using evidence. Several ideals are associated with this aim, including having a model that is supported by relevant, strong, and diagnostic evidence. Several reliable epistemic processes can be used to achieve the aim while meeting the ideals, such as systematically coordinating alternative explanations with the available evidence and analyzing which parts of the explanation are supported (or not) by the available evidence. In thinking about the relationship between a simple causal explanation such as the snapping turtle standing on its hind legs to scare away predators and evidence such as predators swimming away from a blowfish that expanded to double its size, one would argue that the evidence supports the explanation because the underlying mechanism, of making oneself bigger to scare predators, is common in the animal kingdom. In contrast, evidence about where snapping turtles live is irrelevant because despite it being about snapping turtles it does not relate to the mechanistic core of the explanation. Obviously, evidence that posits that predators do, in fact, run away from turtles that stand on their hind legs would be even stronger as it supports both the mechanism and its instantiation in the organism.

Using the GoE framework, in this study we examined elementary (4th grade) students' reasons for why particular evidence supports, contradicts, or is irrelevant to a simple causal explanation. To support students' engagement with coordinating evidence and explanation we used the Model-Evidence Link (MEL) scaffold (Rinehart et al., 2016), which juxtaposes (in table form) one or more explanations in relation to multiple pieces of evidence and helps students systematically relate, using specific types of arrows for support/contradict/irrelevant, each evidence to the explanation/s thus supporting a reliable epistemic process. We asked students to justify their choices of arrows and we analyzed the epistemic considerations evident in their justifications.

Methods

Study context

20 fourth graders (9 boys, 11 girls, M_{age}= 9.64 years old) voluntarily joined a virtual science club that met for an hour once a week for four weeks. Note that some students missed some sessions or parts of sessions and hence the sample sizes shown below (for various claims) are at times less than 20. The students worked in groups of 3-4 students with a researcher acting as facilitator. During the first meeting, students were introduced to the activity of deciding whether pieces of evidence support, contradict, or are irrelevant to two competing claims (e.g., are dolphin's mammals or fish?) and providing reasons for their choices. In the second meeting, students were introduced to the phenomenon of the bad smelling corpse flower and provided with explanation I: The corpse flower smells like rotten meat to *attract* pollinators that like eating rotten meat (i.e., flies). Students were then given, one at a time, four pieces of evidence: a) turtle evidence (same mechanism/different organism) involved a similar causal mechanism of attraction but did not involve smell b) skunk evidence (different mechanism/different organism) involved smell but the mechanism was of deterring predators c) rose evidence (i.e., no mechanism/similar organism) did not provide any mechanism d) lily evidence (same mechanism/similar organism) involved smell in a similar mechanism of attracting pollinators. Students were asked to decide if each piece of evidence supported, contradicted, or was irrelevant to explanation I (attracting pollinators) and to justify their choice. In the third week, we provided a different explanation II: The corpse flower smells like rotten meat to *scare away* predators who don't like the unpleasant smell. Students were shown the same four pieces of evidence as the prior week and asked the same questions. Note that, for week three, the nature of the evidence-explanations relationship changed: a) turtle evidence was different organism/different mechanism (attracting instead of deterring), b) skunk evidence was different organism/same mechanism (smell as deterrent), c) rose was similar organism/no mechanism, and, d) lily evidence was similar organism/different mechanism (attract rather than deter).

Data collection and analysis

Videos and chat responses were transcribed and coded first in terms of the relationship noted (Support, Contradict, or Irrelevant) and then in terms of any justification provided by the students. Justifications were coded in terms of whether the reasoning emphasized the similarity/difference in organism, or the similarity/difference in mechanism. We noticed that sometimes students parsed "mechanism" into two distinct elements: referencing the function (e.g., deter or attract) or referencing the means of the mechanism (e.g., smell). We considered justifications based on the means of the mechanism alone (smell) as less compelling than justifications based on function (deter/attract), and justifications that included both function and means as the most compelling (comprehensive). We also considered a justification that focused on any aspect of the mechanism as better than a justification based solely on similarity (or difference) of organism. We refer to similarity and difference of organism as an "entity-based" justification.

Results and discussion

Students' interpretations of evidence: Mechanism and entity considerations

As noted above, the evidence varied in whether it included a mechanism, and we found that students were able to recognize this difference and preferred mechanistic evidence. When the evidence did not include a mechanism, most students (12 of 15) found it to be irrelevant. Six and seven of 15 students claimed the no-mechanism evidence was least helpful overall when evaluating Expl. I or II respectively. When the evidence included any mechanism at all (same or different), students were more likely to see it as supporting or contradictory rather than irrelevant.

The picture is somewhat more complex when we look at whether the mechanism was the same or different than the one proffered in the explanation. When the evidence had a different mechanism (and pertained to a different organism) students tended to see it as contradictory for Expl. I (11 of 17 students) and all explicitly noted the difference in mechanism in their justification. There were five students who claimed that the evidence was irrelevant, and, of these, four argued that the evidence was irrelevant because the organism was different. Interestingly, for Expl. II, the majority of the students (13) claimed the different-mechanism evidence was irrelevant (9 because of the different mechanism and 4 because of the different organism). Only six claimed it was contradictory and all based it on differences in mechanism. Thus, overall students privileged differences in mechanism over entity.

When the mechanism in the evidence was the same as the mechanism in the explanation, most students preferred evidence in which the organism was also similar as supporting the explanation. In fact, the majority of students claimed evidence with the same mechanism, but a different organism was irrelevant rather than supporting (12 compared to 6). It may be that having the same mechanism in a different organism made that evidence more cognitively difficult to connect back to the claim as students would need to ignore the organism information and just focus on the mechanism.

When we compared how students reasoned about evidence that had the same or different mechanism as the target explanation, yet involved different organisms s, the findings were a bit puzzling. For Expl. I, six students saw the evidence featuring the same mechanism and a different organism (Evidence a) as supporting and 12 students claimed that it was irrelevant. For Expl. II, nine students saw this type of evidence as supporting and only five saw it as irrelevant. Why was there such a discrepancy in how students perceived evidence involving the same mechanism? In both cases, students had to "ignore" the information about the different organism, so the different treatment cannot easily be attributed to differences in the organism. However, there is another "hidden" difference between these evidence pieces—the similarity or difference of the function versus the means of the mechanism. That is, for these pieces of evidence the function of the mechanism (deter or attract) was the same but the means were different. If students attend to the means aspect more so than the function then what we considered to be the "same mechanism" in Evidence a was actually not that similar, and that may explain why 12 students saw this evidence as irrelevant. In fact, 4 students who claimed it was irrelevant also explicitly noted smell as a point of difference. If students attend to function more than means, then the mechanism would likely appear the same to them if they could successfully ignore the different organism information, and they would see it supporting (which 6 students did). When the evidence involved the same mechanism in terms of both function and means. this was less confusing and more students saw it as supporting (9) with fewer students being "sidetracked" by the different organism and seeing it as irrelevant (5).

A similar pattern emerged with when we compared evidence that had a different functional aspect of the mechanism with or without a reference to means and alluded to a different organism. Note that the different functional aspect makes the evidence diagnostic- smell can attract or deter but not both (i.e., when the evidence supports an attraction mechanism, it by default contradicts a deterrent mechanism and vice versa). Here we expected evidence with a different means for the mechanism to be seen as contradictory rather than irrelevant. We found that the majority of students found the no-smell evidence to be irrelevant with 6 others claiming it was contradictory. In contrast, 11 students found the evidence with reference to smell contradictory and only 5 found it irrelevant. Again, we see that when both the means and the function of the mechanism are explicitly mentioned, likely increasing the saliency of the difference in function, students may see the evidence as relevant (and contradictory). When the function is different and no means are noted, it may make the saliency of the difference less clear, and students may tend to see it as irrelevant. Given that students did not always explicitly note the presence or absence of means (smell) as part of their justification, we do not have strong evidence to support this assertion in terms of their reasoning.

Conclusion and implications

In this study, we examined students' engagement with the evidence interpretation dimension of the Grasp of Evidence Framework (Duncan et al., 2018). Our findings suggest that students attend to both the context of the evidence-entity involved and the underlying mechanism of the evidence, and that they prefer evidence that includes a causal mechanism. Moreover, students differentiated between the function and the means of the mechanism.

The causal explanations and evidence we provided to students featured very simple causal mechanisms that included entities (turtle, rose), their properties (the turtle's tongue movements, the skunk's glands), and activities (releasing odors, mimicking worms) towards a final outcome of either deterring or attracting other species. Our findings suggest that students attended to entities and activities and that the nature of the activities, such as whether or not they involved smell, mattered.

Lastly, we wish to highlight another interesting finding: students' attention to the diagnosticity of evidence. The GoE framework posits diagnosticity as an epistemic ideal that can be used when interpreting evidence. That is, evidence that supports one explanation while ruling out an alternative ought to be considered stronger evidence (Haack, 2007). Our design made it such that evidence with a different functional mechanism acted as diagnostic. We speculate that students attended to this attribute of the evidence. We suggest that developers of learning environments and teachers should attend to this epistemic ideal in design and that even elementary students may be ready to attend to diagnosticity if given the opportunity to do so when reasoning with evidence.

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Contesting With Feeling: Childhood in and Through Public Education

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Abstract: In public education forums people create and contest implicit theories of learning and society. We study a community education council meeting where participants address mask mandates, selective admissions policies, and school violence. We used critical discourse analysis to trace how speakers mobilized emotional configurations about children to guide emotion participation. To influence councilmembers' votes, speakers contested which children should get to learn, under which conditions, and toward what futures. By invoking ideas such as innocence and rationality, meeting participants engaged the racist underpinnings of U.S. society in calling for individualist or collectivist approaches to learning in schools.

Introduction

Public education forums are key sites where the public engages policy and contributes to decision-making, contesting far more than the children and their learning they are ostensibly there to support. For example, organized groups have contested racist and colonialist national history, self-determination, and bodily autonomy by advocating particular policies at the local school board level. Since discourse in and about public education decision-making offers implicit theories of learning and society (Philip & Sengupta, 2021) that index powered contestations, attuning to collective action in such forums is a necessary part of studying politics and learning (Curnow & Jurow, 2021; The Politics of Learning Writing Collective, 2017). In the New York City (NYC) Community Education Council (CEC) meeting we analyze here, participants articulated visions of the future by sharing multivocal positions for the public record and to shape decision-making. As part of sensemaking, *emotional configurations* are constructed *in* and form learning targets *of* the practices of activism (Vea, 2020). With the potential to garner support through "productive cultivation and unethical manipulation" (p. 340), emotional configurations and *guided emotion participation* are powered practices that shape which (and whose) contributions are taken seriously. Toward this end, we ask: *How do participants in a public education meeting create and mobilize emotional configurations about children and childhood? With what consequences?*

Situating powered practices of public education engagement

We analyze the situated activities of participants in a CEC meeting to highlight how participants contested meanings as part of racialized histories (Curnow, 2022). As Curnow describes, "these ongoing historical processes assign power to people in dominant groups via institutions and practices, enacted by people in daily life" (p. 4). We focus on how participants engaged histories of racialized power relations in the emotional configurations they mobilized and whose arguments were taken up or dismissed. As Vea (2020) describes, *emotional configurations* are "situated and reciprocal interrelationships between feeling, conceptual sense-making, and practice (including linguistic practice) that give emotion social meaning" (p. 315). How emotional configurations are oriented, what racialized and powered meanings such configurations draw from, and what futures they move toward, matter. People learn to participate in valued emotional configurations through *guided emotion participation* where "experienced practitioners engage in a provision of opportunities, along with normative pressure, for others to participate in particular ways of feeling" (p. 332). Deliberately or not, the participants' calls to action engage racist histories and practices in US public education. We illuminate three interrelated concepts that participants frequently relied upon (childhood, innocence, and whiteness) in relation to whom they have historically served.

First, *childhood* is a contested construction. Racial ideologies guide *which* children are recognized as being innocent, by whom, and in which moments. Such constructions of childhood have consequences for minors and non-minors, such as distributing the negative impacts of carceral systems like increased surveillance and policing (Meiners, 2016). As Meiners (2016) highlights, however, simply "claiming nonwhite youth as children or juvenile does not allow for critical exploration of the conception of innocence… [nor] unpack the underlying nexus of other associations tied to childhood." (p. 62). Therefore, attending to who is allowed to be a child and thereby granted innocence, victimhood, and/or safety can illuminate the power relations (re)produced in public education forums. Second, the workings of *innocence* in political appeals show how "morally ennobled victimization has become the necessary precondition for determining which grievances we are willing to acknowledge and authorize" (Wang, 2018, p. 278). Determining who is innocent, victimized, or safe implicates some people as not-victims and, therefore, as deserving of harm. Tracing attributions of innocence, victimhood, and purported deservingness of safety reveals the ideological positions underlying the emotional configurations that participants mobilized in their testimonies, because "the invocation of personal security and safety presses on our affective and emotional registers and can thus be manipulated to justify everything from racial profiling to war," (p. 282). Finally, innocence has long been connected to *whiteness* in the U.S., and racialization has historically been predicated on determining who is and is not eligible for the privileges and protections of whiteness. Racialization, however, often happens without explicit articulations of race. Bonilla-Silva (2018) illustrates, for example, how "contemporary racial inequality [is explained] as the outcome of nonracial dynamics" (p. 2) through abstract liberalism, an ideology that draws on ideas of political and economic liberalism (e.g. equal opportunity and individualism). It allows participants to contest whether public education should serve public or private interests without explicitly mentioning race or racism, enabling the (re)production of racial inequality. Considering which children are entitled to innocence makes visible the histories of power indexed by emotional configurations. Specifically, we attend to how conceptions of childhood are dynamically constructed and contested; how ideas about innocence distribute harm in racist, carceral, capitalist, and neoliberal systems; and how racial ideologies sustain and conceal this distribution of harm.

Research methods

NYC schools are divided into 32 community-based districts, each with an elected CEC that shares decision-making with the Department of Education (DOE). Since 2020, CEC meetings have been held virtually, recorded, and posted for public record. We analyzed a recording of a 2022 CEC meeting from one of NYC's largest and most socioeconomically diverse districts. This 5+ hour meeting included public speaker sessions where the public signed up to speak for two minutes each and sessions where councilmembers discussed and voted on resolutions: a non-binding resolution on making facemasks optional (masking was mandatory in schools at the time); a student-proposed school name change; sibling and borough priority for school admissions; and academic screening for school admissions. Many participants also spoke about a middle school which had recently been the subject of high-profile news stories about instances of violence. We take this meeting as a case of participants in public education forums mobilizing emotional configurations toward contested futures. We analyzed turns of talk to "identif[y] the ways that social actors express–through their language and material activity–the relations between feeling, sense making, and practice" (Vea, 2020, p. 238) in relation to powered histories. We began with five speaker turns that elicited strong emotional responses from the research team; for example, one turn began with a measured and calm tone and shifted to something one researcher described as leaving her heart pounding. Noticing asymmetries in how these turns framed issues led us to select additional sets of turns that spoke to the same "issue" within the meeting to highlight implied symmetries in their framing while illuminating the actual asymmetries of consequences (Philip et al., 2018). Informed by critical discourse analysis (Blommaert, 2005), which attends to how language constructs power, dominance, and control, we engaged in cycles of group viewing sessions, individual analysis and memo-writing about specific turns and about connections and contrasts across turns, and group discussion of hotspots and themes. In total, we closely analyzed 14 turns from parents, council members, and other community members. In what follows, we use pseudonyms for all speakers and schools.

Findings

Meeting participants mobilized emotional configurations about children that engaged powered relations in education in four ways. First, participants constructed *safety as a condition for children's learning*, using fear and a desire to protect children from fear to persuade the council. Some participants focused on children's safety from physical violence, while others emphasized safety from emotional discomfort. Safety is treated as an important condition for learning and yet mobilized to argue for practices that erode public safety, particularly for children and communities of color. This reproduces long standing associations between "public safety" and white safety, and it reinforces neoliberal notions of responsibility in civic institutions such as schools. Second, some participants *imagined troubling futures for imaginary children* if their preferred policies were not enacted. Three speakers described how hypothetical children would suffer from eliminating academic screening, from failing to implement carceral policies, or from making facemasks optional. Although these speakers worked towards different ends, each of them (and others) engaged in rhetorics of care that promote whiteness to guide emotion participation. Third, participants recruited unspecified "data" to lend *an air of rationality* to false equivalences and righteous arguments. The participants guided emotion participation by implying parity between the consequences of illness and consequences of preventing illness, and by appealing to "data" to argue that, for children, the latter were more dangerous than the former. Finally, participants contested who falls within the *dynamic bounds of childhood*, and therefore innocence, as a precondition to granting victims time, attention, and policies in their favor. Next, we elaborate on a constellation of turns in which speakers did the latter while engaging schooling practices with racist histories and consequences, forming competing conditions for learning.

Contesting (the significance of) who counts as a child

Mobilizing protection for white childhood

Isabella, who had recently participated in a news segment about violence at M.S. 100, positioned herself and her spouse, Esteban, as parents of an innocent child victim of violence. She mobilized fear by framing M.S. 100 as especially violent and "not normal," dynamically bounding the protections of childhood. In describing their son's experiences, Isabella omitted his actions, portraying him as a passive recipient of unprovoked violence. She reported they transferred schools to protect him from peers who "have stolen [his] innocence with all the words he's learned at that school, in the playground, in the bathrooms, in the hallways, in the stairways." She animated this "profane" language with a racialized shift in voice as she named a Snapchat group called "yo we on drugs." Isabella positioned these students as like-adults who "weigh the same as [she does]," and their actions as threatening "safety issues." By contrast, she indexed her son's adult-like actions (e.g. traveling to school alone) as examples of "independence." The pair shared their histories of migration to NYC from Bolivia and Spain, claiming that their "multicultural" background along with "liv[ing] in Hell's Kitchen" made them "not racist" and thus accusations "taking out the race card" were unwarranted, ultimately positioning themselves as victims. "We're taxpayers here…" she says; "If the DOE is not going to defend our children… and you're not going to keep a safe environment, and you're not going to put NYPD [Police] in there… then allow the money to follow the kids…" Isabella appealed to *their* innocence from racist practices while making a racialized appeal to white victimhood for their son. She spoke of "defend[ing] the children," but the context of her argument and demands for increased policing and voucher systems (which are known to harm communities of color, especially Black communities) makes clear that this does not mean all M.S. 100 students. Those whom she constructed as violent are not offered the defense that childhood offers some children–overwhelmingly those racialized as white. Through appealing to relational feelings bolstered by institutional practices of whiteness and white victimhood, Isabella and Esteban sought to guide participants' emotional participation in their favor.

Refusing innocence

Naomi, the M.S. 100 PTA co-president, spoke before Isabella in the meeting but responded indirectly to Isabella's participation in a recent public news story and took a distinct approach, refusing innocence. As co-president, Naomi saw participating in educational decision-making as a practice that encompasses "the good, the bad, the beautiful, and it's hard," in contrast to Isabella's participation only in this particular situation. Her position as a woman of color is relevant, too, in her efforts to name and shift racist practices. Naomi drew on the more full set of activities and debates within educational decision-making and activism to claim that the actions of those who painted M.S. 100 as especially violent and unsafe "reek[ed] of fear and racism." In contrast to guiding emotional participation toward reproducing racist stratifying practices, Naomi declared that "children make mistakes," framing the claimed incidents of violence as within an expected realm of mistakes that schools are meant to support a community in working through. From the position that the school is a "true microcosm of New York City" that "represent[s] every child in [this] district" and all "640 students at M.S. 100," she was proud of students, parents, teachers, and the principal "doing the hard work, the equitable work, the fair work, the work that everyone in [this] district and New York City asked [them] to do." She invited participants to "please lean in and ask us how you can help us doing this work." By positioning members of the community as doing their jobs to support each other, Naomi offered an emotional configuration that moves away from litigating innocence, deservingness, or victimhood to instead consider what the school community might need. Attending to how Isabella's, Naomi's, and others appeals were taken seriously, or not, makes apparent which emotional configurations were valued. For example, later in the meeting Naomi responded to a councilmember who referenced her prior turn, contrasting his claims of racism in calling for screening policies with her not having her "truth [in naming racism] honored."

Who is a victim? (Il)legibility of (mother's) suffering

The enforcement of two-minute turns was inconsistent. Many speakers, including Isabella, spoke for over two minutes, which became contentious. Mia presented a poem about how students' suffering due to the intertwined pandemics of COVID and structural racism should be met with compassion, not merit-based screening. After two minutes, Council President David Rumford repeatedly interjected to end Mia's turn. Councilmember Carmen Ramirez pointed out that "we let someone go over two minutes [previously]," and Councilmember Brooke Donegan countered that "that was the mother of a victim." She differentiated between Isabella, whose racialized constructions of innocence were heard as coming from "a mother of a victim," and Mia, whose speaking about structural racism (and about her child with long COVID) was not granted similar status. Councilmember Ramirez pushed back that Mia "is also suffering," but the council did not recognize her plea. Contemporary discourse on mothers of/as victims allows white mothers to parlay their grief into advocacy; Black mothers, however, face the burden of humanizing their children and litigating their innocence (Carew, 2018). So whose children are victims? Which mothers get to move others with their stories, and in what ways? How does this work in relation to children subject to peer-imposed violence, whose 'innocence' has been stolen and who are victims, while children subject to institutional violence are not? Our analysis shows how relying on appeals to innocence and victimhood to guide emotion participation continues enduring racist relations.

Discussion

Throughout the meeting, participants invoked powered relations in configuring and guiding emotion. Speakers contested which children should get to learn and under which conditions to influence votes and differentially allocate particular futures. Participants' invocations of ideas like innocence and rationality engaged the racist underpinnings of US society while calling for individualist or collectivist approaches to learning. Furthermore, by inconsistently wielding the two-minute turn limits, councilmembers legitimized particular claims about who was seen as victims, innocent, deserving of safety, and whose suffering mattered, and thus, who was not: or, which relationships between feeling, meaning and practice the council valued. Feeling is a powerful part of making appeals. As Vea (2020) cautions, given "the dual capacity of bodies both 'to affect' and 'to be affected,' guided emotion participation entails a form of participation that is not under fully autonomous control" (p. 340). Authoritarian groups increasingly use public education forums to advocate for racist practices, often through rhetorics of protecting children's innocence (e.g., the weaponized white motherhood of Moms for Liberty). Attending to which children are and are not included in constructions of childhood within public education forums illustrates how emotional configurations (re)produce powered relations. Participating in collective action *against* oppressive forces within public education forums, then, might require cultivating different sorts of emotional configurations than those that rely on the terms of childhood, innocence, and whiteness. What might we learn, for example, from Naomi's expansive construction of community or Councilmember Ramirez's explicit naming of suffering, and how might we mobilize emotional configurations toward different ends?

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Exploring Youth Critical Collective Futuring as Learning

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Abstract: Youth critical collective futuring (YCCF) is a constellation of practices and ways of being that come together to shape and refigure the future through actions in the present. Using current literature on relational learning and STEAM making, we present an analytic vignette from a critical ethnography in a middle-grade out-of-school online STEAM makerspace. We argue for exploring YCCF as a form of learning that is relationally constructed across space and time.

So like, [adults] tend to underestimate people depending on their age, skin color, [...] or just anything, but honestly we are all people. Just because you are a child doesn't mean you don't know things, so if people choose not to listen, that's kind of annoying. Like, how they just think 'oh you're a child so you don't know anything, adults know more, adults know more than you do,' so like it's kind of annoying how that's how some people think. But honestly, anybody can know anything; it just depends on what research you do, or like, what you are trying to learn about. - Lily, age 12, Black maker of cat hats

Introduction

In this opening quote, Lily (pseudonym), a member of the Green Club (GC) pushes back on deficit orientations of how she is positioned as a young Black girl who is concerned about the unfolding global climate disaster and COVID-19 pandemic. She states explicitly that "anybody can know anything; it just depends on what research you do," referring to how she feels left out of discourse at multiple levels due to her age and not her capacity for knowledge building. Her statement not only describes the present state, but her ability (and the ability of others) to learn and become in the future. If "anybody can know anything" by conducting research depending on "what [they] are trying to learn," she refers not only to herself as a youth, but herself as a teenager, an adult, and others as long as they are "trying to learn."

We take seriously the concerns raised by Lily and her peers in the GC, and seek to understand the ways in which they attempt to recreate their positions to each other and the world via their work together. Therefore, the basis of this paper aims to answer the following questions: 1) What are the constellations of practices that Black youth engage in as participants in a STEAM-makerspace? 2) How do Black youth embody these practices, and what do these practices say about what they think STEAM can be? 3) What do these practices tell us about what they think the future can and should be? We address these questions with attention also to the conditions that surround Black youth as they work to be and become learners/makers/doers in STEAM, such as anti-Blackness (Jones & melo, 2021) and underrepresentation in STEAM. Taken together, we begin to conceptualize Youth Critical Collective Futuring (YCCF) as a response to these questions, and set the groundwork for future exploration of YCCF as learning.

Background & conceptual framework

Making spaces are often sites for youth futuring practice to occur. Not just in the sense of innovation and production, how the "maker movement" is often positioned (Vossoughi, Hooper, & Escudé, 2016), but in how people come together to organize practice around "making" (Calabrese Barton & Tan, 2018). In this way, relationships are at the core of what drives the making, despite the mainstream emphasis on the tools. Focusing on relationships in making departs from normative views of what it is and who can participate in it (Vakil, & McKinney de Royston, 2019). Through a focus on relationships, we can pay attention to how a learning environment can be (re)organized. Foregrounding youths' moves to "be with" (Villenas, 2019) each other in the online format, we build on work that views STEAM learning as relationships, practices, and discourses that ultimately position them as knowledgeable and creative STEAM makers. Understanding youth's work as a way for them to live out their politics adds dimension to how we understand the relationship between youths' politics and their actions (Curnow & Utttamchandani, 2022; Uttamchandani, 2021). Taken together, we can see how youths' relations push forward their collective work, and in what ways that can impact what their work becomes (Uttamchandani, 2020). Using this framework for making, we discuss how YCCF fits in as part of the relational emphasis on what learning can look like in a making space.

To begin to unpack what we mean by YCCF, we address each term individually. By *futuring*, we refer to the practice of envisioning and enacting the future, and argue that youth often take up futuring practices that are not recognized and therefore not seen as important and actively positioned as deviant. Through *critical futuring*, youth not only take up these dominant practices and invent their own, but they do so in ways that also express political clarity (Vakil, 2018). *Collective futuring* takes into account the multiple different perspectives, backgrounds, and abilities of those who participate in it. *Critical collective futuring* refers to how people come together to not only envision a future, but to bring it into practice through the ways that they interact with each other. This sort of practice is rooted in Black feminist praxis (Combahee River Collective, 1986), in that they recognize that the future is something that is brought about through living it into existence, not waiting for something to happen. Finally, the "youth" in *youth* critical collective futuring is a recognition of the particular ways that youth take up critical collective futuring. Through critical collective futuring, youth come together to be and bring about the changes that need to happen for their survival.

Context, methods, & analysis

The Green Club is an after school STEAM program for middle school-aged students. It is part of a larger after school space located in a predominantly Black neighborhood in the U.S. Midwest. In the 2020-21 school year, this program was online. The work youth did over the weeks and on the different days of the club was varied, yet the through lines included making and sharing, and discussion of their interests as they relate to what we do together. This meant that, although each day of the week had a different purpose, these boundaries were fluid and changed based on the needs of the youth, both anticipated and in the moment. During the 2020-21 year, there were 10 youth total.

The data that we generated during this year consisted of recordings of sessions, field notes taken after each session, artifact interviews with the youth at half way through the year and the end of the year, informal reflective conversations with the youth, debriefs amongst the research team, and meeting notes – documents from co-planning sessions with youth during the year that helped not only shape the club, but helped inform the moments that we looked into for the analysis. The primary data used in the analysis and the basis for analytic memos were the field notes generated by the research assistants.

Starting from field notes, we identified multiple "openings" (Halle-Erby, 2022) that were of interest and worked from those moments to 1) find the contexts that built up to those moments, including the types of actions/activities that allowed for it, 2) identify similar moments and record them to create a "strand" of insights, and 3) what happened because of those moments. We wrote analytic memos to record each moment, and as a team discussed insights from the memos in order to present the initial analysis. In the findings we present the work of Lily, who we argue enacted YCCF through her making practices. We present this as an extended vignette, which focuses on her project work over time.

Findings: Lily's project

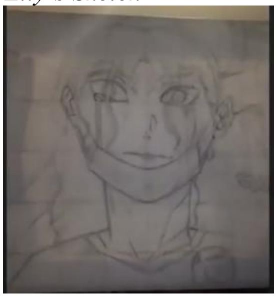
Lily, at the time of this online year, was a sixth grader at a school which had gone completely remote. She is Black, and a fan of many different anime. Her passions were and are drawing, reading, and making animations. The work that Lily takes up in telling her "2020 story" had implications for what it means to be and become in STEAM. Through her work, we can see how the context of a STEAM makerspace, and the expectations of the people in it, affects how she is able to express herself and her ideas.

One fall day in our after school program, our goal was to think about what kind of projects we wanted to do. The larger theme, "2020 stories," was already set, but most of the youth did not yet know what it meant to tell their 2020 stories as they lived through them. It took time for her work to take shape, and we highlight a pivotal moment for her as she developed her project.

A few months into the project, Lily was ready to share an update about her work with the group. She held up the sketch of her painting, which ended up slightly cut off by the Zoom framing. She covered her face so she could point, though she had to move it constantly so she could see what part of the picture she was describing (Figure 1). Front and center on the image was the face of a young girl, while the background and her clothes all held distinct meaning. She highlighted the most important parts: the tree in the back for the Australian and California wildfires, the "I voted" sticker the character wore, "mask because covid," "crying because why not, it's good to cry sometimes," and a "scrunchy because why not." Lily received praise from her peers and the adult mentors verbally and in the chat.

Maria, one of the adult mentors, asked Lily if she was going to make her painting "colorful," to which Lily responded that she would. Maria then asked if she was going to add any lights, by which she meant LED's or similar STEM artifacts, which she was given in a kit at the beginning of the year. At this point, Lily's face lit up, and she responded emphatically with a yes. She then described her idea to paint blue and red lights reflecting off the character's face, representing the police violence against Black people that has become more publicized. In this idea, she took the question as an invitation to think about something she wanted to say about her life, not as a suggestion to add a commonly recognized STEM artifact to her art. While she turned the question on its head, this moment represented a possibly overlooked phenomenon that occurs in STEAM: that ideating on a creative project in the vicinity of STEM tools and resources, youth can come up with powerful representations to express themselves that may not have been open to them before. If Maria had not asked about LED lights (STEM) and Lily interpreted it, that dimension of her work might never have surfaced.

Figure 1
Lily's Sketch



Lily developed her ideas in conversation with others, and in sharing her project ideas she informed others' work. Viewing YCCF as learning leads us to ask us why her process should be overlooked, and challenges us to picture what the youth are envisioning when they take part in futuring. Lily is envisioning a world in which her learning is not defined by the product, but the process. A world where having fun with her friends is as much a part of being in a makerspace as learning the tools involved with it. A world where being in conversation with multiple disciplines counts as engaging with it, rather than just the outcomes of that engagement. The form of making she engages in is an example of how youth challenge and expand the boundaries of STEAM learning, and in doing so create a future where those boundaries become suggestions rather than limits.

Discussion & conclusion

The context of the 2020-2021 school year was unpredictable: youth in this program were navigating the new stresses of online school, not seeing their friends and family as much, and the effects of knowing people who had been lost to COVID-19. Moving school and extracurriculars to a virtual format would have been difficult without a public health pandemic going on in the background, or the resurgence of public attention to racial justice movements arisen from the murder of George Floyd.

These conditions surfaced how youth future in the learning space, and how in doing so they made room to talk about their substantive concerns about the world we live in. YCCF allows for a shift in how we approach education so that it is less tied to neoliberal logics of production, innovation, and competition in favor of developing relationships, exploring new processes, and collaboration. YCCF is an attempt at a "sustainable praxis" (Salo & Heikkinen, 2018), which focuses on experience and developing practices around learning, rather than relying on testing or other assessments to see if learning has been "achieved." The focus on outcomes is de-emphasized in favor of more relational forms of learning and being together (Patel, 2014). In doing this, the logic of a set curriculum that follows a strict, linear time scheme is disrupted.

We see youth futuring in Lily's example in how she sees the future, and how she brings it about now. We can see her in the work of critical collective futuring: she is both reimagining what it means to do a STEAM project about her experiences, and offering what she knows as something that her peers can draw on as well. Further, Lily's work across her project example embodies how she wants her maker practice to look like, and asks us to value her work for what it is rather than what it could have been. Seeing YCCF as a form of learning is to see possibility in all youths' ways of being and doing, not just the ones that are currently valued. It requires meeting youth where they are and working from there, rather than the other way around.

In this paper, we describe how youth take up critical collective futuring in an informal, remote, makerspace, but this has implications even as the pandemic context shifts over time and space. Lily and the rest of the youth in GC continually show us, as adults, researchers, and fellow STEAM-makers, how critical collective futuring is not just a means to continue what we were doing "pre-pandemic." It is an opportunity to figure out what matters most to the people in a learning environment, and take that chance to value relationships and create something new. Through YCCF, we see that the importance of content knowledge expertise in STEM is always there, but with changed emphasis. Youth have expertise in how they want to engage with each other and know how to elicit thought provoking activities/discussions from the group. In this way, they take moments to engage in CCF, and show us how we can learn and become within STEAM without "sacrificing" STEM learning or treating arts as merely a vessel for STEM learning.

Ultimately, YCCF in a STEAM context offers a lens through which we can understand youths' projects, relationships, and interactions that does not center the end products of their work. Youth demonstrate how, when we take the time to recognize the multimodal youth work and conversations that take place in an online environment, new and innovative projects can take shape. It is exciting to see how this can be done, though it is important to take into account the virtual world is not without its challenges and power dynamics. It is important to consider these, given that the potential implications of this work could extend on and offline.

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Understanding How Resettled Refugee Youth Bridge Funds of Knowledge With Science Learning

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Abstract: Refugees' knowledge and experiences are often rendered invisible. Building on an asset-based view, our study investigates the practices of resettled refugee youth bridging funds of knowledge with science learning in an afterschool STEM program. We present findings of how the youth bridged funds of knowledge with science learning about weather, climate, and climate change and how bridging practices mediated their engagement with the science topics.

Introduction

Learning is not limited to school but is expanded across multiple contexts of people's everyday lives (National Research Council, 2015). School learners naturally connect their knowledge and skills developed from diverse contexts outside school to those learned in school. However, students' everyday knowledge and experiences are often either viewed as non-scientific and therefore are not at all utilized or are only superficially referred to (Gutiérrez et al., 1999). These issues are even more salient for learners who come from non-dominant backgrounds. Only dominant (European, White, middle-class) ways of knowing are centered in classrooms, while others are ignored and rendered marginal (Calabrese Barton & Tan, 2020). An alternative view has been suggested to consider diverse ways of knowing as assets (Gutiérrez et al., 1999). Building on this view, we examine learners' participation, engagement, and STEM learning in contexts where non-dominant experiences and knowledge are leveraged. In this study, we focus on science learning of refugee youth who resettled in the United States. Narratives about resettled refugees overwhelmingly focus on their interrupted schooling experiences, trauma, and limited proficiency in the languages of their resettled country (Ryu & Tuvilla, 2018). While providing support for these challenges is an important task of our education system, our work intends to leverage refugee background learners' unique knowledge and experiences from their transnational experiences.

Theoretical framework

We aim to understand what cultural assets the resettled refugee youth brought to science learning space and how doing so mediated their science learning. *Funds of knowledge* and *bridging practices* guided our investigation.

Funds of knowledge

Moll et al. (1992) define *funds of knowledge* as "historically accumulated and culturally developed bodies of knowledge and skills essential for household or individual functioning and well-being" (p.133). Originally funds of knowledge refer to knowledge from households, including family members' employment, occupation, or household activities (Moll et al., 1992). More recent research has extended funds of knowledge to include knowledge and skills developed in communities, from media, and with peers (Calabrese Barton & Tan, 2009; Moje et al., 2004). As this study specifically focuses on Chin (an ethnic group in Burma) refugee youth's participation in science learning, we pay extra attention to their funds of knowledge linked to their lived experiences in the countries they had lived.

Bridging practices

We are interested in understanding not only what funds of knowledge the refugee youth brought into science learning, but also how they connected the funds of knowledge with science learning. We use *bridging practices* as a metaphor to emphasize that connecting funds of knowledge with science learning is more than bringing the two in contact but also making them integrated. Like building a bridge, making two pieces of construction in contact is not complete; they must be riveted together to become a whole bridge. Using *bridging practices,* we emphasize our focus on understanding how the youth integrated funds of knowledge with science learning in the current, situated learning context. We analyzed to what degrees, in what ways, and for what outcomes, the youth participants bridged funds of knowledge and science learning. We also examined how bridging practices mediated the youths' engagement with science topics. We paid close attention to the youths' sensemaking of the topics and their affects shown in the learning processes. Previous studies found that students drew on everyday knowledge and experiences to make sense of science concepts and populated science understanding onto familiar everyday phenomena (Rosebery et al., 2010). When these processes happened, new understandings were generated (Moje et al., 2004). Other than helping with conceptual understanding, drawing on everyday knowledge and experiences also resulted in emotionally engaged participation (Rosebery et al., 2010). For example, nondominant participants positioned themselves as experts when they could connect everyday knowledge to academic learning (Calabrese Barton & Tan, 2009).

Study context

This study analyzed data from Project RESET. The project was part of a community-based afterschool program offered for resettled Burmese refugee youths in a Midwest city (1) in the United States. Project facilitators collected a rich set of data, including video recordings of weekly sessions, audio recordings of small group discussions, student artifacts, and interviews. The project has yielded publications focusing on the youths' self-narratives (Ryu & Tuvilla, 2018), design principles for engaging the youths in critical STEM literacy practices (Ryu et al., 2019), and how the youths negotiated their identity work (Ryu & Daniel, 2020). In the current study, we revisited part of the data (session video, audio recordings, and learner-generated artifacts) to answer two research questions: 1) What funds of knowledge did the resettled refugee youth bridge with science learning? 2) How did bridging funds of knowledge and science learning mediate the youth's engagement with science topics?

Curriculum

Project RESET consisted of 24 weekly sessions (90 minutes each) during the school year of 2016-2017. 10-20 youths participated in each session. The project addressed weather, climate, and climate change. The topics were chosen because of their high relevance to the youths' lived experiences. In the first 18 sessions, the participants learned about the topics through videos, pictures, personal stories, and maps. Learning activities included lab work, drawing, presentation, small group discussions, online research, and creating stories. Facilitators encouraged the participants to apply multimodal and multilingual literacy practices when making sense of the topics. In the last 6 sessions, the participants created videos in small groups to share their learning.

The youths left Chin State, Burma, at the ages of 5- to 11-year-old. They moved to a first asylum country, most of them to Malaysia and others to Thailand, Singapore, or India. They then resettled in the United States. At the time of participation, the youths were sophomores or juniors at local high schools and had lived in the United States for varying periods from 3 years to 9 years. Most of the youths spoke English, Burmese (the official language of Myanmar), and Hakha-Chin (a lingua franca in most parts of the Chin State), with different degrees of proficiency. A few students speak other Chin languages (e.g., Hakha, Falam, Zophei).

Data analysis

We analyzed data from the first 18 sessions because no adequate data were collected in the last 6 sessions. Our data analysis methods were inspired by the grounded theory approach (Strauss & Corbin, 1990). We primarily analyzed the video recordings and referred to the audio recordings and student artifacts to zoom in on interactions and discourses. In initial open coding, we identified episodes where the youth brought in their lived experiences of weather, climate, and climate change in the places where they had lived. Through the comparison of these episodes, we identified nuanced categories of family and community funds of knowledge. We then moved to axial coding, watching the episodes repeatedly to surface the themes of how the youth bridged funds of knowledge with science learning and how bridging practices mediated their engagement with the science topics. Throughout the process, we discussed the codes and reached agreements on interpretations.

Findings

The resettled refugee youth brought into science learning family and community funds of knowledge. Family funds of knowledge are linked to their life in Myanmar and their family's migration history. Community funds of knowledge include their childhood experiences and Chin farming and cultural practices. The youth demonstrated bridging practices in the following ways. They drew on funds of knowledge to concretize scientific concepts. They also applied newly developed scientific understanding to reinterpret funds of knowledge and began to see what was familiar in new ways. While these findings align with those of existing studies (Moje et al., 2004; Rosebery et al., 2010), our findings revealed more nuanced ways of how the resettled refugee youth bridged family and community funds of knowledge with science learning and how bridging practices mediated their engagement with the science topics. We explained our findings in the following three episodes.

Episode 1: Surprising climate differences between countries

When learning about climate, each group received a set of pictures of flora, fauna, natural landscape, and architecture. The youths were asked to identify the country in which their set of pictures was taken. The facilitators marked six countries on the world map as options. After providing some time to discuss in small groups, Facilitator 1 revealed the correct answers and gave them climate data (temperature, precipitation, and wind speed) graphs of each country. The two groups who had pictures of Sri Lanka and Spain were surprised to find out that the patterns of monthly mean wind speed were distinctly different between the two countries. In Sri Lanka, the monthly mean wind speeds stayed pretty much constant throughout the year, whereas in Spain they were higher in January and May through September than in the other months. Pointing at the world map, Joe talked out loud that both Spain and Sri Lanka are surrounded by oceans. The other group members echoed, "Yeah! They are!" Talia said, "Didn't we discuss earlier that places near oceans usually have similar climates and are usually windy?" She continued, "Remember when we were sharing our experiences of weather in Yangon, Kuala Lumper, and Singapore? These places have very similar climates – windy, rainy, and hot." The participants were expecting that Sri Lanka and Spain, both close to oceans, should have similar climates, based on their experience of similar climates in the multiple coastal cities and countries they had lived in. The data graphs of Sri Lanka and Spain contradicted their expectations. The disparity led them to discuss other factors that could shape a place's climate.

In another group, the youths started to examine Australia's climate data graphs. To their surprise, they noticed that the coldest months they experience in the U.S. are Australia's warmest months, and vice versa. The group members started to talk to the group that had the U.S. weather data. A youth described, "They are inverted from each other." Other youths commented, "Interesting," "Weird," and "Why?!" They suggested that maybe this pattern is due to time zone differences. They moved from Southeast Asia to the U.S. and experienced both time and climate differences. They searched online and learned that Australia and the U.S. have time differences as well. Hence, they reasoned that the time zone differences might be the reason why the two countries have climate differences. Facilitator 1 shared that though her home country and the U.S. are in different time zones, they have overlapping months of the four seasons. The facilitator suggested the youths locate the U.S. and Australia on a globe. They identified on the globe that the two countries are on the northern and southern sides of the equator. Facilitator 1 explained to them why the U.S. and Australia have opposite seasons.

As this episode demonstrated, the youths tried to make sense of an unfamiliar country's climate based on their experiences of climates in regions they had lived in. When their predictions turned out to be far from reality, they were surprised, confused, and intrigued to find out why. The contradictions made them aware that climates are influenced by more factors than they had thought.

Episode 2: Commander Leo's adventure story

After learning about climates in several different countries, the participants created their climate stories tied to their experiences of climate in one or more regions. Leo built his storyline along several places he and his family went through when they were migrating from their hometown to the United States. He produced a mini storybook telling an adventure story of a troop marching from Myanmar to the United States. He made himself the commander of the army. After leaving Chin State, the army first arrived at Mandalay and then marched all the way south until they reached a coastal city near Rangoon in June. There they seized all the supplies they needed. Because the army's target was to capture Rangoon, it kept marching despite the non-stop rain and resulting muddy roads. When the army finally reached Rangoon in August, the weather turned sunny - as Leo described, "The sun was all over." Then it took the army less than one month to capture Rangoon. Leo exclaimed, "Think about that! In less than one month! How spectacular it was!" Putting a range of stickers representing a castle and people in his storybook, Leo explained, "Here is the Commander's castle. Everyone is happy because they just captured the capital Rangoon." However, the army did not stay in Rangoon for very long but continued their adventure toward the United States. After a long journey, the army eventually reached America in December. "It was very cold and snowy there as you can see the snowmen and cookie houses," said Leo while he was adding different stickers.

Leo turned his family's migration route from Myanmar to the United States into the journey of his army's adventure. He kneaded into the climate story his experiences and knowledge of climates in different cities of Myanmar and in the United States. Bringing in his lived experiences of family migration and of weather and climates in multiple cities along the migration journey, Leo was engaged in personally meaningful and emotionally rich climate storytelling. He provided rich details of what the weather was like in those places at those times of the year. With the knowledge, he made strategic planning and decisions for his army as they moved along from place to place. Creating and sharing the climate story made it explicit to himself and other participants how weather and climate are different in different places at different times of the year.

Episode 3: Myanmar farmers' farming practices

In the reading materials on extreme weather events including drought, the word "desertification" was mentioned.

Facilitator 1 approached one of the groups and asked the youths to explain "desertification". Simon jumped in, "It means that the land turns into a desert." The facilitator further asked why that could happen.

Pointing at the words "poor farming methods" in the text, Leo explained, "If you grow corn every single year, then you know for sure that your ground is going to be messed up. The Great Plains used to be rich in minerals. But since farmers know nothing about farming methods, they just grow the same crops every single year. That is how it turned into a desert." Leo continued, "You must change crops every season. Potatoes, for example, are good for the soil." Later in another group, Rosa, who had overheard Leo' talk, explained how poor farming methods could result in desertification. Tom in the same group exclaimed, "That [crop rotation] is what farmers in Myanmar do! When it rains a lot, farmers plant rice. In summer when it does not have a lot of rain, they grow peas."

When making sense of desertification and drought, Leo brought in his understanding of how different farming practices impact lands. Tom shared his knowledge of Myanmar farmers' farming practices. Leo and Tom made the science concept concrete by relating it to their knowledge and experiences of farming practices. They were emotionally charged when explaining the knowledge to others. A sense of pride was evident in Tom's emphasizing tone when claiming Myanmar farmers' farming practices as an example of "good farming practices". He enthusiastically described how farmers change crops based on weather and climates in different seasons.

Conclusion

In this study, we identified that the resettled refugee youth bridged family and community funds of knowledge with science learning. Bridging practices helped the youth both make sense of the science topics and develop new interpretations of the funds of knowledge. What is more, bridging practices mediated the youth's engagement with the science topics in emotionally charged ways. The youth positioned themselves as experts who were contributing relevant knowledge and experiences to the science learning community. They merged family stories and community practices into learning tasks and discourses, with a sense of pride. When bridging funds of knowledge with science learning caused wrong predictions and surprises, they were intrigued and motivated to learn more about the concepts. These findings call for engaging refugee youth's life stories, experiences, and wisdom as productive resources for teaching and learning.

Endnotes

(1) All names are pseudonyms.

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Ontological Alignment: Investigating the Role of the Teacher in Supporting Computational Modeling in Science Classrooms

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Abstract: Though the medium of computational modeling presents unique opportunities and challenges for science learning, little research examines how teachers can effectively support students in this work. To address this gap, we investigate how an experienced 6th grade teacher guides her students through programming computational, agent-based models of diffusion. Using interaction analysis of whole-class videos, we define a construct we call *ontological alignment* in which the teacher facilitates discourse to surface, highlight, connect and seek supporting or contradictory evidence for student ideas in ways that align with the level of analysis available in the modeling tool. We identify two practices reflecting this construct; the teacher 1. primes students to orient to interactions between particles and 2. strategically selects evidence to help discern between student theories. We discuss the pedagogical value of ontological alignment and suggest the identified practices as exemplary for supporting students' learning through computational modeling.

Introduction and background

Modeling is a central practice in scientific work and involves explaining a phenomenon by representing its key elements and their underlying behaviors, relationships, and interactions. Computational modeling, and specifically, domain-specific agent-based modeling (ABM), has emerged as an important practice that can simultaneously support students in science and computing (e.g., Kahn, 2007; Wilkerson-Jerde et al., 2015).

Teachers play a critical role in facilitating student engagement with modeling (Ke & Schwarz, 2021). However, uncertainties and challenges persist around teachers' roles in supporting students' computational modeling work. As with any modeling work, teachers must navigate between modeling as a practice for content learning vs. a practice for generating, exploring, and validating or refuting yet unknown scientific knowledge (Guy-Gaytán et al., 2019). As a relatively new representational medium and practice, computational modeling offers unique opportunities and challenges that merit more focused research. Many aspects of programming computational models can be challenging for students, as it requires them to identify relevant content, manage programming structure and syntax, and map content onto the ontological structure of code (Basu et al., 2016). Teachers need to respond to these challenges with tailored support. Incorporating any new epistemic tool or practice into a classroom can be a complex task; teachers and students require time and space to negotiate between their goals and the tool's functionality (Wilkerson et al., 2022) before settling on productive engagement practices. However, despite the central role of teachers in guiding modeling activities, most existing research focuses on the efficacy of diverse teaching approaches using *pre-built models* (Hmelo-Silver et al., 2015) rather than on how teachers can support students in *computational model building* for learning.

In this paper, we investigate how an experienced 6th grade science teacher guides her students through a computational, agent-based model-building unit about diffusion. Specifically, we pursue the following research question: *How does an experienced science teacher support students in expressing and representing their ideas through a computational modeling unit?*

Based on our analysis, we identify a construct called *ontological alignment* that we define as a lens the teacher adopts in facilitating discourse to elevate student ideas that align with the level of analysis available in the tool (in this paper, particle-level behaviors and interactions). We see ontological alignment as important to supporting discourse when using new epistemic tools and practices in science classrooms.

Methods

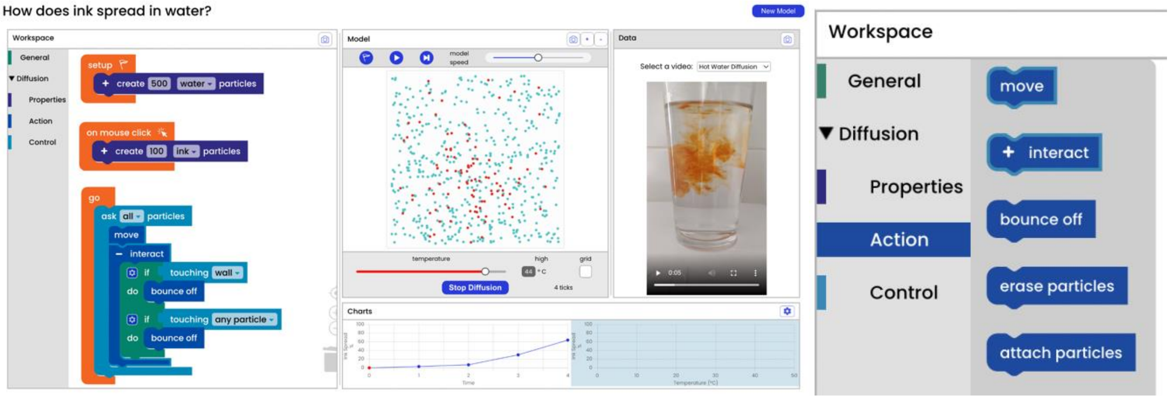
Materials

The computational modeling unit studied in this paper was enacted in MoDa, an agent-based, domain-specific, block-based environment that puts a computational model side-by-side with real-world data of the target phenomenon (Fuhrmann et al., 2022; Wagh et al., 2022). MoDa includes a coding workspace, a space to run simulations, and a real-world data area with video of the phenomenon (Figure 1, left). The code library for this unit includes blocks to define particle-level interactions such as “bounce off” and “attach” (Figure 1, right).

Over 5 days (1 hour/day), students investigated how ink diffuses in water. They ran an experiment comparing the diffusion rates in hot and cold water (Day 1), drew models to explain observed differences (Day 2), and presented their ideas to the class (Day 3). They used MoDa to program models representing their theories about diffusion (Days 3 & 4) and compared their computer models with video data (Day 5).

Figure 1

MoDa with coding, modeling, and data areas (left) and diffusion-specific code blocks (right).



Data collection & analysis

Ms K is a 6th grade teacher at a public school in the Bay Area, CA. She was selected for this analysis based on her 8+ years of experience teaching computational modeling curricula in which students explored pre-built models. This was her second year teaching a computational modeling unit using MoDa in which students programmed their own models. Of Ms K’s two classes, one class was randomly selected for analysis. Data sources include observation notes and whole-class video recordings.

Based on observation notes and video review, we identified 4.5 hours of video of teacher-led, whole-class discussions in which Ms K introduced, reviewed, or contextualized the computational modeling activity. Following interaction analysis methods (Jordan & Henderson, 1995), members of the research team reviewed the videos independently and collaboratively to identify the teacher’s high-level pedagogical practices around supporting her students’ computational modeling work. In mapping the relationships and goals of those pedagogical practices, we developed the construct of *ontological alignment*, which we define as facilitating discourse in ways that surface, highlight, connect and seek supporting or contradictory evidence for student ideas that align with the level of analysis available in the tool (in this case, particle-level behaviors and interactions). Through discussion and comparison, we clustered the initial set of pedagogical practices into two moves critical to establishing ontological alignment, presented below in the Findings.

Findings

We present two ways ontological alignment was visible in Ms K’s facilitation of classroom discourse: 1. underscoring student ideas about particle-level interactions and how those relate to ABM; and, 2. strategically selecting evidence to discern between student theories about interactions.

Underscoring ideas about particle interactions and how they relate to ABM

Ms K emphasized particle behaviors and interactions in ways that aligned with the representational infrastructure of MoDa, an ABM platform. On Day 2, she organized students’ paper models into five groups of “theories” about how ink spreads in water. Words representing MoDa blocks are bold; words used by students in discussions and drawings are underlined: 1. “The water particles are infecting, consuming, soaking in, capturing, dissolving the ink particles"; 2. "Water and ink particles are mixing but not **attaching**"; 3. "The water particles are **bouncing off** the ink particles to cause the spreading of the ink"; 4. "The water particles are combining, growing or coming together, **attaching** to the ink particles"; and, 5. "The compactness or density or space between the particles affects the spread of ink in water." Each theory either highlighted an interaction between particles (e.g., #2 or 3) or flagged the kind of outcome students would expect to see when they run their model (e.g., "not attaching"). Notably, the language for these theories came from students and reflected the block library available in MoDa (e.g., "attach" and "bounce").

In the whole-class presentations that day, Ms K supported students in thinking about how to translate their ideas into computational models. For instance, during Parker's presentation of his paper model, Ms K asked students to consider how they might code their explanation:

> *Parker: In this one, the ink was far apart. In a little bit more time, it was closer together.*
> *Ms K: Did the ink particles increase or break apart? How did there get to be more ink particles?*
> *Parker: It slowly increased because the ink particles were splitting apart.*
> *Ms K: So that'll be super interesting to think about when you make this computer model, like how can you take an ink particle and split it apart?*

Parker explained that the ink spreads in water because the ink particles split apart, but there is no block in MoDa for splitting particles. Aware of the challenge of translating this explanation into a computational model, Ms K asked students to think about how they would represent that idea in their computational model.

On Day 3, after student pairs programmed their first MoDa models, Ms K pulled up four student models representing those theories or combinations thereof. Introducing one pair's model, Ms K said "They're doing kind of an interact and **attaching** theory. So watch what happens to the particles here [*plays simulation*]" (emphasis added). Here, Ms K labeled a student model (#4) and supported students in noticing how the model represented this interaction. Specifically, she instructed students to "pick an ink and water particle and watch what happens to them." After a few moments of watching the simulation, one student commented, "What the heck, the particles are **attaching**" while another student noticed that "only the water seems to be **attaching**, not the ink." In these instances, students saw how each theory, even ones they may not have programmed, could be programmatically encoded and simulated.

Strategically selecting evidence to discern between student theories

When using MoDa, students support or refute the explanations encoded in their models by running the simulation and comparing it to video data of the target phenomenon. By Day 4, the "infect theory," the idea that ink particles change the color of water particles to cause the spread, was popular in the class but could not be invalidated using the video data available in MoDa. Outside class, Ms K discussed at length with the third author what kind of evidence would help students refute the infect theory. On the last day, Ms K asked students how they could test their idea that "the water has been fully infected." Students suggested that "you could evaporate it" or "you could use a microscope." On a projected slide, Ms K showed the class an experimental setup in which water mixed with blue dye was evaporated from a dish covered with plastic wrap (which she referred to as "Saran wrap"). When she asked students to discuss with their partners what color the water on the plastic wrap would be, some students predicted it would be blue.

> *Ms K: Ok, it would be blue if the infection theory is correct. If the water is not blue on top of the Saran wrap, what does that mean?*
> *A few students: That that theory is incorrect.*
> *Ms K: That the infection theory is incorrect. (Shows next slide with clear droplets on Saran wrap)*
> *Ms K: What color is the water?*
> *Multiple students: Not blue.*
> *Ms K: It's not blue. It's clear. So does the ink infect or get captured by the water?*
> *Multiple students: No.*

Ms K strategically brought evidence that helped students discern between their ideas and brought in new evidence to invalidate a theory that could not be disproved within MoDa itself. Here again, Ms K operated from an understanding of the strengths and limitations of the computational modeling possible within MoDa and found ways to support students where the code and simulation fell short. She situated computational modeling as one tool for scientific sense making and exemplified for students how to best pair that tool with other science practices and techniques to advance their theory-building work.

Discussion and conclusion

This paper addresses a pressing gap in the literature about how teachers can support computational model building in the classroom. It defines a construct, *ontological alignment,* to characterize the teacher's work of guiding discourse to highlight the representational infrastructure and level of analysis in the computational tool being used. We present two manifestations of ontological alignment in Ms K's practice: 1. underscoring student ideas about particle-level interactions and how they map onto ABM; and 2. strategically selecting evidence to discern between student theories about particle-level interactions. Collectively, these practices required the teacher to adopt an ontological lens of particle-level interactions and, throughout the unit, to elicit student ideas about interactions, support them in translating these ideas into a computational medium, and find evidence that would help students discern between the different theories. Space constraints exclude our ongoing analysis of how students take up these practices. The paper contributes to research on teachers' roles in computational modeling by illustrating how ontological alignment can guide a teacher in supporting classroom discourse around computational modeling. The focal teacher's understanding of MoDa went beyond simply knowing how to use it; she was intimately aware of its strengths and limitations, which informed how she guided students in her class. Ultimately, our findings highlight the importance of teachers seeing computational tools as supporting the expression and refinement of particular forms of students' existing ideas and facilitating discourse from that perspective. We see ontological alignment as important to supporting discourse when using new epistemic tools and practices in science classrooms.

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Cultivating Historical and Political “Truths”: How Designing for Collective Relationalities and Critical Reflexivity Supports Expansive Historical Thinking

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Abstract: This paper offers preliminary results from a project exploring the cultivation of historical and political ‘truth’ in a critical history classroom. As questions of truth and knowledge production continue to shape public discourse, more work is needed to explore how critical pedagogies can influence disciplinary learning processes and knowledge production. Drawing from critical sociocultural perspectives of learning, I share one vignette from a year-long collaborative ethnography of a U.S. history high school class to understand how the teacher’s critical history pedagogy shaped students’ historical thinking. Based on ethnographic, interactional, and discourse analyses, I highlight how a history class grounded in values of relational collectivity and critical reflexivity invited new conceptions of truth as ever-changing and spatially, temporally, and culturally situated based on new information, perspectives, and re-narrating specifically in history education. Potential implications include nuancing our theorizing, conceptualizing, and design of disciplinary learning by incorporating critical pedagogies.

Introduction

Whether in response to re-imaginings of schooling structures during COVID-19 or ongoing battles over ‘CRT,’ contestations of knowledge production and expansion face new considerations. I explore a microcosm of these grander questions with a case study of an11th-grade U.S. history class in which the teacher engaged an expansive disciplinary pedagogy. The teacher and I wished to understand how his pedagogy informed the history learning students took up over the school year. Based on ongoing ethnographic analysis, I offer initial findings on how his pedagogy ,grounded in values of *relational collectivity* and *critical reflexivity,* invited new student conceptions of truth based on *new information, perspectives,* and *re-narrating*. I share one vignette to demonstrate these constructs and how they became foundational to student thinking. These findings can support nuanced insights into what expansive disciplinary education can look like, how we can achieve such learning initiatives, and why this expansiveness is necessary for current and future envisioning of education.

Literature review

Relational mediation & collectivity

Learning is highly dependent on the quality and care of the relationship between teacher and student (Bang, 2017; Vossoughi et al, 2020). Through foundational frameworks like culturally responsive pedagogy (Ladson-Billings, 1995), cultural modeling (Lee, 2001), and Third Spaces (Gutiérrez, Baquedano-Lopez, Tejeda, 1999), we have built the groundwork to help teachers create positive social interactions with students. Building a relational ethic of trust, dignity, and respect can open rich moments of transformative learning, particularly for young people contending with various forms of oppression (Espinoza et al, 2020; Jackson, 2021). Paying attention to relationship building offers insights into the varied ways relational mediation shapes the teaching experienced by students (Vossoughi et al., 2020). A collective relationality centers multiple subjects as *working together*, each contributing their own conceptual resources and expertise, to accomplish activities that would not be possible without the dialogical attunement to one another (Shotter, 2015). These forms of relating prefigure the world as it could be through just and dignifying co-relations.

Expansive disciplinary learning

Powerful research grounded at the intersections of disciplinary education and critical pedagogical theories offers insights into the nuances of learning made possible through an expansive disciplinary perspective. Across these works (Vossoughi, 2014; Gutstein, 2016; Rosebery et al, 2010), learning was more robust and meaningful to students than normative didactic approaches to disciplinary teaching and inspired new ways of thinking and participating in the disciplines. The valuing of heterogeneous onto-epistemologies alongside the interrogation of the power systems can cultivate the conditions for knowledge-building and social dreaming (Warren et al, 2020). Scholarship exploring expansive approaches to history illuminate unique forms of learning: historical argumentation that directly engages the ideological foundations of historical inquiry (Freedman, 2015), the potential of supporting students' critical receptivity of evidentiary sources (Bain, 2006), and the value of historical sense-making that centers students' cultural and political knowledge and histories as legitimate knowledge sources (Goldberg et al, 2011). How does this happen? What does expansive history learning look like in the moment and? These are the questions my research aims to address.

Theoretical & conceptual framework

I define learning as the shifts in participation and thinking supported within and across cultural activities (Nasir & Hand, 2008; Rogoff, 2003). These shifts often leading to the participation in new, expansive activities (Engeström, 2001), are embedded in sociopolitical systems and ethical assumptions, "articulating the 'how,' the 'for what,' the 'for whom,' and the 'with whom ' (Philip, Bang, & Jackson, 2018) of participation. My approach to seeing teaching and learning requires attuning to the design principles and approaches of learning activities, capturing the moment-to-moment interactions of people within these activities by attuning to the shifting form & function (Saxe & Esmonde, 2005) of learning as a situated experienced.

Project overview & methods

The project I drew from was a year-long ethnography of Mr. Nottingham's 9th-period U.S. history class. During the school year, I visited Mr. N's class three times a week, gathering jottings, field notes, video recordings, interviews, surveys, and student work. My units of analysis were the practices and ways of being designed for and taken up by students; special attention was given to student verbal and embodied communication to trace shifts in thinking participation over time.

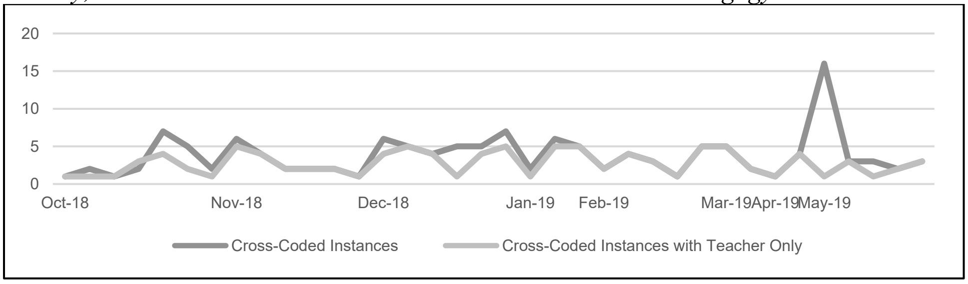
Drawing on ethnographic, discourse, and interaction analyses, I analyzed this large data corpus through iterative coding, conceptual matrices, and memo-ing (Erickson, 1985). I open-coded all jottings and field notes across the school year and synthesized codes into conceptual matrices around unifying themes. I have completed the pedagogy portion of the analysis, focusing on Mr. N's most prominent pedagogical practices (see Table 1).

Table 1
Pedagogical Practices Definitions

Pedagogy Practices	**Asking questions**	**Explaining**	**Encouraging**	**Modeling**
Definition	topics with no clear answer and/or to encourage conversations	class topics and teaching; a story framework using disciplinary, personal, and political	discursively motivate practices or habits of mind	embodying or acting out practices and habits of minds

I then used process coding to further analyze the immediate the longer-term interactional impact these pedagogical practices had on student participation in class. As a result, three primary categories emerged: history (786 coded instances), relational (837 coded instances), and political practices (812 coded instances). We can see the overlap of all moments students engaging in history, relational, and political practices with the teacher's pedagogical practices in Figure 1 (1).

Figure 1
History, Relational and Political Practices Cross-Coded with Pedagogy Practices



Looking more concretely at these moments of student engaging history, relational, and political practices together, initial analysis has illuminated characteristics that student participation in these moments is characterized by an historical thinking grounded in engagement with new information, new perspectives, and re-narrating historical and political narratives.

Initial findings

Initial findings indicate that organizing a history class around values of *relational collectivity* and *critical reflexivity* invited new conceptions of truth as ever-changing and spatially, temporally, and culturally situated based on *new information, perspectives,* and *re-narrating***.** Relational collectivity was the process of understanding oneself as embedded within collectives; the individual is always shaped and shapes the larger world, whether individuals, artifacts, or social norms/beliefs. Critical reflexivity was analyzing new and known information within disciplinary, political, and ethical lenses to refine information based on an ever-changing world, a continuous process of knowing and re-knowing by recognizing the impact sociopolitical systems have on ways of knowing. Mr. N wished to support students in historical thinking grounded in assumptions that history is an ever-changing narrative based on one's sociopolitical status and beliefs. Mr. N's encouragement of collective inquiry primed students to engage in historical thinking as a collective endeavor versus an individual investigation. This led students to conceptualize historical and political truths as determined by new information, perspectives, and re-narrating.

Take this discussion from the middle of the school year. The class was starting a new unit on the Gilded Age and Mr. N wanted students to think about the underlying themes that resonate across U.S. history. He asked students a simple question–what is ownership? This question inspired an almost 20-minute conversation on how to define and conceptualize ownership. I offer a brief vignette from the discussion to demonstrate how students attuned to the perspectives and information offered to one another, shaping their collective inquiry:

> Mr. Nottingham said, "after reconstruction, we were looking for ways to make more money…common theme around ownership, what does it mean to own?" Bolaji, a young Black man, said, "to legally own." Mr. Nottingham followed up, "but what does that mean? What do you actually own?" Borna, a young White man, said, "a house." Sarah, a young White woman, said, "you own your body." After students started to discuss these ideas, Mr. Nottingham asked again, "what does that mean?" Borna added, "you control it."
>
> As more students offered suggestions, Mr. Nottingham repeated the ideas he heard, such as Sarah's response: "I'm hearing 100% control of one's body" At first, Bolaji said no, and Sarah responded, "yes, really." Sarah and Bolaji went back and forth a few times before Bolaji said, "not if you are in the military." A few people said, "oh!" while another asked what Bolaji said. After a few seconds, Sarah repeated, "he said, 'not in the military." There was a discussion about body ownership in the military, with Sarah nodding her head, now agreeing with Bolaji.
>
> Mr. Nottingham said, "y'all are talking about really interesting ideas." Laquantre, a young Black man, referencing another student who seemed to be laughing around this conversation, said, "y'all laughing, but Bolaji is lowkey right."

Students' back-and-forth on body ownership highlights the ideological intricacies embedded in the notion of "ownership." As a young white woman, Sarah's claim could have emerged from many intellectual histories. She could be just using her intuition that since she can move her body, she owns it. She also could be drawing on her experiences of being a woman, particularly during a political moment in which bodily autonomy is effervescent in news media and discourse. The stance for body ownership was still presented as a given because, to Sarah and others, this information aligned with a perspective many already shared, a perspective of being young white Americans. The resulting narrative of people owning their bodies makes logical sense in this framework.

Bolaji challenged this. Bolaji was a young Black man who emigrated to the U.S. from Nigeria when he was 12, resulting in a limited understanding of U.S. history. Although some students knew Bolaji's background, many did not; this often made Bolaji feel insecure about asking questions or raising points that may be 'obvious' to others but not to him. This insecurity is important to remember when reading Bolaji's challenges to Sarah's position. Although most of the class supported Sarah's argument that one own's a body, Bolaji was drawing from different conceptual and historical resources, perhaps not privy to Sarah. Young Black men, whether in Nigeria or U.S., are often discursively positioned as politically disposable resources for national militaries (Corcione, 2019). Bolaji's introduction of this new information not only necessitated adopting a perspective of young Black men but also a re-narration of body ownership in this new context.

Once Bolaji introduced this new information, Sarah's position immediately shifted. She did not negatively receive Bolaji's pushback but acknowledged it to others in the class, ensuring everyone heard his point. This inclusion of new information introduced a new perspective that she and many others in the class may not have had because of their social positioning. Laquantre's further affirmation of Bolaji's point reflected the relational collectivity valued in Mr. N's class. Knowing the precarious status Bolaji held in the class, Laquantre leveraged his role as a legitimate participant to raise Bolaji's argument, just as Sarah did by repeating Bolaji.

The discursive moves by Sarah, Bolaji, and Laquantre invited, responded to, and affirmed new information while they negotiated their perspectives, and thus narratives, on what constitutes ownership. Furthermore, the consensus on Bolaji's information did not negate Sarah's perspective either; rather, you can own your body depending on one's sociohistorical positioning regarding race, gender, and economics. This was affirmed by Mr. N, who didn't say whether one was right or wrong but acknowledged that "y'all are talking about some really interesting things." The new narratives emerging around ownership were neither right nor wrong. Still, they reflected the complexity of using an all-encompassing term to make sense of historical and political questions.

Implications & conclusions

I aim to highlight the conditions and moments in which students introduced and engaged new information, perspectives, and re-narration in their pursuits of historical and political 'truths.' Just from this example we can see how, through pedagogical mediation characterized by collective relationality and critical reflexivity, practices of including new information, perspectives, and re-narration invited students to engage in more expansive historical thinking that is socio-politically situated. Offering detailed profiles can help us 1) recognize how students are unpacking complex ideas through lived experiences, 2) trace the conceptual practices they draw upon to unpack complexity, and 3) the pedagogical practices that create the conditions for take-up of these practices, positioning students to be political and historical actors. This research can contribute empirical insights on what constitutes disciplinary knowledge production and participation, on how to see this knowledge in action, and how to support teachers in this knowledge cultivation (Vossoughi & Gutierrez, 2017).

Endnotes

(1) This is evidenced by the spike in student practices in May. On this day in class, Mr. N asked students to lead their discussion about WWII. We see students engaged in the history, relational, and political practices even more than usual to create and sustain the kind of learning environment they co-created with Mr. N, demonstrating the usefulness of the practices.

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At-Home Engineering: Caregivers' Support During Problem-Solving

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Abstract: The home environment is a critical context in which children engage in STEM activities. Caregivers serve as key influencers on their children's engagement in these activities. This case study of four families explored how caregivers support their child(ren) during moments of problem-solving while completing engineering activities at home and illustrated the variation in caregiver support, caregiver participation/child agency, problem-solving strategies used, and integration of activities into the home. Our findings suggest we need to be purposeful in designing kit activities and supports for caregivers that will contribute to meaningful interactions during STEM activities that draw upon the unique relationship between caregivers and their children in the home.

Background

There is growing recognition of the importance of engaging in engineering practices and processes for young children, both in formal settings (e.g., schools) and informal settings (e.g., home). Caregivers significantly influence children's engagement in engineering and STEM activities, shaping their children's experiences, attitudes, identities, interests and practices (Ing, 2014; Maltese & Harsh, 2015; Šimunović & Babarović, 2020; Vedder-Weiss, 2018). Research in informal environments looking at family STEM engagement often occurs in museums (Callanan et al., 2017; Zimmerman et al, 2010) or workshops (Simpson et al, 2021). Researchers have studied home science practices (Strickler-Eppard et al., 2019; National Research Council, 2009) and have retrospectively interviewed families about open-ended engineering design (e.g. Dickens et al., 2016). However, compared to other informal settings (e.g., museums), the home environment is understudied. We argue that the home is a critical context in which children engage in STEM activities. Within this context, caregivers play an important role, serving as key influencers on their children's engagement in STEM activities. In this study, we seek to add to the scholarship by answering the research question: *How do caregivers engage with and support their child(ren) during moments of problem-solving while completing engineering activities at home?*

Methods

This study was part of an NSF-funded project to (1) engage children and their caregivers in engineering, (2) increase awareness of engineering, and (3) spark or sustain childrens' interest in engineering. We created several engineering design challenge kits for 8-12 year old children. This paper focuses on the Watercolor Bot kit, which contained instructions with video links to more information and examples, a facilitation guide for caregivers with optional question prompts, a variety of materials (e.g., Q-tips, cotton balls), two lithium coin cell batteries (Figure 1a), and two 10mm vibrating disc motors (Figure 1b). Instructions were to design a motorized bot that "paints," which required families to build a bot body, connect the battery to the motor (Figure 1c), attach the motor to the bot, test on various surfaces, and redesign as needed (Figure 1d-e shows sample bots). Caregiver guidance was minimal and focused on supporting the design cycle (research, plan, create, test, improve). The library website hosted a welcome video with kit instructions, including the statement "while you may be tempted to let your children complete the activity on their own, we encourage you to actively participate with them." Kits did not indicate a time estimation for the activities. A watercolor bot could be created in 20-30 minutes, but we expected families to engage in design iterations which would extend the activity.

Figure 1
Examples of Components of and Completed Watercolor Bots

Participants and data collection

We partnered with our local library to distribute kits to families as part of their annual summer reading challenge or to families who participated in Saturday workshops offered to families. Kits were offered to families with no expectation of participation in the research project. A majority of families expressed interest in the research study (26 of the 33 families from the summer reading challenge, three of the eight families from the Saturday workshops). Families who expressed interest in the research study were emailed information about the study, including a unique Zoom link that auto-recorded when the room was opened. We asked families to record their entire making process, instructing them to open the link whenever they engaged in the kit activities together. When confirming their participation, some caregivers expressed discomfort with recording (e.g., concerns about low level of scientific knowledge, recording arguments within family interactions). Families had full control over the recording, deciding when to start and stop the recording and whether to have their video on/off. Researchers were not physically or virtually present during the recordings. Four families recorded their work on the Watercolor bot. Pseudonyms were used for all caregivers and children (see Table 1).

Table 1
Participant Families

Family	Caregiver(s)	Child(ren)	Video Duration
		Name (Gender, Age)	
Harris[a]	Mom and Dad	Ethan (M, unknown)	64 min.: 2 sessions on same day
Williams[a]	Mom and Dad	Bella (F, 6); Charlotte (F, 9)	38 min.: 1 session
Cadshaw[b]	Mom and Dad	Harper (F, unknown)	65 min.: 3 sessions across two different days
Gupta[a]	Mom	Arnav (M, 7); Priya (F, 10)	48 min.: 2 sessions on same day

[a]Participated in the Saturday workshops. [b]Participated in the summer reading challenge.

Data analysis

We utilized a case study approach to showcase interactions between caregivers and children in natural, everyday contexts as they worked through creating the movement for their watercolor bot at home. For each caregiver-child dyad, we were interested in examining the ways caregivers supported their children during moments of problem-solving while completing the task of the engineering kit. For each video in the selected corpus, we used interaction analyses (Jordan & Henderson, 1995) to inductively code segments related to families problem-solving through not knowing something and figuring it out together. After open-coding the full videos, we identified segments that demonstrated moments of problem-solving, specifically focusing on the following: connecting the circuit, maintaining the connection of the circuit, and vibrating the bot. We re-coded those segments with the lenses of participant attention (Vossoughi et al, 2021), caregiver roles (Simpson et al, 2021), and strategies used to solve problems (Cardella et al, 2013). These lenses informed our understanding of how caregivers support their kids during problem solving.

Findings

We present a brief showcase of each family's interactions that highlight differences in caregiver support, caregiver participation/child agency, problem-solving strategies used, and integration of activities into the home.

In the Harris family, Mom helped Ethan get started but then left him to explore and create on his own while she and Dad engaged in other activities nearby. Ethan made comments that pulled Mom and Dad into his exploration as he expressed his success, frustration, and ideas. Mom positioned herself as a novice but continually checked on Ethan, asking him questions about his progress. When Ethan said, "How is this thing supposed to work? I don't know how this thing is supposed to work," Mom told him to "Ask Daddy" and Dad offered advice and referenced the given materials. By the end of the recording, Ethan's bot vibrated around on its Q-tip legs, though Ethan never used the watercolor paint on the Q-tip feet during the video.

Both girls in the Williams family were engaged in the watercolor activity. When Bella switched to painting on her own (rather than making a bot do it), Mom focused on collaborating with Charlotte who was redesigning her bot. Mom suggested ideas, pulling in her knowledge of circuits and balance as she supported Charlotte. Mom celebrated successes, calling Dad over to see their work. Dad also supported by providing his knowledge of electrical circuits when Charlotte struggled to maintain the connection between the battery and vibrating motor wires. Mom, Dad, and Charlotte all theorized why the bot was not moving, wondering if there was too much friction, had too much watercolor paint on it, or the vibration was not happening in the right place. As the recording ended, they celebrated as the bot vibrated the tinfoil across their floor.

In the Cadshaw family, Mom helped Harper get set up and started on the activity. Mom provided resources (e.g., read text from the guide), referenced informational videos, and asked questions to guide Harper in the planning, design, and creation of the watercolor bot. Multiple times across the series of videos, Mom redirected Harper to focus attention on the questions Mom was asking her or rebuked Harper for her behavior, even stopping the recording at one point. Mom admitted that she did not know how to connect the battery and motor and that they would have to figure that out. Harper got the motor to vibrate by pressing the wires hard against the battery and brainstormed many creative ideas to generate "more pressure" to connect the wires to the battery. Eventually, Mom stripped plastic coating off the wires to help make a better connection. Mom was simultaneously caring for baby brother and balancing other family obligations (e.g., friends arrived to drop off dinner), telling Harper, "At some point I need to go get something else done besides this." When Mom asked Harper questions from the materials, Harper slumped in her chair and did not respond. Their sequence ended with Harper having a watercolor bot that painted a bit but still had stability and vibration connection troubles.

Both children in the Gupta family worked on their own watercolor bots for their whole session. Mom sat at the table the entire session and provided hands-on help to both children when they struggled to realize their bot using the materials available to them. Arnav finished his design first but struggled to attach the battery and vibrating motor to his bot body. When he was unable to solve the problem, all three worked together to get the motor to vibrate using available resources (e.g., kit guides, videos, internet searches) and by manipulating the motor, wires, and battery in trial-and-error fashion. They frequently wondered aloud, offering suggestions, ideas, and questions, as they built their knowledge together. After more than ten minutes of problem solving, Mom decided to stop the video while they figured out how to connect the battery. The second video began with Mom announcing they had figured out the connection and held the bot up to the camera. Mom continued providing hands-on help to both children, responding to requests when they ran into issues. Their video ended after they successfully tried their watercolor bots on various surfaces.

Discussion

The four families illustrated variation in problem-solving strategies used, caregiver support, caregiver participation/child agency, and integration of activities into the home. The families encountered each of the three identified problems (making the initial connection, maintaining the connection, and getting the bot to vibrate) to greater and lesser degrees with each family utilizing a mixture of observation, ideation, and testing to solve the problems. Caregivers positioned themselves as a supportive resource, scaffolding the activity when their child got stuck, experienced frustration, could not physically manipulate the materials, or did not know how to proceed. At times physical (e.g., attaching a rubber band), facilitative (e.g., helping child persist when he/she said "I give up"), or collaborative (e.g., offering design suggestions), this scaffolding allowed children to access a larger range of actions and behaviors than would have been possible on their own. Throughout all interactions, caregivers drew on their prior content knowledge (e.g., circuits) and familiarity with their children (e.g., behaviors) as they adjusted the support they provided.

Through their actions and words, caregivers positioned themselves as co-learners and facilitators, working alongside their children in their attempts to support their child's success in the activity. Caregivers positioned the activity as owned by the child who had full agency and ownership of their created watercolor bot. While they at times inserted their ideas and help, caregivers did so in support of their child's vision. Caregiver participation varied on a continuum from being on the periphery nearby but only engaging when the child needed assistance, to participating for the entirety of the activity as co-learners and collaborators. This continuum was evident in the Harris family where Ethan completed the activity entirely independently (except when he requested help) and in the Williams family where Mom could be heard suggesting her ideas but giving Charlotte the agency to make all final design decisions.

Finally, our findings illustrate challenges with integrating and engaging in STEM activities within the home context. The segments of time families chose to record provided a glimpse of the balancing act required by caregivers to provide their children opportunities to learn new things against the constraints of daily life (e.g., caring for younger siblings, household tasks). Some caregivers took a consistently active role in the activity while others popped in and out as they attended to their child as well as other tasks. Additionally, kit completion often occurred across multiple sessions, stopping and starting based on these family obligations as well as the behavior of the child. All of this demonstrates the uniqueness of challenges faced in the home context.

Conclusions and implications

Our examination of four families engaged in completing one at-home engineering kit activity offers a glimpse into family engagement in STEM activities at home. The findings suggested that families draw on different background knowledge, patterns of interaction, and strategies when working together during STEM activities, all while balancing the integration of these activities into existing family activities. All of these factors influence whether and how STEM kits and activities are used in the home context. We need to be purposeful in designing supports specifically for caregivers, many of whom are not confident in their ability to support their children in STEM activities (Knox et al, 2022). Such support could include supplemental materials that provide entry and expert level activity support, strategies to engage caregivers as co-learners and collaborators while fostering children's agency in STEM activities, and tips for adjusting support based on their children's individual needs. Additionally, since the home context allows for more time and flexibility in completing activities (e.g., across multiple days), activities should be designed to easily accommodate occasional stops/starts and varying levels of caregiver participation as they are pulled away to do other tasks. Continued work is needed to understand how best to support children through moments of productive struggle (Warshauer, 2015) which often is an aspect of the problem-solving required during open-ended STEM activities. Attention to these design features may contribute to more impactful interactions during STEM activities that draw upon the unique relationships between caregivers and their children.

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The Design of a Critical Machine Learning Program for Young Learners

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Abstract: Machine Learning (ML) is integrated into many of the technologies we use daily. However, biased training datasets have shown to be harmful for marginalized populations. As future consumers and producers of technologies, children should have the technical and social expertise to engage with such issues in ML. In this study, we describe a series of activities designed for elementary and middle-school aged children to learn concepts of machine learning (ML), bias, and the sociopolitical implications of ML. Grounded in critical constructionism principles, we describe how children engage in reflective discussions, tinker with existing ML tools, and build an ML-based robot for social good.

Introduction

Machine Learning (ML) is integrated into many of the technologies we use daily. However, the socio-ethical implications that arise due to biased training data sets have shown grave implications, especially for underrepresented minorities. For example, while working as an MIT computer scientist, Joy Buolamwini, uncovered racial and gender bias in artificial intelligence (AI) services from companies such as Microsoft, IBM, and Amazon (Kantayya, 2020). With other numerous documented instances of ML bias (Piano, 2020), it is essential to equip youth, as future consumers and designers of technology, with the technical expertise and experience necessary to engage with ML. To broaden youth engagement with ML, a number of studies have developed programs and curricula that teach young learners basic ML concepts and operations (Chan, 2019). However, few studies have integrated AI ethics (Payne, 2020) and sociopolitical issues in educational programs. To address this gap, we co-designed with learners between 3rd-5th grade and implemented a critical machine learning (CML) program that attempted to integrate teaching concepts of ML with sociopolitical issues in ML. In this paper, we describe critical constructivist activities that children engaged in and provide examples of how youth integrated ML concepts with sociopolitical issues. This paper is a part of a larger study on critical constructivist activities designed to enable children to think critically about the sociopolitical implications of ML and design ML applications for social good (Arastoopour Irgens et al., 2022). This paper presents a description and analysis of critical constructivism and an application of its active-learning principles to developing a CML program for elementary and middle school youth in afterschool programs.

Designing for CML education with a critical constructivist lens

Our design and pedagogical approaches for facilitating children's critical engagement with machine learning (ML) were based on critical constructionist perspectives (Holbert et al., 2020; Kafai et al., 2020). The critical constructionist design framework promotes a learning environment that builds upon learners' lived experiences and provides tools that mediate learners' development of creative ideas and artifacts that reflect and challenge their lived realities. In this framework, educators connect concepts to personal and communal structures of inequities that shape the meaning and application of such concepts. Learners reflect, tinker with tools, and design futures that challenge the identified structures. Holbert et al. (2020) argue that engaging students in a cycle of connection and critical reflection about knowledge gives learners the opportunity to infuse their own perspectives and values into their creation. Moreover, learners play an agentic role in reducing or creating awareness about systems of inequalities in society and the critical nature of knowledge-building leads to a better understanding of the content (Holbert et al., 2020).

Methodology and CML program design

The activities described in this paper were designed and implemented with youth from two after-school centers in the United States consisting of Black, Latinx, and White children with a mix of those who presented as girls and boys and ranged between 9 - 13 years of age. The goal of the program was to provide children with learning experiences that enable them to understand ML bias, critically reflect on the harmful effects of ML bias at the systemic level, and design ML systems while attempting to mitigate bias. The activities, inspired by MIT's AI + Ethics Curriculum for Middle School and AI Ethics Education Curriculum (Payne, 2020), have been designed and tested in three iterations with forty-four children and three staff counselors from two separate after-school youth programs. Each iteration lasted approximately seven weeks and the activities with the youth occurred 2-3 days per week and lasted 1-2 hours each. Through these bi-weekly sessions, the researchers evaluated and amended the activities in light of the children's behaviors, conceptual grasp, direct and indirect input, and observed level of involvement (Arastoopour Irgens et al., 2022). The children's input, perceptions, values, and needs were taken into account and contributed to re-designs during implementations and between iterations. In this way, the children engaged in the co-design process as testers, and informants (Druin, 2002). We describe the set of activities implemented in the third iteration of the project following the changes that were implemented in the first and second iterations (for examples of the iterative re-designs in this study, see Bailey et al., 2023). The section that follows describes the CML program activities in light of the program goals: 1) engage children in reflective discussions on bias in ML algorithms, 2) engage children in 'tinkering' with existing ML tools with adult guidance, and 3) promote opportunities for children to use their gained knowledge and experience to design and build an ML-based robot for social good. Alongside the activities, we present qualitative data from interviews with children and researcher observation notes to provide some context of learners' engagement in activities.

Engaging children in reflective discussions on bias in ML algorithms

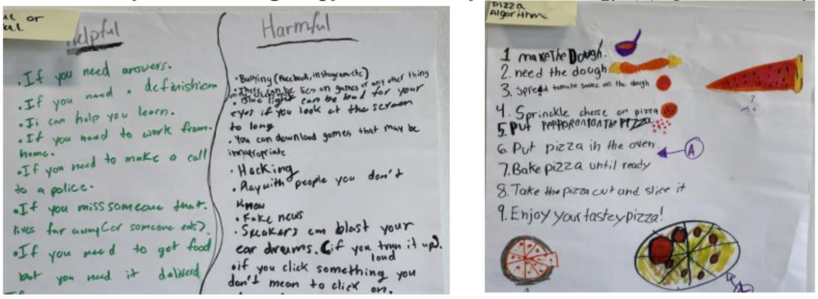
The goals of the following discussion-based activities—*Harmful/Helpful Technologie*s, *Pizza Algorithm*s, and *Coded Bias*—were to guide children in critical reflections regarding the advantages and disadvantages of ML technologies, as well as understanding that algorithmic bias may exist within these technologies.

Harmful/Helpful Technologies: The children worked in groups of 3-5 participants to create a list of technologies they use. They were asked to document whether the identified technologies are helpful or harmful. Each group used large poster boards and markers to illustrate or list technologies within the categories of helpful or harmful (see Figure 1a). The youth worked in small groups and then in a whole group discussion with program facilitators.

Pizza Algorithm: We introduced the children to the concepts of algorithms and bias and the children worked in groups to write or draw a set of instructions on how to make the "best" pizza using markers and large posters hanging on the wall (see Figure 1b). They explored what represented the "best" pizza to each group and according to our observations, voiced how their preferences were reflected in their algorithms.

Figure 1

Children artifacts showing helpful and harmful technology (a), pizza activity (b)



.If you need answers.
.If you need a definishion
.Ii can help you learn.
.If you need to work from home.
.If you need to make a call to a police.
.If you miss someone that lives far away(or someone els?).
.If you need to get food but you need it deliverd

.Bullying (facebook, instagram, etc)
.There can be lies on games or any other thing
. Blue light can be bad for your eyes if you look at the screen to long
. You can download games that may be innapropriate
. Hacking
. Play with people you don't know
. Fake news
. Speakers can blast your ear drums. (if you turn it up loud).
.if you click something you don't mean to click on.

1 make the Dough.
2. need the dough
3. spread tomato sauce on the dough
4. Sprinckle chesse on pizza
5. Put PEPPORONI ON THE PIZZA
6. Put pizza in the oven
7. Bake pizza until ready
8. Take the pizza out and slice it
9. Enjoy your tastey pizza!

(a) (b)

Coded Bias: Children watched the Coded Bias film trailer (Kantayya, 2020), which featured Joy Buolamini's realization of racist facial recognition technologies. Subsequently, children critically reflected on the concepts of bias, facial recognition technologies, and the socioethical implications of such bias with the researcher's guidance. In a group discussion, children responded to prompts such as: *What was interesting in this video? Who was being mistreated in this video and how? Who was creating the technology that was harmful?* During the discussion, one child commented: "*What I thought was interesting is a lot of people's life could be changed by, what the cameras [facial recognition software]…, on the streets pick up…*" Another child in the same group added, "*Just because of the software the person wasn't recognized to a certain, like house or where they live, they could get locked out of their house or they could be denied housing.* Statements made such as this one suggest engagement in the discussions around how technologies can be biased and the socio-ethical implications, such as AI making mistakes and people being denied housing.

Engaging children in tinkering with existing ML tools with adult guidance

The goals of the activities—*Google Search*, *Quick, Draw!*, and *Cat and Dog Teachable Machine*—were for children to tinker with tools and explore concepts of testing and training data, outputs, and algorithmic bias.

Google Search: To explore how algorithms have the creator's biases and opinions embedded within them, a researcher used a laptop and projector to guide the children through a group activity that required running a Google image search for words such as "basketball player." The search returned images of men and the researcher asked: *Who might not be represented in this group? Why do you think we are seeing the images we are seeing? Who or what decides what we see?* During the discussion that followed this search, one girl stated "*If you look up basketball… you should be able to see both of them [men and women]. If you look up anything,* ***you should see women and basketball.****"* After completion of the program, another girl revisited the activity in her post-interview: *"Like, when we did the Google algorithm… When we searched up the basketball player, I liked how we could like to express our opinions on if it should be male or female."* Here, the girl liked expressing her opinions about the output of the search algorithms. These girls felt comfortable in the space to provide their opinions and display a critical lens towards existing search algorithms.

Quick, Draw!: The children explored Google's "Quick, Draw!" to see an example of how a neural network predicts in real time. The application randomly assigned six drawing prompts. The user draws the object and after 20 seconds the AI guesses the drawing by extracting from a database of drawings that other players had contributed to the application in the past. In their post-interview, when the researcher asked what children liked best about the entire program, one child stated "*Oh, the Quick Draw! I thought that was interesting."* Another child answered, "*I really like the drawing thing like where you gotta draw something and then you had to guess it."* These responses suggest they enjoyed the drawing and that this type of hands-on activity could initially engage children to participate in learning activities around ML.

Cat and Dog: Children built, trained, and tested ML models as they tinkered with Google's Teachable Machine (GTM). This web-based tool allows users to develop simple classification models using images, audio, or video. Children were given photographs of both cats and dogs to use as a training and testing set for their models, but they were unaware that the researchers had given them a biased dataset that contained images of more cats than dogs. The goal was for children to discover the bias in the training dataset and then retrain their machines with new and less biased datasets. One child directly connected concepts of biased data sets from this particular activity with her final project. In her post-interview, she remarked, "*I don't think my [final project] machine is biased because I tried to get the same amount of pictures so it could, like, make it even. So, it wasn't biased, like the cat and the dog one."* Here she was comparing her final project with the cat and dog activity.

Using gained knowledge and experience to design an ML-robot for social good

The goals of the three final activities—*Build your own GTM, Superhero Robot Story, and Build Superhero Robot*—were to design an ML-based robot machine through storytelling and block-based programming. The children were given the challenge to identify issues in their communities and apply concepts of what they had learned in previous activities to create an ML robot for social good.

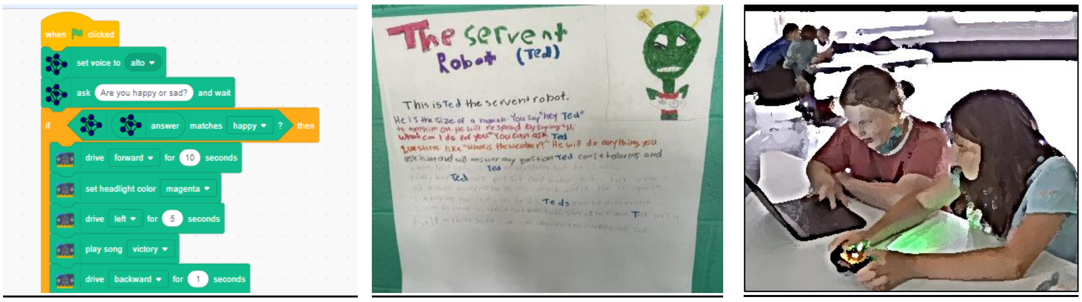
Build a GTM: After introducing the children to supervised ML in the cat and dog activity, children were challenged to create their own machine that recognized images, poses, or sounds using GTM. One child described her machine saying, *"I did a lot of pictures of guinea pigs and hamsters because they look alike. And I tested it… And it didn't work as well. So, I just added more pictures of different hamsters and different guinea pigs… I think 16 each… from the web. I put a lot of different pictures of different hamster and different guinea pigs and not just like one type of hamster and one type of guinea pig."* Here, the child explained how she applied her knowledge of how to mitigate bias in ML algorithms by using a balanced training set of a variety of both hamsters and guinea pigs.

Superhero Robot Story: Children created narratives about robots that could help their community. They used large poster boards to visualize their imagined superhero robot. Afterward, they shared their Superhero Robots story with the group by responding to prompt questions such as: *What does your robot do? Who does your robot help? Why did you decide to design this robot?* Children told stories about robots that could contribute to social good in a way that they could relate to in their own lives. For example, when describing her robot design, one girl stated, "*My cousin, when she was growing up, she didn't have the opportunity to watch TV shows that teach her colors and stuff… So I thought to myself that could be happening to multiple other kids all over America. So, I thought, I could make a machine that can help kids with that."*

Build a Superhero Robot: Children worked in groups to build a minimal viable prototype of their superhero robot. By integrating the principles of training and testing data, the children built their ML models using GTM and linked their model with block-based programming (see Figure 2a) with a micro:bit robot. For example, one group described "Ted" as a helpful robot that answers questions and helps with household chores (see Figure 2b). Using this baseline story, the girls created a minimum viable version of Ted (see Figure 2c) by training a ML algorithm that combines with a micro:bit robot to ask a question: "Are you happy or sad?" The robot then responded to the answer by making movements, displaying lights, and playing a sound depending on the feedback.

In this activity children designed an artifact that incorporated their own perspectives and values while also practicing ML concepts and, in some cases, mitigating bias.

Figure 2
Children artifacts, a code block (a) superhero robot story (b), training and programming a robot (c)



```
when [flag] clicked
set voice to [alto ▾]
ask (Are you happy or sad?) and wait
if < (answer) matches [happy ▾] ? > then
    drive [forward ▾] for (10) seconds
    set headlight color [magenta ▾]
    drive [left ▾] for (5) seconds
    play song [victory ▾]
    drive [backward ▾] for (1) seconds
```

(a) (b) (C)

Future study and redesign of the CML program

We observed children as they engaged in what Holbert and colleagues (2020) described as "cycle of connection and critical reflection about knowledge." Children critically contributed to discussions in activities like Coded Bias and Google Search and integrated their personal experiences while creating their superhero projects and building ML algorithms. They used knowledge gained from prior activities for building and evaluating their designs for bias, with some youth making reference to the earlier activities. The final activity; *Superhero Robot Story* helped us realize storytelling is a powerful way to help young learners engage actively with CML concepts and integrate a critical lens with their design projects (Chan, 2019). Thus, future work includes designing a narrative-driven role-play experience that incorporates ML bias activities but is a more cohesive set of activities and requires a critical lens for *every* activity. We believe these efforts are vital for children to develop a critical consciousness as the future generation of consumers and producers of technologies.

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Learning Through Play at the Intersection of Problem-Solving, Epistemic (Un)certainty, and Emotion

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Abstract: Although play is often viewed as a buffer against failure, our nascent work in this paper argues that play is teeming with emotional and epistemic complexity. Based on the epistemic cognition, emotion, and problem-solving literature, we are developing a coding scheme for exploring how people learn in puzzle video games. Preliminary findings revealed a significant negative relationship between self-reported confidence and time spent on a level ($r = -.52, p < .001$). In addition, players' problem-solving moves showed different co-occurring patterns with epistemic stance and emotional valence. The study's initial results demonstrate its potential for enhancing understanding of what it means to learn from playing video games by conducting a fine-grained process analysis and bridging literatures.

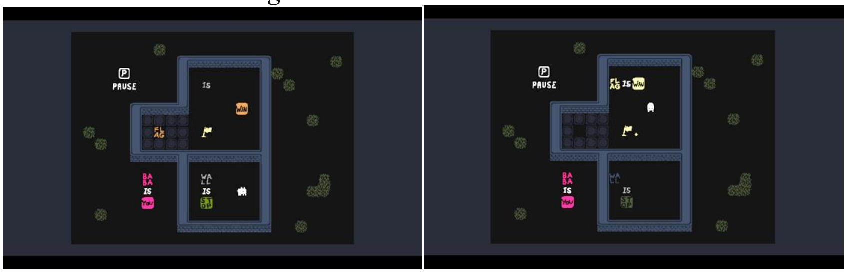
Introduction

Engaging in any kind of learning entails experiencing fluctuating certainty about what you know, surrounded by a wide range of emotions. Indeed, science education researchers have argued that both epistemic (un)certainty and emotion play a pivotal role in learning (Watkins et al, 2017; Radoff et al, 2019). Alongside this context of learning science, rich literatures illuminate how uncertainty and emotion influence learning processes and outcomes. For example, many models of epistemic cognition (EC) include a component focused on differing levels of certainty, some focusing on it as a characteristic of knowledge (Hofer & Pintrich, 1997) and others focused on the epistemic stances (ES) one can take towards knowledge (Chinn et al., 2011). Furthermore, researchers have shown that emotions are inseparable from learning processes (Pekrun et al., 2017). Bridging these research topics, our work in this paper explores how ES and emotion work in tandem alongside the problem-solving processes that shape learning in a puzzle video game. Learning in a puzzle game requires problem-solving, a process that involves noticing when you get stuck, understanding why you're stuck, and trying to get unstuck (DeLiema et al., 2022). However, we know very little about how problem-solving processes, which drive learning in play, are laden with epistemic experiences of (un)certainty and emotion (e.g., joy, frustration). To bridge the cognitive and affective divide that still resides in much work on learning, we argue it is essential to understand the dynamic, moment-to-moment interactions between these processes. Our work here is guided by the following question: How do emotional valence and epistemic (un)certainty relate to problem-solving *while* players learn the mechanics of *Baba is You* (Teikari, 2019), a challenging puzzle game? To answer this question, and to allow for more granular claims about the interconnectedness of ES and emotion, we use eye gaze along with talk-aloud data and game actions to provide a process-based account of learning.

The learning context: Baba is you

Baba is You, and many games in general, create generative spaces for micro-longitudinal, process-based analyses of the dynamic expressions of ESs and emotions because players must grapple continually with moments of failure and uncertainty (Juul, 2013). This game was chosen in part because it offers a unique blend of ill and well-defined problem elements, and the rules structuring the game are explicitly shown on the screen, which affords the use of eye gaze to support inferences about what the player might be thinking. The game's structure also resembles programming, which makes possible a connection between computer science education and a playful learning space. The game has over 200 levels spread across worlds with different themes. Figure 1 shows that the different elements of each 2-D puzzle—such as text blocks (e.g., WALL-IS-STOP) and objects (e.g., the little, white sheep character Baba)—are presented to the player in a one-screen format. Players are given control of a character and move around the play space by using the keyboard's arrow keys. The game's core feature is that players change the text-based rules (e.g., breaking off WALL from WALL-IS-STOP) to change the objects in the space (e.g., making the wall permeable). By either creating or breaking text-based rules, players can turn one object into another object, change the physical properties of an object, or even change which character they are controlling, among many other possibilities. For example, a player could complete the level shown in Figure 1 by combining the two text blocks, "IS" and "WIN", with another text block to create a winnable game state. If the player uses Baba to push the text blocks around to form the sentence "FLAG-IS-WIN", the flag object would sparkle, allowing the player to win when they move over the flag object. The game also affords numerous other ways players can change the nature of objects in the game by rearranging the text-based rules.

Figure 1
The left picture shows the initial game state of a Baba is You level, and the right picture shows the WALL-IS-STOP rule deactivated and the FLAG-IS-WIN rule formed. The player wins when Baba moves over the Flag.



Method

18 undergraduates participated in the study. Both play sessions consisted of a short setup period to calibrate an Eye Link II (SR Research) eye tracker and a 40-minute play period (the eye tracker was recalibrated after the first 20 minutes). While students played the game, the first author remained in the room staying silent except to inform students of the general game controls and ask the following confidence question when a level was completed or skipped: "On a scale of one to ten how confident did you feel over the course of that level?" In the first session, players were told to imagine themselves as a Twitch or YouTube streamer and describe what they were thinking out loud. Screen recordings of the play sessions were captured, and players filled out a demographic questionnaire at the end of the second session. Due primarily to equipment failure and three cases of attrition, the data from eleven participants are used in the analysis here.

Overview of coding scheme development

Our exploration of the above-described confidence measure led to the discovery of a significant negative correlation between player confidence and time spent on a level ($r = .51, p < .001$). Though perhaps unsurprising, this finding prompted us to ask what the player experienced during the level that culminated in that confidence rating pattern. Our prior interaction analyses (Jordan and Henderson, 1995) showed that players frequently gave clues about their knowledge states and emotional experiences (e.g., "I do not know what to do" and "That is so annoying"). We conjectured that players' end confidence rating might be related to their level of certainty concerning the knowledge they were gaining (e.g., their ES) and their emotional experience of the game (Melander Bowden, 2019). We consider players' level of certainty toward their generation of knowledge to be centered on four aspects of knowing: (1) I know that I am stuck, (2) I know how I am stuck, (3) I know why I am stuck, and (4) I know what to do. Instead of labeling specific emotions (an analytical move fraught with complexity), we focused on valence. Valence is the intrinsic pleasantness (e.g., joy) or unpleasantness (e.g., sadness) of emotion, and it is argued to be a salient component of emotion (Barrett, 2006).

We used a prior problem-solving coding scheme built around *Baba is You* (DeLiema et al., 2022) as a point of departure. The framework is theoretically grounded in literatures such as play, problem-solving, self-regulated learning, productive failure, and debugging; it focuses on how players notice or describe something deviating from their approach (Noticing deviation, ND), how they propose a cause of an observed deviation (Causal explanation, CE), and how they describe a plan to revise and enact a new approach (Action revision, AR). When players revised their approach and deemed it a success, we labeled it a successful revision (SR). We also added a code called "Action" (A) because we wanted to differentiate between players enacting a new approach not following a deviation. An action that is determined by the player as successful was also labeled a successful action (SA). Table 1 shows how we build off the existing coding scheme by including binary ES codes (certain/uncertain) and emotional valence codes (positive/negative) that we *only coded together with* a problem-solving move. For example, one player experienced their character "dying" on a level. The player said "No!" followed by a short sigh (negative valence) while their eye gaze moved quickly away from the site of the deviation and they restarted the level. Together, these provided evidence that the player was certain that something in the game deviated from their preference, what we labeled in our framework an epistemically *certain* ND layered with negative valence. This is distinct from players suspecting or being uncertain about whether something went wrong. Another player treated an outcome as misaligning with their preference (e.g., undoing an action), but did not vocalize anything; we coded this only as an ND. Thus, ES and valence were coded only when a problem-solving move was coded, and when the player made a vocalization. An additional note is that epistemic stance and emotion are complex constructs that almost certainly exist outside of binary classification, but we opted for a simplified approach as an initial exploration of these constructs in play.

Table 1

Overview of the coding scheme. Each problem-solving code can be layered with epistemic stance and emotional valence.

Problem-solving move	**Action revision (AR)/(A)** Definition: The player revises their approach after experiencing a deviation (AR) or enacts an approach without experiencing a deviation (A).	**Noticing deviation (ND)** Definition: The player signals recognition of an outcome misaligning with their preference.	**Causal explanation (CE)** Definition: The player proposes a potential cause of the deviation.
Epistemic stance	**Certainty** Definition: The player's conviction that they understand and/or can plan game actions. Markers: saying "I know …", "I am going to do …", "oh". Speaking confidently. Taking directed action and moving without hesitation. Gaze can help determine what the player is referring to when language is vague.	**Uncertainty** Definition: The player's lack of conviction that they understand and/or can plan game actions. Markers: saying "I don't know …", "I am not sure…", "I think…", "um", "uh". Speech has questioning prosody. Moving aimlessly and/or with hesitation. Gaze can help determine what the player is referring to when language is vague.	
Emotional valence	**Positive** Definition: The player signals an overall evaluation of a game event as pleasant. Markers: Saying things like, "I am so proud of myself", clapping, cheering, smiling, laughing.	**Negative** Definition: The player signals an overall evaluation of a game event as unpleasant. Markers: Saying things like, "I am frustrated", "I don't like this", "Ugh", etc. Sighing.	

To explore patterns across varying levels of confidence and experience, we selected a subset of the data. We chose game levels where players reported the highest, lowest, and widest range of confidence (i.e., the highest standard deviation); we also chose some levels that were further into the game and levels that most players attempted. This selected data consisted of three levels from the introductory overworld ($M_{Confidence}$ = 4, 7.04, 5.73; $SD_{Confidence}$ = 2.49, 1.27, 2.8) and three levels from the first unlockable world ($M_{Confidence}$ = 3.1, 7.63, 4.32; $SD_{Confidence}$ = 1.66, 1.2, 2.5). The subset includes a total of about 5.5 hours of video across 66 clips. We then randomly selected 18 clips to use for interrater agreement checks. We iteratively checked and adjusted our codes after coding three clips at a time. Currently, we are still in the process of coding, but our interrater agreement has been charting toward strong agreement (overall simple percent agreement was equal to 74.6, 75, 89.7, and 95.3 across the first four checks). Because our agreement was quite high in our last check, the final check will include the six remaining clips.

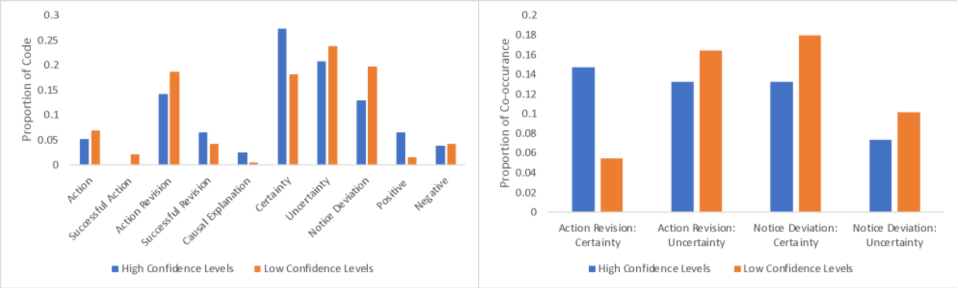
Initial findings and next steps

In addition to the confidence findings showing a significant negative relationship between time and confidence, there are two other initial findings described below. First, an unexpected pattern emerged regarding the coding scheme's granular representation of problem-solving processes. More specifically, we were able to capture dynamic switching between epistemic stance and emotion *while* players were enacting a problem-solving move. For instance, one player experienced a deviation and said, "what" and studied the deviation for a moment (this would be coded as uncertainty). Then, after gathering evidence and/or retesting their approach to explore if the same outcome occurs, they said, "oh, I see", (coded as certainty) and then revised their approach. This means it is possible to code each problem-solving move multiple times as players attempt to find their footing and shift back and forth between being certain/uncertain or experiencing positive/negative valence. Although we do not go into these patterns in detail here, we think they will further our understanding of what it means to study students' reasoning as they engage in a task.

We also explored the overall distribution of the codes in the currently analyzed data and what codes co-occur. We use proportions to compare high and low confidence levels because low confidence levels tended to be played for much longer, increasing the likelihood that more codes would be applied to them. Two emergent trends are shown in Figure 3. First, the most applied codes were ARs, NDs, Certainty, and Uncertainty, with higher confidence levels showing higher rates of certainty and lower rates of uncertainty. This suggests that the more certain players are about the knowledge they are generating, the more confident they will be. Second, the graph on the right provides more nuance than the graph on the left by providing what codes co-occurred with another code. We chose to focus on the level of certainty paired with ARs and NDs because they were the most salient. The most noticeable difference here is that high confidence levels showed higher rates of certainty and lower rates of uncertainty co-occurring specifically with ARs, suggesting players' certainty about their actions in response to deviations is a core piece of their sense of confidence. Overall, these initial results suggest that higher confidence may in large part relate to students knowing what plan they want to pursue after getting stuck.

Figure 2

The graph on the left shows the distribution of codes across high and low confidence levels, and the graph on the right shows codes that most often co-occurred with ARs and NDs across high and low confidence levels.



Our goal in this short paper was to present some initial findings from an exploratory study that used multi-modal data to inform an extension of a prior coding scheme. By connecting ES with emotional valence, our initial results showed that learning in *Baba is You* is a process that involves problem-solving while shifting between (un)certainty intermixed with positive and negative emotion. These initial results have the potential to move beyond the results of previous work showing emotion and uncertainty impact learning (e.g., Ozcelik et al., 2013) by exploring how these constructs emerge in problem-solving moves, which can apprise teachers of when to intervene in a student's problem-solving process. Beyond the small sample size, there are at least a few noteworthy limitations. First, we rely on outward expressions of ES and emotion, which could either be misinterpreted or misaligned with subjective experience. Second, since we are only coding ES and emotion with a problem-solving move, we are likely missing much of players' private, internal experiences of these dimensions. With these limitations in mind moving forward, we still hope to expand on the results presented here, deepen connections between constructs, and apply what we have learned in this study to other settings. A few next steps of the project are to finish coding the data and to continue to explore different qualitative and quantitative analyses.

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Orchestrating Students' Systems Thinking About the Rock Cycle

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Abstract: This study examined middle school students' development of systems thinking as they explored the rock cycle in an interactive diagram. In this paper, we focus on the analysis of a design experiment with two students to discuss the teacher orchestrations that supported their reorganizations of meanings about the rock cycle's chain of materials and processes.

Background

Teaching and learning about the rock cycle, or the interconnected processes that change the earth's rocks over time, has been a concern of science educators for decades. Traditionally, the rock cycle is considered to include five materials, three of which are different types of rock, and the processes that transform them (Table 1).

Table 1
Processes and Materials of the Rock Cycle

Process	→	Material Created
Weathering and Erosion	→	Sediment
Compacting and Cementing	→	Sedimentary Rock
Heat and Pressure	→	Metamorphic Rock
Melting	→	Magma/Lava
Cooling	→	Igneous Rock

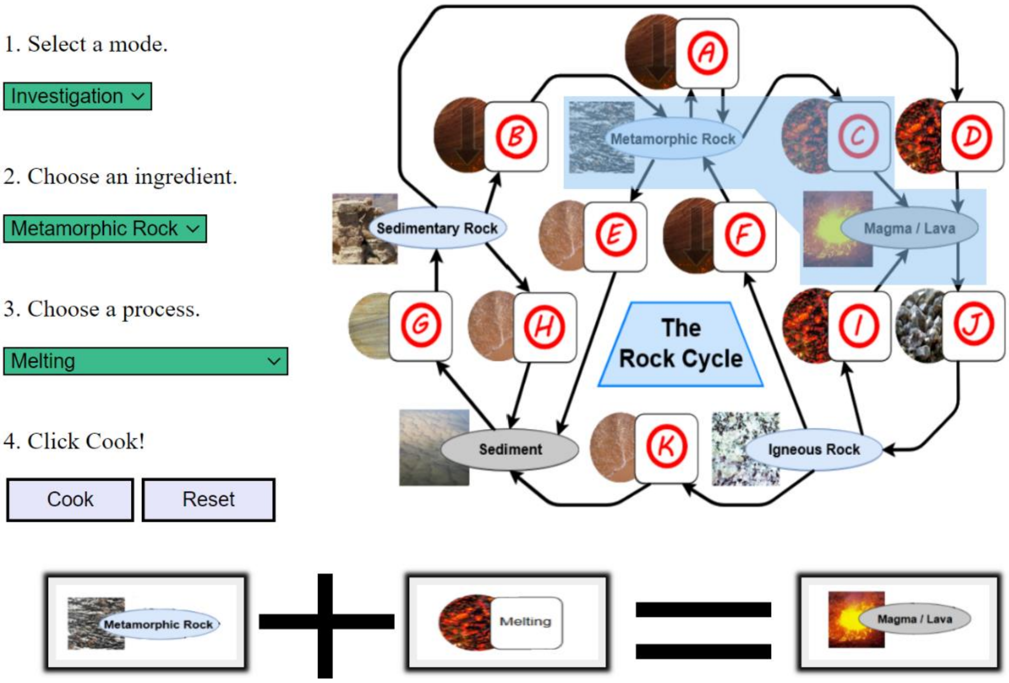
The teaching and learning of the rock cycle has been difficult due to its complexity (e.g., Vasconcelos et al., 2019). To support students' learning, diagrams have been used to show how the same processes can affect each of the types of rock and may also include the depiction of physical locations such as mountains as contexts (Peloggia, 2018). Research has also focused on developing students' systems thinking of the rock cycle, which involves (a) understanding the various materials and the processes producing them, (b) understanding causal relationships among specific processes and their input and output products, and (c) understanding the rock cycle system as a whole by recognizing that each output product of one process may serve as an input product for another resulting in an endless chain of processes and products (Kali et al., 2003). To support students' systems thinking, Kali et al. (2003) turned to the use of a digital learning environment that fostered students' reflection upon the interconnectedness of the rock cycle's processes and materials. In this work, students were found to have a static view of the rock cycle and struggled to internalize the idea of the rock cycle as a dynamic and cyclic system. However, students' development of systems thinking about the rock cycle was not described or how the teacher influenced that development. By looking at students' systems thinking from these perspectives we can understand how to best facilitate students' development of reasoning about the rock cycle within a technological environment. Thus, we aimed to explore: *(a)* How may students' systems thinking about the rock cycle progress as they interact with a technological environment?, and *(b)* How may the teacher orchestrate this development?

To study the students' development of thinking by interacting with a technological medium, we situated our study within the theory of instrumental genesis (e.g., Rabardel & Bourmaud, 2003). Through their interaction with an artifact, the student builds an *instrument,* which consists of both artifact and cognitive schemes. Each new instrument becomes part of a system of interlinked instruments developed earlier, which is constantly reorganized. To assist students' reorganizations, the teacher engages in *instrumental orchestration* (Trouche, 2005), a plan of action that involves forming conjectures based on the affordances and constraints of the artifact and acting as an orchestra conductor to engineer opportunities for them to reflect on their activity and reorganize their meanings.

Methods and design

We conducted a whole-class design experiment (Cobb et al., 2003) in a sixth-grade classroom in a large suburban district in the Northeast U.S. We created a new rock cycle diagram (Figure 1) that uses visual aids to depict a separation between processes and materials and clear connections between them. For example, all three of the melting process boxes are grouped near the magma/lava material oval to support students in noticing that the melting of any rock transforms it into magma/lava. We then designed an interactive computer simulation based on the metaphor of the earth as a rock cooking machine that allows students to select an ingredient (a rock cycle material) and a rock cycle process in order to build a recipe at the bottom of the screen. By clicking the Cook button, students can view the results of their selected recipe. If their selection is invalid, the result box will display a red X. A valid result is displayed both in the recipe and by the relevant path being highlighted in blue.

Figure 1
Cooking Rocks Interactive Diagram (*https://acmes.online/htmls/cookingrocks/interface.html*)



1. Select a mode.
Investigation

2. Choose an ingredient.
Metamorphic Rock

3. Choose a process.
Melting

4. Click Cook!

We prompted students to examine one process at a time and experiment with different possible recipes to determine which process belongs in each location. We conjectured that this focus on the processes would support their reasoning about the relationships between different processes and materials. This paper focuses on the retrospective analysis (Cobb et al., 2003) where we identified excerpts that illustrated the elements of systems thinking about the rock cycle described by Kali et al. (2003) and examined the teacher's orchestrations that facilitated students' constructions and reorganizations.

Findings

In this paper, we focus on one student, Laura, to present constructions and reorganizations of meanings that are possible when students engage with our specific instrumental orchestration.

Reasoning about various materials and the processes producing them

During a few minutes of free exploration, Laura tried combinations of materials and processes that presented her with both valid and invalid results. She was asked questions, such as "What two things do you control in this simulation?", "Which of these are processes that you can use to make recipes?", and "Which of these are materials that you can use as ingredients to make recipes?" Laura identified the variables of the diagram and distinguished between the two inputs. She stated, "You can choose the processes and the ingredients, to make a rock or sediment or magma." When asked to identify the non-rock materials she replied, "Because sediment and magma/lava are used to make certain types of rocks. They're not actually rocks themselves."

Reasoning about causal relationships among processes and their inputs/outputs

Next, Laura was prompted to explore relationships between the materials and processes. Laura discussed weathering and erosion when she was asked what process turns each rock into sediment. By trying this process with other ingredients in the diagram she explained, "To make sediment, it has to have other rocks eroding and weathering away." This showed the construction of the relationship that *other rocks + weathering and erosion* → *sediment*. Later in the investigation she was asked what patterns she noticed and she responded, "I noticed that all of the rocks, if you choose weathering and erosion, they turn into sediment," illustrating the relationship that *all rocks + weathering and erosion → sediment*. The researcher then asked her to clarify what she meant by "all rocks" and she explained, "Igneous, sedimentary, and metamorphic. If you choose all of them." Laura concluded, "If any type of rock weathers and erodes away it can turn into sediments," illustrating the relationship that *any rock + weathering and erosion → sediment*. The orchestrated questioning by the researcher encouraged Laura to reorganize her meanings into a more precise relationship.

When Laura was asked what patterns she noticed in her exploration, she talked about cooling: "Like ingredients, you can't cool some stuff because, you can't cool sediments, you can't cool sedimentary rock." Her reasoning shows that she identified that not all materials could be cooled, for example, *sediment, sedimentary rock + cooling → X*. When she was prompted to explain further, she stated, "You can cool magma and lava, you can't cool sediments or metamorphic rock, sedimentary, igneous." We interpret Laura's statement to show that *only magma/lava + cooling* was valid without focusing on a specific output. Laura was again asked about patterns she noticed and responded, "When magma is cooled, it turns into igneous rock," showing that she reorganized her meanings about cooling into the specific relationship that *magma/lava + cooling → igneous rock*.

When asked about other processes she explored, Laura stated that "Igneous rock turns into magma." Here she identified a valid relationship between an input ingredient and an output product, *igneous rock → magma/lava*, but did not note the process that was used to 'cook' the rock. The researcher then asked whether all the rocks turn into magma/lava and Laura responded, "No, I don't think so." She continued to try different combinations, and discovered, "Oh, they do. Sedimentary rock and melting can turn into magma and lava if it's hot enough." Her reasoning showed the construction of another relationship: *sedimentary rock + melting → magma/lava.* The researcher then prompted her to examine if all the ingredients turned into magma/lava when melted. Laura used the diagram to test out different combinations as she explained, "I think so. Oh nope. Because sediment, if you melt sediment, I think it's because it's like it's too small to turn into magma and lava. And you can't really melt lava. … Because magma's already melted." Laura's reasoning shows that she constructed a more precise relationship: *all ingredients except sediment and magma/lava + melting → magma/lava*. Laura's reorganization of meanings was orchestrated by the researcher's questioning that required her to reconsider the material and process combinations.

The researcher asked Laura about compacting and cementing and she explained that "If you compact sediment it turns into sedimentary rock." Laura's statement, *sediment + compacting and cementing → sedimentary rock*, was further questioned by the researcher, who asked if it was possible to compact other rocks. Laura used the simulation to test out other combinations before stating, "No. … When you compact sediment and it's like pressure when it's compacting it, over like millions of years, it turns into sedimentary rock."

Laura was asked how metamorphic rock was made and she stated, "Metamorphic rock is made out of compressed magma and lava. I'm not sure if that's igneous or, I mean, metamorphic." The researcher brought her attention back to the diagram and asked the question again. Laura responded, "Igneous and heat and pressure," illustrating that she reorganized her meanings into the relationship that *igneous rock + heat and pressure → metamorphic rock*. Laura was then asked if heat and pressure on all other rocks would produce metamorphic rock. She tried combinations on the diagram and replied, "Yes. So, I think it's created with heat and pressure." We interpret this as a statement of the relationship that *all rocks + heat and pressure → metamorphic rock*. Laura was later asked about the possible things that can happen to rocks. She explained that "if igneous or sedimentary rock has heat and pressure applied to it, it can turn into metamorphic," demonstrating the relationship that *igneous rock or sedimentary rock + heat and pressure → metamorphic rock*. The researcher questioned Laura about whether it was possible for metamorphic rock to undergo heat and pressure and encouraged her to use the diagram. Laura answered, "It stays to metamorphic rock," illustrating the relationship, *metamorphic rock + heat and pressure → metamorphic rock*. Through the researcher's orchestrated questioning, her meanings about the heat and pressure process were reorganized to a set of more specific relationships.

Reasoning about the system as a whole

After the Cooking Rocks lesson, students explored the life of a rock using a different simulation (https://acmes.online/htmls/bobslife/bobslife.html) that illustrates what material form the rock is in but does not show the related processes. When asked what she noticed in this simulation, Laura explained: "[It] turns into igneous, then it breaks down to sediment and turns into sedimentary rock because it gets compacted and then the pressure increases so then it turns into metamorphic for most of it. Once it reaches the lava it turns back into magma." Her reasoning shows that she was able to describe one complete path through the rock cycle by describing the processes the rock would experience. Laura recognized that the product of one process may serve as the input to another, illustrating a meaning of the rock cycle as an endless chain of processes and products.

Concluding discussion

Using the interactive diagram and probing questions, Laura developed her systems thinking about the rock cycle, showing evidence of the three elements described by Kali et al. (2003). Our analysis shows how specific orchestrations during the exploration supported Laura's constructions and reorganizations of her meanings about the relationships between the materials and processes of the rock cycle (Table 2). To elaborate, questions reduced visual complexity by focusing the student on one specific process at a time. Targeted questioning helped scaffold her exploration by starting with generic questions about her noticings and individual recipes before moving onto questions that asked her to generalize relationships between processes and input materials.

Table 2

Orchestration of Rock Cycle Systems Thinking

Systems Thinking	Supportive Orchestrations
Understanding the various materials and the processes producing them.	● Questions that led the student to identify variables in the simulation, e.g., *What two things do you control in this simulation?* ● Questions about the distinction between rocks and non-rocks, e.g., *Which two of the five ingredients aren't considered to be types of rocks?*
Understanding causal relationships among specific processes and their input and output products.	● Sequenced questions that led the student through each process, e.g., *What process turns [each material] into Sediment? Sediment is formed when any type of rock…* ● Questions about noticing, e.g., *What do you notice? What patterns do you see?* ● Questions about identifying all the materials that work or do not work with each process and explaining why, e.g., *Does it work for all materials? Why/Why not?* ● Student trials of ingredient/process combinations.
Understand the rock cycle system as a whole.	● Asking the student to reason about one possible path a rock might take through the rock cycle in a hypothetical environment (no diagram or process labels visible), e.g., *What processes do you think this specific rock experiences during its life?*

Table 2 thus helps us understand how to orchestrate students' development of systems thinking about the rock cycle within a technological environment. We are currently analyzing how other students' reasoning progressed through the Cooking Rocks exploration and examining patterns between different students. Because the findings of this study were a result of an interview between one student and a researcher, we also need to examine further how a teacher can provide similar guided questioning in a whole class setting.

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Students' Constructed Explanations for How Artificial Intelligence Generates Recommendations in YouTube

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Abstract: This study examines high school students' dynamically-formed intuitive conceptions of one type of frequently encountered artificial intelligence (AI) technology: the recommendation system used in YouTube. Drawing from videorecorded interviews, we sought to understand how 18 students assembled explanations about how the platform's design used AI to provide users with video suggestions. Our findings have implications for how students construct knowledge of AI-systems by their own means, and yields implications for designers of curricular resources seeking to build from students' prior knowledge.

Introduction

The motivation for the present study is twofold. On the one hand, as new technologies appear and become more commonplace, this paper follows conceptual research that asks about the intuitions that youth have about how novel technologies work. The second motivation is that we wish to inform design of new learning experiences about specific classes of technologies. Currently, calls are being made to build artificial intelligence (AI) and machine learning (ML) learning experiences for school-aged students (Touretzky et al., 2019). While preparing students to pursue future work in these areas can be one motivation, public understanding of how AI works at a conversational level is also important for an informed citizenry and to reduce the risk for documented harms to groups that are frequently marginalized and harmed by technologies.

Based on collection and analysis of interviews with high school-aged students in the United States, we present three "assemblies" of knowledge resources that students drew upon in explaining the presence of AI in YouTube's recommender system. We ask: what explanations do students construct about how artificial intelligence generates recommendations? Recent work has looked at how children understand the operations of voice assistant technology (Beneteau et al., 2020) or the extent to which teens understand algorithmic bias (Lee et al., 2022). It is a research area we hope learning scientists will continue to contribute to now and in the future.

Theoretical framework

This work operates under the "knowledge in pieces" (KiP) framework (diSessa, 1988) by which student knowledge and reasoning can be understood productively as involving a complex system with many knowledge resources that are differentially accessed. KiP offers an overall orientation for how broadly and precisely knowledge should be described. However, on that foundation, various approaches have been used to recognize and refer to specific knowledge elements of importance. Theorized "collections" are one known type of knowledge element, and within "collections," "coordination classes" are a way of modeling "concepts" as they rely upon perceptual extractions and inferential networks of interconnected knowledge elements.

For this study, which explores what "collections" of knowledge elements are involved in explaining a contemporary technology, we draw from Sherin et al.'s (2012) "mode-node" framework. While maintaining the KiP commitment to modeling knowledge as a complex system, the mode-node framework is intentionally neutral about what is the precise form of those knowledge elements. Modes are functionally-grouped activations of nodes. Diverse knowledge elements are all considered "nodes" and could include remembered slogans and factoids, specific remembered episodes, and other knowledge resources in the extant literature. Given that we are focusing on contemporary technologies used in everyday life, students are likely to have varied specific experiences they recall, things they have heard, and general intuitions about how things should work in the artificial digital world. At the same time, when pressed to explain certain phenomena or observable behaviors, we expect that students are able to actively generate explanations. In this paper, we focus on those explanations and refer to them as "assemblies" to reiterate that they are constituted of sub-elements (nodes) in the moment.

Methods

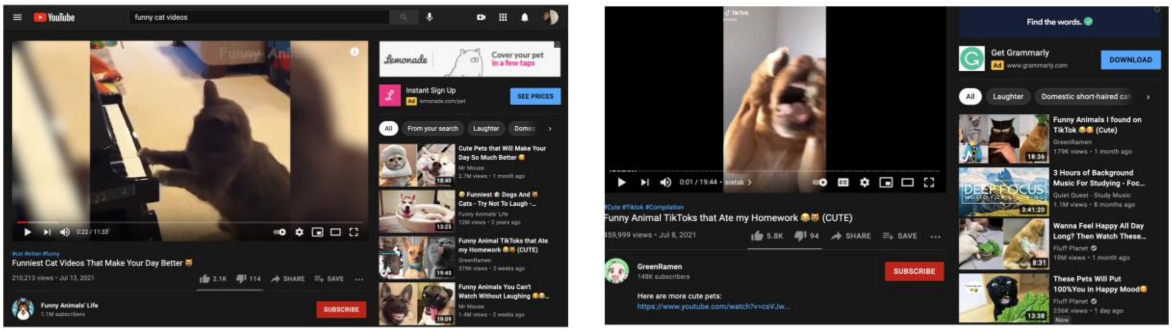
Participants and procedure

The participants in this study are 18 high school-aged students from a range of local high schools between 14 and 18 years old. 11 identified as female, 6 as male, and 1 as gender non-binary. Most (16) attended public schools, with 1 student from a patriarchal school and another from a private school. Only 2 students had taken AI-related coursework, which was achieved through after-school enrichment programs. A few students encountered AI concepts and ideas through their caregivers' career. Four researchers conducted 45-minute interviews with participants on the Zoom videoconferencing platform from January through March of 2022.

The interviewer asked each student if and how artificial intelligence was involved in three contemporary AI-based scenarios: iPhone's Siri voice assistant, YouTube's video recommendation system, and a hypothetical AI-based college recruitment technology. In this paper, we unpack students' ideas from the second scenario.

The interviewer displayed a visual prompt of the AI-based technology to students and asked them to state what they noticed aloud. Figure 1 shows an example of the visual prompt shown to students for YouTube's recommendation algorithm. Then the interviewer followed a semi-structured protocol with the goal of determining how students believed artificial intelligence operated within YouTube's recommendation algorithm. The interviewer followed up with clarification questions until they gained a complete understanding of the student's theory, or until the student said, "I don't know."

Figure 1
Visual prompts shown to students from YouTube.



Data analysis

This study follows a knowledge analysis tradition (diSessa, Sherin, & Levin, 2016) and is of the "microanalytic regime". After data were transcribed, students' assemblies about YouTube were identified and agreed upon. To be counted as an assembly, students' utterances needed to contain a causal explanation about how AI operated within the system, however primitive or incomplete. Some students constructed a single assembly, some students constructed multiple assemblies within the same response to the interviewer, and one student did not construct any assemblies at all. In total, we identified 37 distinct assemblies. Next, we analyzed and coded the data to unearth and categorize assemblies. Working first as individuals, we examined each student's explanation carefully, then identified the causal mechanism in each. Then, the research team held several joint review sessions where we systematically discussed and agreed upon groups of student assemblies. We discuss several patterns of explanations that appeared across students in the findings.

Findings

The *profile assembly* appeared in 14 of 18 responses. In this assembly, YouTube attends solely to the user and constructs a profile of that person's interests and habits. Then, it makes recommendations based on what content fits with that "type" of user. Mokund explained how the algorithm can do this using one's "watch history":

> "Maybe if you're really into, let's say, pencil videos like "how to build a pencil" … based on their watch history, they might have other suggestions that may not be as related to the video they're currently watching." (*Mokund's interview*)

Mokund suggests that the algorithm can parse a user's watch history and group videos by topic. He does not explain how YouTube does this, but it seems that recommendation algorithm needs to intuit that the video "how to build a pencil" falls into the category of "pencil videos." Once the videos have been grouped into categories, Mokund notes that YouTube can deduce what types of videos the user is "really into." Once again, he does not say how it does this. Finally, YouTube searches through existing data for other videos that fit into that category.

Other students described profiles as facts that YouTube's algorithm believes about the user:

> "Maybe … they think you have a pet. And since you're looking at a cat video, maybe they think you have a cat. So, they want to recommend some of their products." (*Jennalin's interview)*

When Jennalin describes the user's profile, she does not explicitly mention watch history or the patterns of user behavior. Rather, YouTube has a collection of beliefs about the user (e.g., "they think that you have a pet"). Like Mokund, Jennalin understands a profile to be dynamic and contain data that the algorithm uses to make recommendations. Yet, Jennalin does not articulate a theory about how those beliefs were formed.

Finally, McKenna described a profiling pattern based on intentional user differences:

> "It's branching out to more content. So, it's something in the viewer's comfort zone. But it's something different that could get them to look at different content and different creators." (*McKenna's interview*)

In McKenna's interpretation, the algorithm is aware of a user's profile ("comfort zone"), but it makes intentionally different recommendations to encourage the user to diversify. McKenna seems to think that the algorithm will generally recommend similar videos because users tend to stay within their comfort zone; so, videos that are only slightly different are likely to be successful recommendations.

Other students intuited that YouTube provides recommendations from attributes of video content or search. We labeled explanations like this as *attribute assemblies*. Students suggested that YouTube provides recommendations by comparing the keywords, content, or author of the current video to the keywords, content, or author of a potential video to recommend, absent of the users' search history. 10 out of 18 students described an attribute assembly. For instance, Wilhelm describes the impact of keywords in the user's current search:

> "Because of that input in the search bar, funny cat videos, that might prompt YouTube to search for videos that are related to cats, or just animals. Because, it also has that word funny. You can see the title of that first video is "cute pets that will make your day so much better." Maybe it's not directly related to cats, but it could be related to funny. And so, I think that they're searching for the keywords in the search bar, and then like finding videos that may relate based on the title." (*Wilhelm's interview*)

Wilhelm's description reveals several aspects of knowledge coming together to form an attribute assembly. First, he notices and connects terms in the search bar to content within videos. Then, he realizes that recommended videos on the screen contain content and keywords other than cats, such as "animals" and "cute pets," and he updates his theory to include words similar to "cats" and to "funny." Wilhelm demonstrates knowledge that multiple attributes (e.g., nouns or adjectives) are used by YouTube to assess similarity. Finally, his last utterance reveals a belief about how similarity comparisons are conducted: that keywords during search are matched or similar to ("relate[d] to") words in titles of recommended videos.

Other students built attribute assemblies from metadata. Erma noticed the content author:

> "If they know, for example, you like this creator, if it was from the same period, they could know that it's more likely that you like multiple videos from one creator than others." (*Erma's interview*)

Erma credits the YouTube algorithm to "knowing" that users enjoy videos from the same author, and explains that "it's more likely that you like multiple videos from one creator than others." To Erma, the aim of YouTube's algorithm is to identify similarity based on video authorship, then provide recommendations.

Finally, some students identified that YouTube's algorithm works by referencing the preferences and user histories of like-minded others. Only 4 of 18 students constructed theories about YouTube based upon others, which we labeled as *social proof.* Akshay proposed that YouTube provides recommendations by creating "lists" (e.g., rankings) of similar content between users:

> "Because [other] users that searched up funny cat videos, they might have clicked on one of those... you might have clicked on something that came up in the [recommendation] list, so

> they've just made like a recommended list of videos that you could watch after you've finished." (*Akshay's interview*)

Akshay's assembly draws upon social proof by highlighting how intersections in users' interests can be used to create lists of recommended videos. He suggests that users who view similar content likely have conducted similar searches. Then, he shows knowledge that what videos users click on informs their next searches. Akshay infers a structure used by YouTube ("something else that came up in the list"), suggesting that search histories are organized into lists and that recommendations are presented according to what each user's list contains.

Other students, like Annabeth, articulated the goal of providing novel content through social proof:

> "I think the technology wants to give them fresh videos, because if they see that people are searching it up, they would want to get eyes on something else and not the same [videos]." (*Annabeth's interview*)

Annabeth suggests leverages user communities to recommend videos whose content is intentionally different than what the user may be watching currently. The algorithm's goal is to examine what content users within the community are watching, and then to recommend different videos, because users desire novelty.

Discussion

Our findings illustrate how students who use AI-reliant tools make inferences about their functionality. We observed that visual aspects of the user interface cued various pieces of knowledge about AI for students at different times and in different, sometimes inconsistent, ways. For example, of the students who noticed the video view count, some related it to aspects of social proof ("popular videos") whereas others related it to content novelty ("new videos"). This finding suggests that while students are able to notice various features of digital technology, it is less apparent how the feature relates to the innerworkings of an algorithm.

Our study has implications for curriculum designers who seek to construct learning experiences based on students' prior knowledge of AI-based systems. We found that students do possess informal knowledge about artificial intelligence from their daily encounters, but there are some areas where instruction could build upon students' intuitive understandings. We hope that this study will serve as a first step toward developing a more nuanced model of how students make sense of AI-systems.

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Adults as Users and Facilitators in Family Interaction with Multimedia Exhibits

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Abstract: The study is concerned with adults' and children's participation at multimedia museum exhibits. I examine how adults deal with their role as both facilitators for children and as users of interactive exhibits. To reveal which situated resources adults rely on to assess a child's interaction with an exhibit and to construct their own stance, video excerpts of visitors exploring a museum exhibit are analysed using videography. I demonstrate that adults treat repetition and unfinished action as indicators of children's trouble in interacting with the exhibit. The exhibit's material, spatial, and multimedia features, such as voiceover or shared display create opportunities for relevant feedback and subsequent action.

Introduction

Museums present diverse opportunities for self-guided, free-choice learning (Falk et al., 2006). Various hands-on activities and interactive multimedia installations are a crucial tool to convey educational content and construct meaningful and entertaining museum experiences for children and adults.

Interactive objects that visitors encounter often are unusual, and scripts they have to follow unclear (Laursen, 2013; Scott et al., 2013). This can pose a problem for family groups, where adults simultaneously aim to facilitate children's learning and themselves are faced with the necessity to examine and comprehend interactive exhibits. In this study, I elaborate how families interact with interactive exhibits in a museum of science and technology. I take the perspective of interactional analysis and use videography to study how adults deal with their dual role as facilitators in supporting children in exploring the interactive exhibit and as users of the exhibit. Two specific questions are considered: Which situated resources adults employ as feedback to assess a child's interaction with the exhibit? How do adults construct their own stance in the interaction?

Theoretical background

Family visitors have complex, mixed preferences and agendas. Multiple studies have analysed communication in family groups in museums and explored the ways to support their collaborative learning. Researchers argue that exhibits that promote collaboration between family visitors and allow them to build upon each other's interpretations lead to improved learning (Gutwill & Allen, 2010). Iterative design process has been implemented to study family groups engagement and develop principles for museum interactives encouraging rich parent-child sensemaking (Beheshti et al., 2018). Research of how families provide social scaffolds to each other and how social and material scaffolding are related in their interaction with exhibits shows that both communication and material features of the museum environment are important (Dornfeld Tissenbaum, 2018). Family members' modes of participation in the interaction ("roles", "stances", "contributions") have also been under examination (Shine & Acosta, 2000; Dietmeier & Devane, 2020). Family interaction is dynamic, participants take on different roles and are able to switch between them. Both children and adults lead interaction, however, their participation is qualitatively different (Dooley & Welch, 2014). The question remains how these adaptive practices are accomplished by visitors and how they are connected to the specific material informal learning environments.

As research shows, it is common for museum visitors to spend much time and effort on trying to work out the way to interact with a hands-on exhibit instead of engaging with its content (Hornecker, 2008). On the one hand, interactive objects often prescribe a strict sequence of actions which users have to follow to get the desired effect (Heath & vom Lehn, 2008), on the other hand, there also is evidence that visitors invent new scenarios (Laursen, 2013). Ambiguity of the script may lead to problems in interaction, leaving visitors confused and unwilling to engage with exhibits (Scott et al., 2013). Research has also focused on the ways to design for productive collaboration in open-ended and exploratory informal learning environments, where participants' tasks are not aligned (Tissenbaum et al., 2017).

In this study, I follow the idea that museum visit should be viewed as an embodied, situated social experience (Shaby & Vedder-Weiss, 2021; Heath & vom Lehn, 2008; Christidou & Diamantopoulou, 2016). Ecology of participation is formed around museum objects, with many modes and levels of engagement. Embeddedness of social interaction in the physical environment and multimodality of interaction are reflected in the concepts of embodied participation and embodied interpretation (Steier et al., 2015).

Methods

The data was collected in 2015 in a museum of science and technology in Moscow, Russia. In total, over 10 hours of video were recorded. A camera fixed on a tripod was placed in several museum halls so as not to bother visitors, but at the same time be visible to them.

Videography (Knoblauch, 2012) captures the multimodal orchestration of interaction and is able to overcome some limitations of methods that rely on participants' self-reports. The video fragments were transcribed using conversation analysis notation system. Transcripts graphically present action as it unfolds in the fragment. To note when and what happens, and which actions are responses to what, multiple iterations of rewatching the recording and updating the transcript are needed. Sound and visible transformations of the exhibit, as well as visitors' talk and actions were transcribed. For the sake of readability and brevity, transcripts are not included in the paper. One limitation of the study is that our recordings do not allow elaborate analysis of talk, as the museum was quite noisy. There was little opportunity to record sound near the exhibit and not to be too intrusive. Some of the audible utterances are included in the analysis.

In this paper, I will discuss two video fragments of visitor interaction with the same multimedia exhibit. Both cases involve a family engaging with the exhibit called "Rocket Launch", located in the hall devoted to space exploration. The exhibit has several parts, including a launch pad and a large screen, and is supplemented with a voiceover. A script for operating the exhibit goes as follows. After turning on the voiceover, the user heads to the box with the plastic details. The image on the screen changes: the metal door opens with a loud noise, and the visitor sees a launching pad with a silhouette of a rocket on the ground. The rocket must be assembled on the screen from plastic parts which attach due to magnets. If the rocket is not assembled on time, one can press the Continue button on the dashboard and get extra time. When it is ready, one presses Start. Rocket then takes off: the background image changes so that the assembled rocket looks like it is ascending. At a certain "altitude", "stages" of the rocket detach. Voiceover narration is intended to provide instructions and immerse the visitor in being present in a control center. In what follows I describe how social interaction unfolds in two similar cases: at the beginning stage of visitors' exploring the "Rocket Launch" interactive exhibit.

Analysis

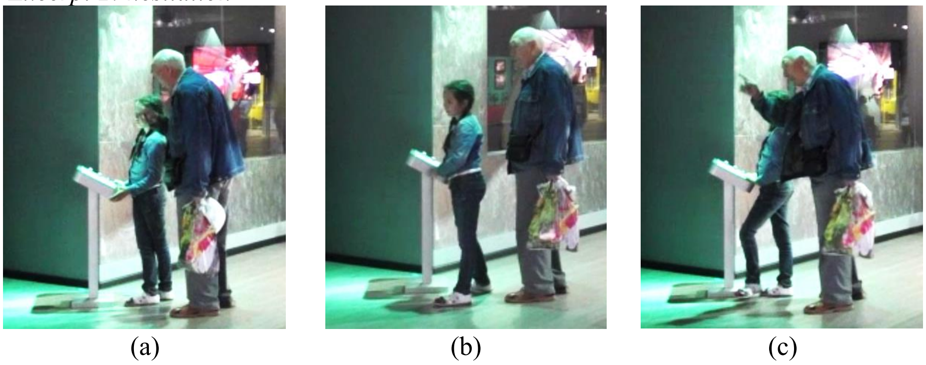
Excerpt 1. A woman and a boy approach the exhibit. After the boy turns on the exhibit, they go forward together and look inside the box. The boy stays near the screen, while the woman takes two steps back, taking the position of an observer. As the door on the screen opens, the boy moves a step back too. In his case, though, he is not withdrawing from the exhibit, but taking a visibly temporary position (his weight on one foot) which allows him to see the screen better (Figure 1a). The boy moves closer to the screen, picks up a detail and attaches it. As he holds the second detail, something catches his attention and he turns away from the screen. The woman uses his head turn as an opportunity. Gesturing toward the screen from a distance, she tells him he is holding the detail wrong and gives a hint ("look how it's drawn", Figure 1b). Seeing that he does not follow the hint, she comes to the screen and shows him where the magnets are (Figure 1c). She stays a few steps behind the boy, occupying a position that allows her to remain an observer with but also to rapidly intervene (Figure 1d).

Figure 1
Excerpt 1: giving instructions


(a) (b) (c) (d)

Excerpt 2. In the second excerpt, a girl and a man start by standing by the dashboard. They spend some time listening to the opening voiceover speech. Throughout the video fragment, the man almost does not change his body position. However, during the speaker's instructions he briefly points at the screen and immediately lowers his hand (Figure 2a), drawing the girl's attention to something. The girl then starts moving towards the screen, but as seen in the still, she does not let go of the dashboard. She does not make any further steps and after a hesitation returns to the initial position (Figure 2b). Her return leads to another hand gesture by the man, this time more pronounced and prolonged, as he points at the screen and tells her something (Figure 2c).

Figure 2
Excerpt 2: hesitation


(a) (b) (c)

The girl eventually comes to the screen and attempts to attach the first part. The attempt is unsuccessful, the rocket part does not stay in place. The girl holds the detail close to her chest and looks at the screen (Figure 3a). Then puts it back in the box, turns around and with her head oriented toward the dashboard returns there. The moment she starts to move away from the screen, the man takes a step back (Figure 3b), although he never moved closer to the dashboard. His step back is unnecessary - there is enough space for the girl anyway. His gesture works as production of certain role distribution in interaction, re-establishing the girl's leading role.

Figure 3
Excerpt 2: attempt and return


(a) (b)

Results

What details of the situation did adults orient to in order to assess a child's strategy of exhibit exploration? They are available to the analytic through pinpointing what preceded an adult's change of participation stance: what happened before an adult's pointing gesture, instruction, correcting or hinting utterance, etc. In excerpt 1, *repetition* of the same actions caused increasing adult's intervention: the woman comes closer to the screen to show the correct way to place parts after the boy does not change the way he tries to attach them. *Unfinished action* also serves as an indicator of troubles in interaction, as is evident in excerpt 2. At first, the girl hesitates to go to the screen: she starts moving and abruptly stops. Following it the man encourages the girl by gesturing toward the screen and talking to her. Likewise, when the girl holds the detail and looks at the screen without resuming to attaching it (Figure 3a), it is a part of constructing a "failed attempt". She returns to the initial place at the dashboard right after this. However, the girl's actions this time do not result in man's intervention. Instead, he takes a step back from the dashboard, allowing the girl to manipulate it (Figure 3b). Although he sees that she experiences trouble in figuring out how to assemble the rocket, he also sees that she does not look at him, but is headed straight to the dashboard. Her *gaze direction* thus does not open the supporting position for him. Children make their understanding intelligible. Performance of "not-understanding" tells the co-present adults that they can, or should, engage more actively.

Spatial organisation of interaction at the exhibit was a crucial resource for adult visitors to construct their stance. In excerpt 2 by not moving from the spot near the dashboard the man publicly establishes his role as not directly engaged. He actively makes room for the girl when she returns, allowing her to hold the leading role and explore the exhibit on her own. By contrast, the woman in excerpt 1 gradually occupies a more "authoritative" place, as she moves from a spectators' spot to instructor's spot right behind the boy. Her intermediary position halfway to the screen creates opportunity for more active engagement.

Finally, affordances of the exhibit contribute to feedback and action construction opportunities for adults. "Rocket Launch" has a stage-like area at the screen, so that it creates a *shared display*. While children are preoccupied with manipulating the exhibit, adults are able to observe the screen and a child's actions at the same time. By having the same objects in front of them as children have, they are able to quickly intervene. Moreover, the exhibit's voiceover sets up a particular *temporal order*, synchronises the action for all participants. The material, spatial, and temporal organisation of an exhibit enables certain modes of participation and creates opportunities to monitor children's actions. These findings are consistent with previous research which showed that shared space of tabletop exhibits offers opportunities for spontaneous collaboration even when participants have divergent tasks (Tissenbaum et al., 2017), and that exhibits' material scaffolds complement families' social scaffolds by enabling joint activity of visitors (Dornfeld Tissenbaum, 2018).

Conclusion

This study elucidates how adults deal with their dual role as facilitators for children exploring interactives and as novice users of the same exhibits. I demonstrate that adults treat repetition and unfinished action as indicators of children's trouble in interacting with the exhibit. Gaze, gestures, and body position serve important roles in coordinating the actions. Children's gaze direction tells adults if they are confused. Gestures help orient participants and give instructions. Body position, specifically the place occupied by a child or an adult, provides opportunities for participation and forms publicly available "roles" of spectators, active explorers, or instructors. The exhibit's material, spatial, and multimedia features, such as voiceover or shared display create opportunities for feedback and subsequent action. Thus, specific affordances of interactive exhibits are important if we want adults to have a clearer understanding of whether they need to engage in interaction and how they can do it.

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Equitable Socio-Ecological Learning Across STEM Disciplines Through a Histories of Places Framework

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Abstract: Socio-ecological histories of places are political, contested, and intimately linked with ways of knowing and being in the world. Thinking within and across time scales is necessary to understand the complexity of socio-ecological systems more deeply and to account for these layered and intersecting scales as a part of ethical decision making with and for places. In this paper, we describe our work as an interdisciplinary team of geoscientists, ecologists, fisheries biologists, and learning scientists to understand how STEM educators can use the Learning in Places Socio-ecological Histories of Places Framework, to support justice-centered, field-based learning. Our initial findings show that the framework supported STEM faculty in 1) situating humans as a part of the natural world, 2) making visible Indigenous peoples' time as central to disciplinary learning, and 3) thinking about ethical decision making as a central practice in disciplinary STEM work with students and communities.

Introduction

Socio-ecological histories of places are political, contested, and intimately linked with ways of knowing and being in the world in everyday as well as disciplinary contexts. Histories span across land, waters, plants, animals, and human communities over time, yet undergraduate science education in the U.S. is often taught in ways that render the powered and historical intersections of social and ecological systems invisible to learners and researchers (Learning in Places Collaborative, 2021). Thinking within and across many time scales is necessary to understand the complexity of socio-ecological systems more deeply and to account for these layered and intersecting scales as a part of ethical decision making with and for places– a practice that is critical to enacting just and equitable STEM research with places and communities. The Histories of Places framework involves thinking across six time scales to support learners in understanding how decisions lead to ethical, just, and sustainable futures and possibilities for humans as a part of the more-than-human world (see Figure 1). Providing a framework for thinking across multiple time scales supports learners and educators across contexts (i.e. K12, undergraduate, and professional) in being able to think about past, present, and future impacts to our lands and waters when engaging in field-based learning and research.

Environmental science research and learning rarely address colonialism in their fields of study, and often reproduce colonial structures and practices by engaging in ahistorical, universalizing, and discovery-focused field-based investigations that invisibilize the heterogeneity and complexity of ecological process that occur across peoples, lands, and waters at multiple scales (Liboiron, 2021). Supporting educators and learners in perspective taking and reasoning through contested histories of places are equity practices that allow for multiple and diverse stories to be told, honored, and incorporated into environmental and STEM professional learning and practice (McGrath & Jebb, 2015). Providing a framework for STEM researchers and faculty to engage in powered and historical analyses around the social, historical, and ecological dimensions of the places they study is required for enacting more just decisions in the future (Learning in Places Collaborative, 2021; Liboiron, 2021). Further, a failure to incorporate these histories reduces opportunities for STEM professionals to understand the complexities of social and ecological systems central to 21st century challenges, such as the environmental injustices that arise from the intersection of ecological crises and systemic racism.

The work we describe in this paper describes Learning in Places (LiP), a four-year, participatory design research study funded by the National Science Foundation. Learning in Places seeks to co-design (with classroom educators, families, and community-based organizations) learning engagements that support science learners and educators with equitable, culturally-based, socio-ecological systems learning and sustainable, ethical decision-making using field-based science education across settings and in partnership with families and communities. In this work we come together as an interdisciplinary team of geoscientists, ecologists, fisheries biologists, and learning scientists to understand how undergraduate STEM educators can use the Learning in Places Socio-ecological Histories of Places Framework, associated tools, and practices to support justice-centered, field-based learning in their own contexts that include undergraduate courses, projects, and multigenerational citizen-science efforts. **Research questions that guided this analysis are: (a) How do two STEM faculty across disciplines**

take up and use the Histories of Places framework in their own research and teaching?, and (b) How can attending to Histories of Places create more just and equitable framings of disciplinary learning across classroom, field, and community contexts?

Theoretical framing

STEM fields are increasingly recognizing the need to address social theories and context in the study of natural systems (Schell, et al, 2020; Hildebrandt, et al, 2018; Liboiron, 2020). We draw heavily from work in social design experiments (Gutiérrez & Jurow, 2016) and participatory design research (Bang & Vossoughi, 2016) to co-construct meanings and applications of Histories of Places across disciplines and contexts in partnership with STEM faculty in ways that integrate core principles of Learning in Places into their fields of study. These principles include positioning humans as a part of (rather than apart from) natural systems (Learning in Places, 2021), broadening what counts as STEM knowledge to include cultural and community ways of knowing, and making visible racialized and powered human decisions and actions that have shaped socio-ecological landscapes over time. Participatory design research requires a fundamental examination and critique of structural sources of inequity, and collective dreaming of alternative, more just forms of partnering. In the work, we intentionally engaged in co-design with STEM faculty to support the development of co-designers as historical actors (Gutiérrez & Jurow, 2016), and designers of their discipline's present and future orientations towards justice in higher education as well as community contexts. This involves not only a sense of one's own identity in broader cultural and systemic contexts, but also a historicized understanding of how certain practices--in particular, practices that perpetuate inequality--came to be and are sustained over time within STEM fields. We use this as a lens through which to examine the case studies presented below.

Design

In the Learning in Places project, we have designed a set of *educator frameworks* that make visible core dimensions of practice for just and equitable field-based science education. In this paper, we focus on one of those frameworks, called *Socio-ecological Histories of Places* (Learning in Places Collaborative, 2021). When scientists study complex systems phenomena in places, they need to understand those places across different scales of time and space. For example, when engaging in restoration, scientists need to first understand the history of a place and the various historical decisions that have been made to shape the land and waters of a place. They need to think across timescales–from geologic time to nation-state time to global time to the future–to understand how natural processes intersect with human decisions and the effects those might have on the future health of a place for all of its inhabitants (cf. Santos-Martin et al, 2019). The socio-ecological histories of places framework (see Figure 1) provides a pathway for supporting more expansive framings of disciplinary learning, teaching, and doing to account for the temporal and spatial variation of natural phenomena at scale, with a focus on centering humans and human decision making as a natural and emergent part of ecological systems.

Figure 1: Histories of Places visual graphic

Geologic Time includes the histories of lands, oceans, and other water processes.

Plant, Animal, & Soil Time includes the histories of plants, animals, and soils and their relationships to lands and waters.

Indigenous Peoples' Time recognizes First Peoples' histories, presents, and sovereignties in places and across time.

Nation-State Time refers to global shifts in political and economic structures that often include human movements across continents, powered shifts in technology, language, culture, and human relationships with the natural world.

Global Time includes how our local places are connected to, impact, or are impacted by other places across the earth and interact with other time scales.

Living Ethical Responsibilities and Possibilities Time includes the possible stories for places in the future.

Socio-Ecological Histories of Places diagram, Learning in Places Collaborative 2021

Methods and analysis

This study takes place in one public university in the Pacific Northwest. We use a case study method to understand how two STEM faculty members, who are co-authored on this proposal, understood, applied, and adapted the Histories of Places framework to their own teaching and research (Yin, 2017). For each faculty case study, we have collected multiple sources of evidence that included collaborative discussions about the nature and use of Histories of Places in their work during monthly faculty meetings (18 hours total), artifacts of their adoption of the histories of places framing for their work across contexts (including multigenerational citizen science programs, and STEM course design), and recordings of academic and community talks and workshops in which each faculty member describes their work the six socio-ecological timescales.

Initial findings

We found that the Histories of Places framework was taken up across multiple faculty members that participated in a small, interdisciplinary co-design group aimed at developing just and equitable models of science learning across STEM fields. Below we highlight two examples of how this framework was used by a geoscientist in an undergraduate GIS course, and a fisheries biologist in a university-partnered citizen science program.

Case Study 1: Visualizing socio-ecological Histories of Places with geospatial mapping tools

In co-design conversations geoscientists, Luis, shared that "most environmental issues or problems have a spatial and temporal dimension. When we teach undergraduates about these issues, we need to make sure they have an understanding of the complexity that this entails. There are many tools we can use today to help students visualize and interpret the interconnections between multiple socio-temporal dimensions to gain insights about where and why socio-ecological issues arise. These are usually contentions spaces, where people compete for resources and geopolitical control, but this is all mediated by particular cultural and socioeconomic conditions between people and places. Geospatial technologies such as geographic information systems (GIS) can help assess complex socio-ecological systems to address global environmental challenges and can help students visualize the scale of powered decision making over time."

In this case study, this faculty member shared how he used multiple layers in ArcMap to engage his undergraduate students in thinking about the multiple, historically-situated, and politically-contested socio-ecological histories of the areas around our University. These mapping layers moved from *hydrogeologic time* to *plant, animal and soil time* by showing how glacial formations shaped our region in ways that supported the emergence of unique ecosystems. He then positioned humans as a part of (rather than apart from) nature through these emergent systems by layering *Indigenous peoples' time* onto the map, noting that "we have a map of the ancestral territories of this area, and we can have a clear image of the human footprint even before Europeans arrived." In moving towards *nation-state time*, Luis shared that, "we know that these landscapes are contested and shaped by socio-ecologic and geopolitical factors, and here we have a layer of land that is currently under the jurisdiction of Indigenous peoples in the area." In moving between Indigenous peoples' and nation-state layers, students could clearly see the immense scale of land loss for Indigenous peoples locally as well as nationally. These visualizations supported students in understanding the patterns and lasting impacts of colonialism on peoples, lands, and waters in ways that oriented their independent GIS work towards proposing pathways for more just and equitable futures in relation to land-based decision making.

Case Study 2: Histories of Places through Stories and Study of Kokanee Salmon

In our second case study, a fisheries biologist, Greg, shared how the Histories of Places framework enabled him to "draw connections between biological systems and their historical and socio-ecological context" for Kokanee salmon. Greg noted that "there is a complicated history between what settlers have done to the landscape and what historically has been." Greg shared how he used the Histories of Places Framework across multiple contexts, including his work with tribal research partners, his undergraduate courses, a STEM field camp for marginalized youth, and a citizen science salmon monitoring program in order to tell the "many stories that can emerge from the study of Kokanee." In a talk with local community members about the future of Kokanee salmon, Greg shared that, "the story of Kokanee begins in the ice ages… much biology was built after the glacier receded and left behind freshwater lakes…Native Americans and Kokanee have lived here together since the retreat of the glacier over 10,000 ago. Historical records and stories show the origins of this relationship over time…. Just over 100 years ago the small streams were loaded with Kokanee salmon, which were thought to have gone extinct by the middle of the 20th century… but in 2021 we found middle-run Kokanee in a local stream. We found that these salmon that are historically important and culturally important are still with us, which brings up ethical responsibilities and possibilities for how to [sustain these populations] into the future."

In this excerpt, Greg makes visible the significance of Indigenous knowledge systems and relations to Kokanee in the region, and the impact of settler colonialism and resource extraction on both ecological and human communities over time, with an emphasis on ethical decision making for re-making more just relations with tribal members and Kokanee now and in the future. Greg recognized how colonial practices work to invisibilize these layered histories and how conservation work requires us to make them visible and present as a part of our decision making practices. In talking with local community members, Greg reflected, "If you think about kokanee and their cultural history of their evolution in lake systems… all of that is still here, but it's easier to overlook because our views are limited by our day-to-day interactions and it can be hard to see this history [because of powered decision making about the land and waters in our area].” In moving between timescales, Greg noted that “Native Americans and salmon have been here together since the departure of the glaciers, and Kokanee have and continue to be very important to Native Americans living in and around [our local lakes]. Greg shared how historic records and stories were foundational to understanding the biology and significance of Kokanee over time. In this talk, Greg shared a portion of the origin story for the Snoqualmie tribe, but juxtaposed this historical account with a contemporary one, stating that “Kokanee continue to be an important cultural component for the Snoqualmie tribe today and in the future” as is represented by the two quotes below. In this way, Greg, uses the Histories of Places Framework to uphold Indigenous presence in present and future awareness.

> “There’s a little story about how the Snoqualmie came to settle in Lake Sammamish, Lake Washington. To find that red fish and that red fish was only in two lakes, I think … Then they got a taste of that red fish, and they settle there.” -Ed Davis, Snoqualmie community elder (1888-1987)
>
> “Gathering on days like this, on this beautiful evening, is one small step in honoring the kokanee and caring for the communities connected by this little red fish. The Snoqualmie Tribe and these kokanee have been here since time immemorial.” - Snoqualmie Tribal Council Member Jolene Williams. 10/12/22

Our initial findings show that the Histories of Places framework supported STEM faculty in 1) situating humans as a part of the natural world, 2) making visible Indigenous peoples’ time and cultural knowledges as central to disciplinary learning past, present and future, and 3) thinking about ethical decision making as a central practice in disciplinary STEM work with students and communities.

Conclusion & implications

Shifting the dynamics of power and historicity in moment-to-moment interaction is central to creating educational equity and forms of education that support culturally thriving communities. We have a paucity of work that traces the learning pathways of STEM faculty learning more justice-centered practices, particularly as it relates to Indigenous peoples and histories. This study marks a new dimension of how place-based science education addresses the complicated and layered social histories of places as central to equitable learning within and about STEM fields.

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Examining Teenagers' Spontaneous Play in a STEM-Based Out-of-School Time Experience for Refugee-Background Youth

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Abstract: This linguistic anthropological case study examines one episode of play involving refugee-background teenagers participating in an informal STEM learning experience. This empirical case shows how the disciplinary practices of cosmic ray detector building were productively interwoven with spontaneous play directed by participating youth. The analysis reveals the need for a greater focus on play, which designers and researchers may initially dismiss as "off-task," but may in fact be an important component of disciplinary practice. Furthermore, we call for attention to play as a potentially important feature of designing and researching culturally sustaining pedagogies (CSPs) with and for diverse learners in informal STEM learning contexts.

Introduction

In this paper, we examine one scenario of extended play among five teenage boys making jewelry out of tinfoil whilst they are constructing a cosmic ray detector in an afterschool program for refugee-background youth. This spontaneous play had no direct content-based relationship to the disciplinary work students were engaged in. However, we argue that this moment of extended play encouraged students to interact with each other in relationally productive ways. And, we argue that by playing along with the students, instructors legitimized a form of youth-directed play to create a learning context that supported the participation of culturally and linguistically diverse refugee-background teens.

Literature review

Play has long been examined in educational settings for its social dynamics and for the role it has in learning (Goodwin, 1999). Research on play has also addressed impacts on learners' ability to work with peers, problem-solving skills, and use of prior knowledge to support learning (e.g., Taylor & Boyer, 2020). While these studies have addressed play-based learning among elementary school learners, fewer studies have examined the concept amongst older learners. Furthermore, the existing scholarship examines the experiences of learners in designed play opportunities (e.g., the "Physics Playground," Ba et al., 2021) as well as spontaneously while "tinkering" in a makerspace (McLean & Roswell, 2021). However, within STEM education, less attention has been given to play that researchers deem "off-task" or unrelated to prescribed disciplinary practices. In parallel to research on play, scholarship on creating more equitable informal STEM learning environments has explored the ways in which programs are culturally or linguistically sustaining for youth participants, ways in which programs fail to offer sustainment for students of color, and ways in which youth push back against hegemonic practices that leak from formal contexts into informal ones, to instead claim informal learning spaces as their own and to reshape the values and practices of those spaces (Calabrese-Barton et al., 2022). The CSP movement focuses on humanizing, decolonizing, socially just, and sustaining pedagogies that re-center the values, practices, and lifeways of marginalized students, thereby reversing course on the processes that lead to their marginalization (Paris & Alim, 2017). However, spontaneous play has not been specifically conceptualized within CSPs. Thus, we examine spontaneous play as a practice and suggest how such play might be conceptualized in the design of CSPs in STEM.

Theoretical framework: Identity pathways

As noted above, foundational research on play has focused on both its social functions and its role in structuring conceptual change or disciplinary knowledge development. We take the theoretical position that learning and social identification are inextricable (Wortham, 2006). Thus, in any moment of play, participants enact social roles (local identities, however momentary or enduring they may be) and orient themselves through language and embodied action to particular objects (e.g., components of a cosmic ray detector, or any other materials or tools in the physical space). In so doing, learners engage in identity work that crafts local personae that both reflect and construct their participation in the learning context. When designers endeavor to craft CSPs that create equity for traditionally marginalized students in STEM, we argue that they are attempting to design learning environments that afford students opportunities to engage in STEM-related identity work as part of a local process of becoming. In such processes of becoming, engaging in or refraining from what might traditionally be labeled "off-task" conversations about dating and other social activities can interweave with students' physics learning experiences and inform how students develop expertise in the disciplinary work of physics lab exercises (Braden, 2022). To explore and begin to understand how another commonly disregarded practice, play, may be related to designing CSPs with a diverse group of teenagers we ask: How does the students' jewelry-related play interweave with their detector building activities?

Methods

Context

This analysis comes from year two of a three-year ethnography studying the STEM identity development of teens in an afterschool program that specifically serves refugee-background youth. The program involves twice weekly sessions during the school-year, and a 1-week intensive summer experience in which students build and learn to analyze data from cosmic ray detectors and create digital stories about cosmic rays and detector building. The program also hosts twice yearly family and community events in which students share what they are learning with others. The research is guided by a linguistic anthropological framing with the goal of tracing students' pathways of STEM-identity development over time. Instructional design is informed by culturally sustaining pedagogies (Paris & Alim, 2017) and specifically focuses on relationship-building, power-sharing, student agency, and student-driven inquiry. The jewelry-making episode analyzed in this paper occurred during a detector building session at the end of year two during the summer session. Students were involved in wrapping the scintillator (produces light when struck by a cosmic ray) and light guide (directs the light towards a photomultiplier tube) to create a light tight seal around these components. The wrapping involves delicately cutting, folding, and smoothing multiple pieces of aluminum foil cut to size and taped down with electrical tape, followed by affixing pre-cut thin black plastic sheets and sealing the edges with electrical tape. To complete the detector, students then attached a photomultiplier tube to the light guide so that the light produced from the scintillator as a result of being struck by cosmic rays can be converted into a measurable electrical signal.

Participants

The five students represented in this analysis have the following national and linguistic backgrounds (all names are pseudonyms): Ali (Iraq; Arabic), Fabien (Congo; Swahili), Raphael (Mexico; Spanish), Habte (Ethiopia; Amharic) and Raj (Nepal; Nepali). Three of the students moved to the U.S when they were young through refugee channels, while Habte (refugee parents) and Raphael (unrecognized refugee status) were born in the U.S. Of the 5 boys, Fabien often seemed disengaged and disconnected socially from his peers and program staff. We noticed a shift in Fabien's engagement in the moment analyzed in this paper. The adults present in the data include the instructor, Ricardo (US - Puerto Rico; Spanish), who recently left a physics PhD program, Jordan, a PhD physicist (US; English), and program support staff (US; English).

Data collection

Audio and video recordings capturing naturalistic conversations, field notes describing communicative practices and episodes of interest related to how students discursively performed or resisted performing expertise in cosmic ray physics, and photos of students engaging in program activities were recorded in every program session by members of the research team who acted as participant-observers.

Data analysis

In this paper, we analyze one 25min jewelry-making episode which occurred during a detector-building session. The episode was initially identified in the broader corpus as an instance that might reveal success in delivering a culturally sustaining science learning experience. Specifically, we identified instances where students engaged in joint activity and conversation that transcended social lines around which the students sometimes organized (e.g., shared national origin, race, or language), and episodes in which students behaved playfully (e.g., laughter, smiling). The episode was transcribed for talk and embodied action using a linguistic anthropological approach (Wortham & Reyes, 2020), with modifications to enable us to examine the simultaneous activity of nine participants. The transcript was then viewed simultaneously with the video and coded in two rounds. The first round of coding traced and categorized the topics of talk and embodied action that students engaged in over the course of the episode (e.g., detector work, jewelry play, shooting play, conversation about psychics, etc.). The second round of coding focused on tagging moments of shift between play and detector work, which allowed us to see student-led changes in orientation, as well as to identify how the adults, the "physics experts," oriented to the students' play and detector work. During this phase, still images were made from the video to capture shifts in activity and joint attention to the jewelry and detector. Images were rendered into line drawings using Adobe Photoshop for inclusion in this paper.

Findings: How play interweaves with detector building

We found that all students who participated in the jewelry play alternated between constructing and commenting on the jewelry and wrapping the scintillator with foil. The jewelry play episode begins when Ricardo slides a piece of foil from the bottom of the detector and Raj gently slides the foil away from Ricardo and picks it up. Raj holds up the foil strip and looks at Raphael as if he is going to place the foil on him, but Raphael is not looking and leans forward to smooth the foil on the detector with the proper tool, a popsicle stick. Raj then puts the long strip of foil around his own neck and attaches the two loose ends together, carefully adjusting the strip to widen it slightly onto his shoulders. Fabien and Raphael pretend to shoot each other with popsicle sticks. Ali comments to Raj, "that's clean," which is slang for cool new attire. Ali and Raj are smiling and laughing, Habte looks on with a broad smile, briefly gesturing up at the necklace and continuing to smile and laugh. Fabien and Raphael continue alternating between smoothing the foil on the detector and play-shooting at each other with popsicle sticks, sometimes making gunshot noises. Habte then gestures to Raj and says, "diamond test it, bro, that's glass," and Raphael turns to Raj to examine the necklace. Raphael places the edge of the popsicle stick on the necklace and makes a sound "dee, dee, dee, dee," (simulating a beeping sound). An electronic diamond tester often beeps as it is reading the stone to indicate whether or not the gem is a diamond. The boys laugh hard. Ali and Ricardo are then folding the corners of foil around the scintillator. As the episode continues, the boys alternate back and forth between the jewelry play and work on the detector as depicted in Figure 1.

Figure 1

Alternating between detector work and play. The images span 4 min and are ordered chronologically from a-d.

(a) 18:04 - Fabien smooths foil with a popsicle stick as Ricardo unrolls it on top of the scintillator. Ali, Raj & Habte look on. Raphael and Raj are wearing their aluminum foil necklaces. Talk centers around Ricardo's back pain and posture.

(b) 18:46 - Habte reaches over the detector to pretend to diamond test Raphael's pendant on his necklace using a popsicle stick, Raj looks on and smiles. Fabien begins crafting a bracelet out of foil as he watches the diamond test. Ali and Ricardo look at the base of the scintillator.

(c) 20:39 - Fabien and Habte work together to tape down foil using electrical tape. Raj and Ali look on, Raphael touches his necklace looking away for a moment.

(d) 21:03 - Raphael picks up an audio recorder and pops out the USB plug to diamond-test Fabien's ring. Habte, Ali, and Raj watch smiling along with a staff person. Ricardo holds out a piece of tape.

The sequence of activity in Figure 1 shows how play was interwoven with detector construction. For example, Fabien's attention alternates between detector work in (a) and (c), and jewelry making and diamond testing in (b) and (d). Eventually, Raphael, Habte, and Fabien all construct tinfoil jewelry. As scraps of tinfoil are produced from cutting the sheets that they are using to wrap the scintillator and light guide, the boys smooth and wrap the foil on the detector and use the extra bits to make their necklaces and rings. Over the course of approximately 25 minutes, the boys transition back and forth between the jewelry play (including rounds of diamond testing), the work on the detector, and additional conversations that might be deemed "off-topic" in a more formal learning setting such as the difference between a psychic and a side-kick, and how to manage back pain.

Rather than taking away from the experience of detector building, we argue that this moment of extended play allowed the boys to construct practices that they found enjoyable while working on a scientific project. Two of the five students (Ali and Raj) had previously expressed interest in cosmic ray physics and coding. They frequently participated in science conversations with physicists in the program. Ali, Raj, and Habte had also been involved in constructing a detector prior to this one. For Raphael and Fabien, this was their first time participating in detector construction. Interweaving play with detector construction work created a joyful and engaging space for this racially and linguistically diverse group of students where they crossed social lines that were previously present in the afterschool program. Prior to the summer session, we had seen Raj and Ali work together, Habte and Fabien work together with other students from African countries, and Raphael usually worked with another Latinx student who was not present. By engaging in play surrounding jewelry making, students co-created a local version of youth culture that interleaved with their work on the scientific project of cosmic ray detector building. Crucially, rather than shutting down this play, the instructors and staff in the program celebrated the jewelry making by taking photos (Jordan & a staff person) and by validating the play with joint laughter, smiling, and engaging in talk around topics other than detector-making (Ricardo). The students and instructors were nonetheless focused on detector construction and worked steadily to complete the detector with playfulness along the way.

Conclusion & discussion

In offering this analysis, we begin to theorize moments of play as the construction and reproduction of youth culture. When these moments transcend the cultural and linguistic subgroups of the afterschool program, we argue that they reveal important relational work that is part of building an equitable informal STEM learning space. In informal contexts, designers and instructors should have freedom to (re)define the role of play in their programs and to develop strategies to support spontaneous play. Researchers may begin to see play as a sign-post of youth culture in the making in their learning contexts. And, rather than dismissing or shutting down this play as a distraction or unimportant component of the learning context, researchers might instead look to these moments to identify ways to further build spaces for youth culture to thrive as a means of creating inclusion. Such revision may require reimagining what counts as a "disciplinary practice." More research is needed on the playful practices of teenagers in order to further build the knowledge base on how to design CSPs in STEM.

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Learning With Stories: Characteristics and Learning Outcomes in Narrative-Centered Science Learning Environments

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Abstract: In K-12 science education research and design, narratives are commonly employed to contextualize content and foster engagement. This literature review analyzes 104 empirical studies, identifying three primary narrative types: authentic, realistic fiction, and science fiction/fantasy. Students are often positioned as problem investigators or professionals in story plots. The narrative types are correlated with nine science learning outcomes, revealing their use and student positioning in K-12 science learning environments. Future research will focus on evaluating the effectiveness of narratives in enhancing science learning and exploring supporting technologies and mediation.

Introduction and background

Sociocultural theories emphasize the importance of embedding learning in meaningful tasks (CTGV, 1997). By creating narrative flow and mimicking complex scenarios, using stories in learning environments can contextualize learning objectives and promote learners' immersion and involvement (Barab et al., 2007). Given the role of storytelling in art, communication, social life, and sensemaking across cultures, it is an appealing tool for educators and designers to use in creating engaging and effective science learning environments (Mawasi, 2020). However, many types of narratives exist, ranging from simple one-time animating scenarios to expansive immersive learning environments. Further, narratives can be embedded in different instructional models such as problem-based, project-based, or game-based learning environments (Hmelo-Silver, 2004). To explore what kinds of stories researchers have designed and their effectiveness, we initiated a systematic scoping literature review on the role of narrative in science education. Based on this review, the present paper focuses on the kinds of stories researchers design and how different story types affect science learning, with the following research questions:

- What types of stories has the field used in K-12 science learning environments?
- How are learners positioned within these stories?
- How are different types of learning outcomes related to types of narratives?

In this paper, we use "narrative" and "story" interchangeably. Both fiction and non-fiction narratives are pervasive in human life and integral to cognition (Dickey, 2011). They represent information in terms of sequences of related events, often with cause-and-effect relationships (Prince, 2003). Humans have used stories to construct, communicate, and learn (Mott et al., 1999). Therefore, when narratives are embedded in learning, they leverage learners' inherent cognitive competencies to situate them into the context formed by the narrative (Wells, 1986). However, given the wide use of narratives in science education, it is not clear if there are important differences in what kinds of stories are told, how students are positioned in those stories in K-12 science education, and whether different kinds of stories promote different learning outcomes. We build on Mawasi et al's (2020) review to examine narrative in both digital and non-digital environments from a learning sciences perspective.

Method

To conduct this literature review, our team followed practices outlined by Alexander (2020). We iterated on search terms and selected databases. We ultimately used the search terms:

- ("narrative-centered" OR "story-centered" OR "scenario-centered" OR "problem-centered" OR "narrative-based" OR "story-based" OR "scenario-based" OR "problem-based") AND (STEM OR science OR engineering) AND (learn OR learning OR education) AND (classroom OR school OR class) AND (method OR study OR studies OR methods OR methodology)

We searched four databases using specified terms: Web of Science, ERIC, selected ACM conferences, and the ISLS proceedings repository. Ultimately, we prioritized studies that met each of four inclusion criteria, namely that the articles had to include: (1) narrative-related instruction, including scenarios, stories, and problems, with the specific narrative explained in the article; (2) empirical data about student performance in the environments; (3) studies based in a science discipline; and (4) K-12 school contexts. An initial search yielded 4,273 hits, and after two review rounds, 109 articles remained as valid studies. Excluding five articles with narratives only for assessment, 104 articles were analyzed.

Employing an inductive approach akin to thematic analysis (Braun & Clarke, 2006), we examined scenarios in each article, assigning initial codes to narrative features and developing groupings. Themes were identified and described preliminarily. Our systematic review aimed to characterize existing narrative types in studies, focusing on how stories support learners considering their age, curricular standards, and learning outcomes. To assess the effects of narrative learning environments, we examined each dependent variable for positive, negative, or neutral (i.e., no effect). Utilizing a vote count approach, we included qualitative and quantitative studies, deeming an effect positive if statistically significant or qualitatively improved.

Findings

Types of narrative

Inductive coding identified three narrative types concerning reality: (1) authentic scenarios, (2) realistic fiction scenarios, and (3) science fiction and fantasy scenarios. *Authentic narratives*, found in 31 of 104 studies, involve real-world events, people, or phenomena, making science learning personally relevant and plausible. In some studies, natural phenomena were described, such as the mechanisms for how vaccinations work (Yang et al., 2021). Other studies focused on narratives that requested students to investigate social issues (Sterling, 2007) or environmental issues (Evrim & Dadli, 2020). In another example, Drymiotou et al. (2021) used STEM-related career-based scenarios to situate students within personally relevant contexts.

Realistic fiction, following realistic logic, the objects in the stories exist in the real world, and the characters behave as real people would (Chavez, 2022). As the most frequent narrative type in 55 of 104 articles, realistic fictions mimic real-world situations, allowing researchers to incorporate scientific concepts into the narrative more easily. Fifteen of the 55 studies positioned the realistic fiction narratives as requests from stakeholders (Cerezo, 2004). Still others positioned their realistic stories as mysteries to be solved. For example, Sabourin et al. (2013) put students in a game-based learning environment called Crystal Island to investigate a mysterious disease. Often used in problem-based learning environments, these narratives can be presented as requests from stakeholders or mysteries requiring investigation.

The remaining 18 studies employed non-realistic stories, including *science fiction* and *fantasy*. Science fictions are tales of potential future science and fantasy with supernatural elements (California Department of Education, 2021). Examples include Alien Rescue, a technology-enhanced STEM astronomy curriculum that employs PBL (Liu et al., 2002). Some other studies utilize widely known fantasy stories, including *Harry Potter* (Beaton, 2004), *Cinderella* (Talaue et al., 2015), and *Frankenstein* (Mawasi et al., 2022). These narratives offer complex systems for exploring science concepts without real-world constraints.

Student roles

We examined whether the 104 reviewed studies positioned learners as characters in the narratives. 65 studies involved students as active participants, adopting *professional roles* or acting as *problem investigators*, while in 39 studies, students had *no role*, learning from a third-person perspective.

In 29 studies, students assumed *professional roles*, designing projects for stakeholders. Such curricula often involved writing, drawing, or hands-on exercises. For example, in a study by Lee and Bae (2008), students were requested by the city board to propose and present solutions to two problems involving the construction of a high school and vocational issues in Hawaii. Adopting professional roles provides simulated experience, allowing students to apply knowledge and develop skills like communication and collaboration. In 36 studies, students were positioned as *problem investigators* of a mystery (e.g., Sabourin et al., 2013), phenomenon (e.g., Cheng et al., 2017), or object (e.g., Sterling, 2007). For example, students investigated car accidents using Newtonian Kinematics and Friction (Kapur & Kinzer, 2007). The position of problem investigator may enable experience narrative transportation by drawing students into the story as agentic participants in the narrative flow.

Finally, in 39 studies, narratives served as instructional materials providing context and problem triggers *without* assigning student roles. This could be because the stories were based on or imitate real-world events that had already occurred; students could not change what happened (Batlolona et al., 2019). Some studies provided multiple scenarios around disciplinary ideas. For example, Evrim and Dadli (2020) arranged five independent scenarios about the ecosystem and related concepts. These stories were authentic or realistic fiction, allowing students to investigate and analyze situations from a third-person perspective.

Types of learning outcomes

Our final research question addressed science learning outcomes associated with narrative use. We identified nine themes characterizing the outcomes: (1) content learning; (2) inquiry skills; (3) other cognitive, higher-order thinking, and ethics skills; (4) collaboration and interaction; (5) argumentation; (6) motivation, engagement, and participation; (7) self-efficacy and confidence; (8) interests and attitude; and (9) self-regulation. Using a "vote count" approach, we examined learning outcomes in both quantitative and qualitative studies. For each type of narrative, we identified the types of outcomes measured and then the number of positive effects. We analyzed the relationship between learning outcomes and narrative types, noting that multiple outcomes were examined in many studies, totaling more than the 104 studies reviewed.

Various assessment tools were employed to measure learning outcomes including qualitative, quantitative, and mixed-method approaches. *Content learning*; *inquiry skills*; and *other cognitive*, *higher-order thinking*, *and ethics skills* were primarily assessed through formative and summative assessments, while *collaboration and interaction*, and *argumentation* skills were often measured using surveys and questionnaires. *Motivation*, *engagement*, *and participation*; *self-efficacy and confidence; interests and attitude;* and *self-regulation* were typically reported through questionnaires and interviews. Realistic fiction was the most studied narrative type for promoting disciplinary learning, such as content knowledge. For instance, Georgiou and Kyza (2021) used a mystery to foster collaborative problem-solving and achieve high conceptual learning gains. Realistic fiction was also used to facilitate learning and to support practice of inquiry collaboration, and self-regulation and thinking skills. Content knowledge was the most frequently measured outcome across all narrative categories, with inquiry skills also frequently assessed in realistic fiction studies.

Vote count results show predominantly positive outcomes, particularly for content learning (93%). Inquiry skills and argumentation also demonstrated uniformly positive results. Measures of inquiry skills include problem solving, scientific inquiry, investigation, and data collection. Other cognitive and higher-order thinking skills, which include reflective thinking, critical thinking, and creative thinking, had lower proportions of positive effects, but there were also a relatively small number of studies in which those were measured. These were lowest in authentic scenarios and highest in realistic fiction. A small number of studies measured collaboration, and these were generally positive across narrative types. Argumentation was only measured in realistic fiction with all positive results. Affective and strategic measures were generally positive, with the exception of interest in science fiction and fantasy narratives, where only 3 out of 6 studies showed positive effects.

Discussion and implications

This review aids in building our understanding of how narratives have been used in K-12 science classroom research and their associated learning outcomes. Our findings suggest that many types of narratives have been effective, but that it is productive to consider the desired learning goals as well as how disciplinary knowledge can be embedded in narrative-centered inquiry before making decisions about narrative type and student positioning. For educators, this often may require making choices about what narratives and positions will be most engaging to students in ways that increase participation as compared to a non-narrative-centered discussion of the topic. Learning designers should engage in in-depth research or co-design with target students, teachers, and communities to develop relevant content and storylines with a deep attention to the relevant science ideas and how they can best be situated in a learning progression as well as a narrative. Further research is needed to understand the what alignments between different narrative types, problem types, tasks, and pedagogical approaches result in which kinds of learning gains in narrative-centered learning environments.

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Worldmaking in COVID-19:
Youth Restructuring Reality via Anime Roleplay

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Abstract: This paper examines youth co-creation of anime-focused roleplay practices in an online program during the COVID-19 multi-pandemic. These roleplay practices reimagined and repositioned the online learning environment as a disruptive, multimedia space of new possibilities for youth direction of expertise and imagination. We argue that youth roleplay can be a justice-oriented, participatory learning practice, with potential to disrupt informal learning environment design and support a regenerative shift toward new ways to learn and engage.

Introduction and significance of youth worldmaking

The COVID-19 pandemic forced millions of U.S. students into virtual life: school, extracurriculars, and peer socialization structures were digitally transformed. At the same time, decades of local and national labor, health care, and housing injustices put Black and low-income communities under greater economic stress and at greater risk of COVID-19 infection and complication. Situated within these unprecedented-yet-historicized contexts, youth created structures of support to connect, imagine, and create together. As our after school makerspace program went online in the 2020-21 school year of COVID-19 quarantine, we observed youth spontaneously begin discussing and roleplaying anime as lenses and languages for reimagining and restructuring relations to one another, to their work, and to the world. They laughed and joked within favorite anime/manga roles, cultivating shared narratives and ways of being/speaking to reposition reality as more playfully malleable. They layered on top of this repositioning their own desires, hopes, fears, worries, and ways of being to create a new world of expanded possibility. We refer to this as ***worldmaking***; a practice wherein youth restructure and reposition themselves in relation to each other and the world around them. This was an act of reimagining and reorganizing the world towards more playful possibilities, leveraging specific ways of being to reimagine learning in pandemic context.

Worldmaking

We situate our study in the idea of worldmaking (or worldbuilding) as a social process by which people collectively imagine in order to co-construct. We define the worldmaking we witnessed in our community as a reimagining and repositioning of the online learning environment into a disruptive site for new possibilities. Worldmaking is about seeking something further than systemic collapse of traditional power structures. As youth "require more than resistance," they engage in inventing the future towards new sociopolitical narratives (Hassler-Forest, 2016, p 174). In centering youth imagination and co-construction, we honor youth-expressed desires to expand the possible. As worldmaking includes reimagining and reorganizing the present as well as multiple possible futures, this necessarily involves identity development (Holland & Lave, 2009, p 2). In our online makerspace program context, then, we recognize broader forms of learning that comprise all interactions that youth participated in together as they sought to make shared sense of the complex and unjust world around them in the midst of a multi-pandemic. Such a youth-centering focus on community practices involves paying attention to the subtleties of youth interactions and repertoires of practice as imbued with "radical political potential" (Hassler-Forest, 2016, p 17). But rather than centrally organized argumentation, such practices get shared among youth in more untraditional and joyful ways. In this way, youth find ways to engage together in worldmaking with "multitudinous energy," using learning spaces as sites for "looser, more playful form(s)" of disruption that embrace alinearity (Hassler-Forest, 2016, p 20).

Anime-mediated practices to reimagine reality

In the context of a multi-pandemic of health suffering exacerbated by racial and economic injustice, we are interested in how youth used our online afterschool program as a type of digital-imaginary reality to accomplish this regaining of control over their reality by inventing new forms of collective control (Hassler-Forest, 2016, p 174). We aim to highlight how the emergent youth roleplay was a way to reimagine and reorganize our digital space into the site of new potentialities youth needed in the 2020-2021 remote school year. Following Stornaiuolo and Thomas (2017), we position this study to "emphasize and amplify youth efforts to be heard and to affect change in order to disrupt deficit discourses" (p 338). Anime roleplay and related digital self-representations and restructurings were speculative practices developed from youth knowledge and culture, where "friendship itself frequently became a resource on which to draw in the moment of creation of a new game." (Potter & Cowan, 2020, p 260)

Framework: Worldmaking via collective, imaginative digital practice

In the in-between and undefined landscapes of online reality (McDougall & Potter, 2019), youth find access to sites of social/emotional and sociopolitical freedom to be and become in radical ways that align with efforts towards social transformation. In digital media spaces, knowledge and expertise can be developed outside of the constricting confines of sexist, racist, and classist power hierarchies (McDougall & Potter, 2019; Parry et al., 2020). The "productively disruptive" spaces of youth digital practice require peer collaboration to negotiate and map out progress (Parry et al., 2020, p 409), lending themselves towards "flatter structures" of social transformation and new creation (Cannon, 2018, p 8). This imaginative remixing also connects worldbuilding to identity work as a part of a collective learning-and-development process. By looking at youth-produced digital media as identity artifacts and assemblages, we can witness youth efforts to become as they seek to change the world around them.

Context, methodology, & methods

The data for this paper was generated in a community of youth who attended a local community-based makerspace, the Green Club (GC), housed in an afterschool center in Great Lakes City, a medium-sized city in the U.S. Midwest. GC is a community-centered makerspace, meaning that youth who participate in this program design, prototype, and build projects that are meaningful to the community. In the 2020-21 school year, this program was taken online in response to youth and parent requests and co-design conversations. The lead researcher of this program and the last author has a decades-long partnership with this organization, while the first two authors have been working with the youth in this program for 9 and 3 year(s) respectively. The third author is a volunteer and former member of GC.

Using critical participatory ethnography with six participating BIPOC youth (ages 12-14), data include recorded Zoom sessions, Zoom chat logs, interviews, focus groups, informal dialogue with youth and parents, and 2020-2021 youth-produced artifacts. Data also included participant-observation and co-viewing (multiple sessions involved peer debates about what character traits fit program adults, with three authors following youth recommendations to watch particular anime).

Data analysis included youth artifact co-analysis using youth artifacts and multiple rounds of researcher analytic memos, shared across co-authors. We co-analyzed data with participants using critical inquiry/grounded theory, in a constant comparative, continuities/contradictions approach (Charmaz, 2017). We developed a set of emergent open codes, focused on forms and focus of roleplay. We generated analytic memos for each Zoom session that involved roleplay, using critical feedback from participating youth to guide iterative analysis. These memos helped us organize open codes into relevant categories and generate insights on youth worldmaking practices of roleplay. Then in axial coding, we referred to our conceptual frameworks to establish relationships between forms/focus of roleplay and purposes as described by youth. Meanings were debated until coauthors came to a consensus interpretation of themes of youth engagement in digital practices as part of our afterschool program.

Findings

Youth co-created and leveraged anime in multiple ways to reimagine and reposition their learning environment as a disruptive, multimedia space of new possibilities. Here, we describe roleplay as an anime-mediated digital practice youth engaged in towards this reconfiguration. For more, see our forthcoming paper (Greenberg et al., 2023).

Anime roleplay as worldmaking

Youth collectively, and unprompted by adults, engaged new acting repertoires to create and be/become in ways that supported them to navigate through COVID-19 extreme isolation and uncertainty. We saw this support youth to assert a coconstructed sense of stability through an imagined alternative reality, shared within trusted peer relationships of silliness/goofiness and joyful resistance to traditional interaction modes. We highlight two dimensions of this roleplay: renaming and teasing/play-fighting. We highlight these to bring attention to how roleplay shaped youth's engagements with one another and how this ultimately created the conditions for youth's relationship building. Over time, such roleplay practices reimagined our maker program as a multimedia playground for remaking reality as more playful and malleable. Youth layered their own desires, hopes, fears/worries, and ways of being/speaking/thinking on top of their work, creating a new world of expanded possibility.

Renaming practices: Role of the characters

Roleplay was a reimagined way to be with friends despite social isolation, but also a way to embody and enact identity work in active and peer-encouraged ways. Youth changed their names continually throughout the program. They enacted new identities-in-practice by taking on alter-egos, personas either directly reflective of favorite anime/manga characters or hybridized with their own identities and names. When arriving to our digital sessions, many of them had already signed into their Zoom programs with these alternative names and had already changed their Zoom backgrounds to feature images of their chosen characters. They would take characters names from their favorite animes, create nicknames as character-referring aliases, and combine their own name and character names to visibly announce their desired hybrid identities, such as "Finn Midoriya." These practices solidified both how the youth related to each other in the virtual space and also helped understand each other.

Teasing and play-fighting in character

Teasing and play-fighting in character, as we see in the example, occurred almost every session we met during the 2020-21 school year. Roleplay often took on rough-housing playfulness, surrounded by laughter, one-upping practices of improvisation, and debate-style arguments weighing evidence presented by peers. Importantly, in an interview after the year ended, Lulu mentioned that Bakugo shares similarities to her personality of good-natured teasing but also short fused impatience (the character is overconfident and aggressive, though his beliefs in his own abilities drive him to work hard and support others). Lulu channeled him often through changing her name, using his sayings in chat and in maker projects, and changing her background to his image. This shows that what was important to the youth was who the characters are- the relationships can be rewritten as the youth see fit.

Anime-lensed digital production as worldmaking

Reorganizing our online program through an anime-centered lens helped youth remake our learning community. This allowed for a shared language and shared origin stories to serve as a foundational background of solidarity and social/emotional safety, contextualizing their ways of hanging out and chatting with each other as they engaged in digital practices. We witnessed youth leverage this shared background to enhance their practice engagement. For more information about our second finding, see our forthcoming paper (Greenberg et al., 2023).

Discussion

As our community went online, we witnessed youth engage in practices to co-create and reimagine existing relationships, structures and resources. As adult facilitators, we sought to recognize, support, and begin more explicitly planning around such practices, to incrementally leverage them towards enhancing engagement in our digital space. As we did so, we noticed how central anime roleplay was becoming to youths' daily engagement repertoires in our Zoom sessions, leading to new possibilities to direct expertise and imagination. Their collaborative efforts supported a regenerative shift toward new ways to be and become together, including new forms of identity development and new relationalities to scaffold collective maker practices. We consider broader implications of these findings, for youth learning and development and for program design in a multi-pandemic informed future.

First, youth in this study demonstrated how anime-mediated practices opened up new possibilities for being and becoming together in the context of digital making, with digital production technologies as tools of identity play and tools of storytime with friends. This was a joyful resistance against the felt personal constraints and social isolation of youths' lived realities outside the maker program. In the context of a global multi-pandemic, we know that engagement in digital practice often served as a conduit for access to social/emotional support (e.g., online art and coding communities, anime affinity websites, and friend networks). In our disciplinary learning space, we saw how dynamic and fluid processes of sharing and co-constructing knowledge were integral to productive digital practice (McDougall & Potter, 2019). Supporting youth-defined imaginative and collective uses of digital tools can support youth wellbeing in learning spaces. We seek here to call attention to the "fluid non-linear affordances of digital media that favor collaboration and plurality" and how such dynamic fluidity allows for imaginative remixing or repositioning of reality in collectively beneficial ways (Cannon, 2018, p 8).

Second, in engaging anime-mediated digital production practices, youth helped us to reconsider the design and purposes of a maker learning environment. Our positionings as youth accomplices helped us facilitate youth disruption and restructuring towards collective reimagining of our learning environment. As part of this, youth disrupted our own assumptions about learning outcomes, pushing for expanded "sociomaterial practice" in making (Friesem, 2020, p 263). We were invited to reevaluate our own understandings and values (our own epistemic and axiological perspectives) of what counted as learning and participation in a maker program.

This can serve as a wakeup call to reconsider structures of hierarchical engagement in informal learning spaces. Unique patterns of youth-agentic discourse develop in different learning spaces, especially where youth feel empowered to express themselves and support each other. What discursive patterns develop in these spaces are important to notice in service to learning how to better facilitate and leverage them towards expanded opportunities for learning and development that acknowledge youth lives, ideas, and dreams as valuable forms of knowledge and practice. By prioritizing collective youth imagination, we could support youth-directed positionings and identities. This opened up ways to digitally embrace and facilitate who youth were and wanted to be and become, while offering a space of social and emotional support in a time of fear and uncertainty.

Conclusions

We studied how youth brought specific forms of knowledge and ways of being to reimagine what an online space could become and how this helped youth remake the world towards new possibilities. During the COVID-19 pandemic, youth had to process rapid, extreme changes in many aspects of life. Embracing anime roleplay online allowed youth support and recognition for using new tools towards identity exploration and shared meaning-making in a time of heightened uncertainty about life and the world. It also supported youth in leading imaginative structural reorganization. All of this contributed to enhancing their shared learning and their reimaginings of what community practice could look and produce. Youth maker work became acts of reimagining and reorganizing the world they saw around them, when they decided that that world was simply not enough.

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Material Anchors for Young Children's Spatial Planning: Contextualizing Path-Program Relationships

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Abstract: Planning a path from an origin to a destination is a common task for studying children's spatial thinking and a foundational part of many early programming environments. This paper examines children's means of abstraction between the grid space and the program domain through an exploration of the strategies they used to plan a robot's routes in 2-D space. Qualitative analysis focused on ways children used materials to aid in spatial planning and programming, advancing previous work on material anchors for concepts (Hutchins, 2005). Through an elaboration of several path planning strategies, we illustrate how children varied in their use of materials in space to represent a path-program relationship. We argue that these strategies represent multiple ways of contextualizing and abstracting in a programming task, with implications for design of equitable CT assessments in early childhood.

Introduction

The material world is implicated in how we conceptualize spatial activities. For example, Hutchins (2005) theorized how a concept of "queuing" is informed by encountering the physical arrangement of bodies forming a line towards some destination; people learn to get in a queue by relating the conceptual space of the queue with its material referent. This complex interplay of conceptual notions and material setting presents questions about the role of concrete objects in dynamic spatial concepts, such as forming a line or following a path. Planning a path from an origin to a destination is a common task for studying children's spatial thinking and a foundational idea in programming environments frequently used in early childhood. For children who are still acquiring directional language like left and right, planning the steps of a route can be challenging. In addition, the symbolic system of navigational arrow codes can be confusing for children who are in the process of associating a wide variety of symbol systems with meanings and material structures (Clarke-Midura et al., 2019; Silvis et al., 2020). Verbalizing or visually representing instructions for another agent to move in sequential steps makes the task even more complex, as the child must engage in perspective taking and reconcile sometimes conflicting spatial orientations (Clarke-Midura et al., 2021; Flood et al., 2022). This paper presents research on children's materially-based strategies for path planning on a two-dimensional (2D) grid with a tangible agent (i.e., a robot) and manipulable directional arrow codes (see Figure 1).

The tasks were intentionally designed to observe children's thinking through their interactions with the materials. As children planned and programmed instructions for the agent, they manipulated arrows in different ways and demonstrated a range of strategies for conceptualizing a path-program relationship. For young children, planning routes involves tacking back and forth between a path and programming materials to anchor abstractions of space across physical and conceptual domains. Our findings highlight the critical role of material context in task design and implicate abstraction in spatial planning.

Contextualizing path planning

The relationship between material and ideational tools mediating human knowledge is an important pillar for situated theories of cognition, child development, language, and mathematical thinking. Hutchins (2005) referred to the "association of conceptual structure with material structure" as "a general and ancient human cognitive phenomenon" (p. 1555). Hutchins used the cultural practice of queuing to theorize how people learn to encode spatial relations to form concepts. He suggested that "in order to see a line as a queue, one must project conceptual structure onto the line" (p. 1559). Not all lines are queues, and not all queues are straight; in order to have a concept for a queue, one must turn line-like structures into a meaningful type of line, one that sequences bodies as they progress towards some location. What Hutchins called "material anchors" are the physical, material, (in our case) tangible objects used in bodily interactions with the physical world as part of the process of conceptual development. A question that Hutchins asked was "*Where* does queueing happen?" Does queueing happen in the conceptual space where the queue-concept takes shape and stabilizes, or in the world where the queuing body takes a place in line? At stake in this question is the role of concrete objects in forming spatial concepts.

This example was instructive for us as we examined the literature on children's development of route planning and spatial thinking. For example, Rogoff (1991) investigated 4- and 5-year-old children's development of route planning through guided participation in a task where children and parents planned a series of imaginary errands on gridded maps representing their neighborhoods and grocery stores. She found that it may be particularly difficult for young children to engage in abstract thinking about future events or anticipated spatial movements when these activities do not have "concrete, present referents" (p. 361). Sophisticated planning strategies involved marking map destinations with colors and symbols to facilitate planning the optimal route that *children themselves* could conceivably follow if they ran errands or navigated the grocery aisles. Similarly, in Hutchins' example, the queue represents a conceptual-material space that the queue-conceptualizer will use. Our tasks were different in that the planner was designing a route *for another agent*.

Providing instructions for another agent involves spatial perspective taking (Clarke-Midura et al., 2021) and draws on Papert's (1980) notion of "body syntonicity," or the ways children use a sense of body and self to learn abstract concepts like codes (Flood et al., 2022) or states of matter (Danish & Enyedy, 2020). Our work draws on the paradigm of LOGOs turtle geometry and tangible computing (Papert, 1980). The tasks described below situate abstract spatial movements in Cartesian space within a "program space" (Silvis et al., 2020). Children must make a series of associations between the abstract codes representing directional movement in the program space and the concrete physical path where movements happen on a grid. It is this relationship between physical space and abstract symbols that prompted us to consider a version of Hutchins' question: Where does the path happen? We use this theoretical question as a point of departure for asking: *How did materials help children represent their conceptual understanding of a path-program relationship in CT tasks?*

Study design and context

This analysis is part of a broader study in which we used Evidence Centered Design (ECD; Oliveri et al., 2019) to iteratively develop a CT assessment for kindergarten-age children that measures their ability to engage in CT practices (e.g., write or enact sequences of code, debug buggy programs). Materials include 2D 6x6 grids (Figure 1) that provided storyboards to situate the tasks, a small wooden agent/robot, and wooden tiles depicting four individual arrows: rotate right on a point (R), rotate left on a point (L), move forward one square (F), and move backward one square (B). Children were instructed to line up or sequence the directional codes in a row *underneath* the grid ("left to right like reading a book"). Despite this instruction and gentle reminders in-task, children developed a range of different strategies for sequencing arrows to build programs.

Participants, data, and analysis

We conducted qualitative analytic coding of video-recordings of children (N=272), ages 4-8, across five semi-rural elementary schools in the United States, as they engaged in CT assessment tasks (average length = 15 min). Assessments were standardized and administered one-on-one by members of the research team.

Figure 1
Materials used in CT tasks.

(1) box of 4 types of arrow codes
(2) storyboard grids
(3) wooden robot agent
(4) administration items/scripts
(5) observational record sheet
(6) pre-set programs

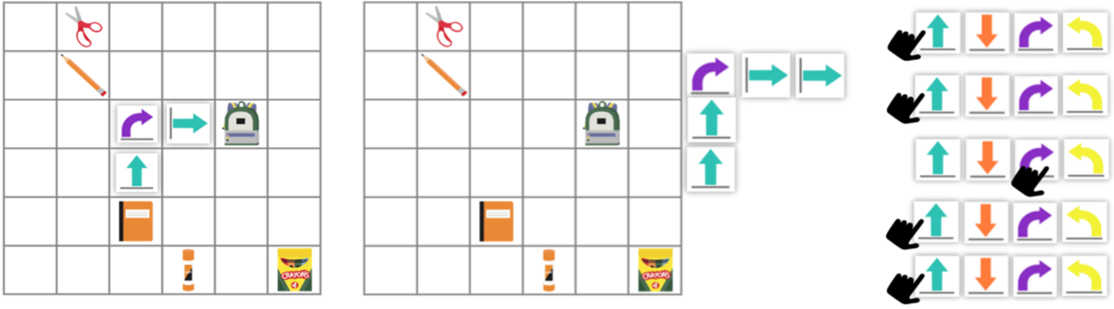
Prior to the current analysis, we conducted a round of coding, where we established a preliminary analytic code system for children's programming strategies, including how they used materials during tasks, how they used movement and gesture while coding, and how they verbalized program planning. Starting with this *a priori* code system, two research assistants coded the majority of the assessment events (83 hours of video). First, they open-coded a subset of the video, adding to the *a priori* codes and reducing redundant codes. The research team met weekly to establish agreement for strategies that were unclear or were hard to determine from the video record. We reached saturation with descriptive codes after coding approximately 50 assessments. Then both research assistants coded approximately 100 students, to refine the strategy code definitions. One theme that cut across categories involved *children's path planning*: how children were using materials, their bodies, and spatial language to plan the robot's routes during tasks. We focus on several forms of path planning selected because they represent both common and uncommon material-based strategies and because they speak to our larger theoretical question about the "where" of path planning.

Findings

Some children placed the arrows on each grid square. Others assembled the arrows in the shape of the path off the grid. Some stacked arrows in a tower vertically, while others placed arrows in random, nonlinear positions on the table. Children also interpreted path planning creatively, sequencing instructions that sent the robot "elsewhere" to a destination image on the grid, even when the task did not specify a destination. We illustrate three of these strategies: *mapping symbols onto spaces*; *path-shaping off-grid*; and *remotely planning a path*.

Figure 2

The Notebook Task, Robot travels from notebook to land on backpack. (Left) mapping symbols onto space; (Middle) path-shaping off-grid; (Right) remote path planning



Mapping symbols onto space

Program and path planning involves conceptually mapping a correspondence between the symbolic meanings of the directional codes and the material movements of the agent in physical space. For many children, mapping this correspondence meant placing codes directly on the map or grid-space. Children using the grid as a programming space allocated one code per grid square, creating a path-shaped program on the grid. This strategy was frequent in the Notebook Task (Figure 2), where children were asked to write a program for the robot to travel from the notebook to the backpack. The correct path was FFRFF. Because the rotation code just reorients the agent, children placing codes on the grid often undercounted their codes, producing FRF.

Path-shaping off-grid

Some children sequenced their codes spatially in the *path shape*, or what we call off-grid "path-shaping" with codes. As with programming on-grid, the Notebook Task served as a useful task to make off-grid path-shaping observable (see Figure 2). Children who performed path-shaping off-grid relocated the program from the grid space to an adjacent area on the table for path planning. This new context off-grid lacked the grid lines that had scaffolded reasoning about path-program-movement correspondence for on-grid programmers. However, the programs children assembled on the table in the shape of the path continued to resemble the grid.

Remotely planning a path

On-grid and off-grid path planning strategies described above represented alternatives to linear program sequencing. Less often, children declined to use the directional arrows to *build* programs altogether and took another approach to path planning. One radically different approach was to select one of each of the directional codes (even those not needed for a given task), place them on the table, and press them like buttons on a remote control to execute each code. Using this strategy to perform the Notebook Task, required tapping FORWARD twice, then ROTATE RIGHT, then another two FORWARD taps (Figure 2). Tangible sequencing that we had designed our assessment tasks to simulate, was instead associated with a different computational context (e.g., TV remotes, video game controllers), where remote controllers operate the machine. Remote paths did not take shape on the grid, nor did they materialize on the table in a path-shaped program. Rather, children planned paths in a remote space, where each movement was invisible, rather than a durable, manipulable sequence of codes.

Material anchors for CT assessment design

Path planning in tasks where an agent moves around a gridded space involves mapping a correspondence between at least two domains: the domain of the grid (path) and the domain of the arrow symbols (program). Children's use of the arrows indicated how they were understanding the relationship between these two domains. Their material strategies demonstrated how they abstracted from the immediate physical grid to the directional codes (mapping symbols onto space), from the grid-space to the program-space (path-shaping off-grid), and from directional codes to imagined movements (remote path planning). This series of abstractions allowed children—at different moments, in different items, and selectively employing different strategies—to traverse task contexts and bridge path-program concepts in ways that are important for emerging CT.

While we would not claim children were making huge leaps in abstraction characteristic of programmers who treat algorithms or problems as decontextualized objects (Hazzan, 2003), our CT tasks and materials elicited modest context-shifts that allowed children to move freely between levels of abstraction. Decontextualizing and recontextualizing problems is a critical part of abstraction and central to CT (Flood et al., 2022). Rather than progressive levels of abstraction—whereby children perform increasingly sophisticated forms of path planning from the grid, to the table, to the remote control— we prefer to see children's diverse strategies in terms of *varying degrees of material anchoring* (Hutchins, 2005). The various shapes their solutions took was another reminder for us, as designers, that an abstract, linear logic of programming is not inherent to computing, it is but one way of thinking computationally (Turkle & Papert, 1990). Even in a relatively constrained system of four directional arrow codes, children demonstrated a range of concrete strategies for approaching programming. Our findings are making us question the underlying rationale for prompting children to write linear algorithms for complex, dynamic paths. Particularly for preliterate children for whom "left to right like in a book," already involves abstract, arbitrary conventions, we want to incorporate multiple ways of using materials in our task models so that our assessments are accessible and equitable.

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Axiological Tools for Expanding Ideas About Elementary Science

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Abstract: This work reviews and analyzes how elementary teachers connect their professional development (PD) experiences to the science lessons they plan and implement in their classrooms. We present the SRL framework–Surface, Recognize, Leverage–as an axiological tool that supports teachers to value students' experiences and ideas, and therefore, make space for student-driven science inquiry about the world in which they live. Hence, teachers are actively working to "expand what constitutes science" and promote collaborative sensemaking across multiple ways of knowing and being.

Introduction

The consensus report, *Science and Engineering in Preschool through Elementary Grades: The Brilliance of Children and the Strengths of Educators* (NASEM, 2021), emphasizes "expanding what constitutes science" as one way to approach equitable science teaching and learning. This includes inviting and building on "learners' and families' diverse sensemaking and cultural and linguistic resources" and "accounting for heterogeneous understandings of the natural and designed world" (p. 24). The literature on teacher responsiveness (Kang, 2022), noticing (Sherin et al., 2011), and culturally sustaining pedagogy (Alim & Paris, 2017) provides insights into how to organize professional development (PD) to nurture teachers' learning about students' equitable sensemaking. Yet, there are few studies that document PD designs and facilitation that enhance elementary teachers' responsiveness to promote equity in science (Kang, 2022). We report on the final year of a four-year, ongoing PD effort with 14 elementary teachers, most of whom teach large populations of multilingual learners. The PD has consistently emphasized: 1) a centrality of representations in eliciting and being responsive to students' thinking and 2) "making space" for students' heterogeneous sensemaking (Bell et al., 2021; Haverly, et al., 2018). Here, we report on an emergent framework—*Surface, Recognize, Leverage* (SRL)—co-developed *with* teacher-participants. We asked: how does the SRL framework function as an axiological tool to expand what constitutes science toward teaching in more equitable and responsive ways?

Conceptual framework

The teacher responsiveness literature emphasizes: 1) *attending* to student ideas; 2) *interpreting* the meaning of students' ideas; and 3) *responding* appropriately (Jacobs et al., 2010; Jessup, 2018), or A-I-R. Our SRL framework is a parallel one, created with teachers using language, mediational means, and definitions they were comfortable supporting within our PD community: *surfacing* is a form of eliciting or attending to students' ideas; *recognizing* is a form of interpreting students' ideas; and *leveraging* students' ideas for the group's collective sensemaking is a form of responding. Louie et al. (2021) critique the AIR framework because it overlooks the ideological framings of students, the discipline, and interactions. They argue that the practice of *framing* provides opportunities to understand the sociopolitical nature of AIR. For instance, framing (shifting AIR to FAIR) allows participants "to understand what kind of task they are engaged in, what kinds of knowledge are relevant or valuable, and what sort of behavior they or others are expected or entitled to engage in" (p. 97). Culture, power, and injustice are inevitably implicated in AIR practices, even if they appear neutral (Kang, 2022; Louie et al., 2021). *Anti-deficit noticing with the FAIR framework* became an interpretive lens to help us understand how SRL worked as a practical tool to shift teachers' perspectives about what is valuable in science learning; but it is an incomplete way to explain the robustness and nuances of teachers' learning.

During the last two years, a responsive goal of our PD project focused on how teachers can "make space" (Bell et al., 2021; Haverly et al., 2018) for students to bring their personal experiences into the classroom for science learning. Our work engaged teachers, in community, to reflect about how they validated and supported students' multiple ways of knowing and being for sensemaking. PD conversations called attention to institutional constraints (e.g., 30 minutes a week for science) and sometimes foregrounded hierarchical language used to define student identities (e.g., low, high, EL). Among these tensions, SRL emerged as a co-constructed tool of shared language about what teachers were doing when they made space for students' experiences. We developed SRL as a tool together using sticky notes, chart paper, videos of practice, and focused conversations to engage in critical reflection about how students' science engagement and teachers' responses to their engagement. Bang and colleagues (2016) explain this approach to design as *axiological innovations* which are "theories, practices, and structures of values, ethics, and aesthetics that shape current and possible meaning, meaning-making, positioning, and relations" (p. 29). We acknowledge that the language of SRL is not necessarily 'new' in teaching and learning practices. Yet, we view it as an *axiological tool*—recursively co-constructed through PD sessions, teacher practice, and reflection—with which the PD community defined shared values and commitments to expand ideas about what science is.

Methods

This is a multi-year, design-based research project (Barab & Squire, 2004). For four years, we worked with over 20 elementary teachers across 12 schools in a large metropolitan southeastern U.S. community. The data analyzed here is from the current cohort of 14 teachers: five teachers from year 1, seven teachers from year 3, two teachers from year 4. Each year began with a 5-day summer workshop. Throughout the year, we conducted two classroom observations of science lessons per teacher, followed by a post-observation interview about each lesson. We held four video clubs (Danish et al., 2021) throughout each school year wherein teachers shared student artifacts from science lessons through gallery walks and engaged in social viewings of video excerpts of their classroom activities. Every activity was video recorded (Hall, 2000). We present data from Year 4 (22-23). All names here are pseudonyms. After several planning sessions using digital media and concept maps to coordinate our stances, practices, and goals, SRL emerged (in name, theory, and practice) as an *intentionally incomplete* framework for engaging with teacher sensemaking about science learning. We conducted iterative video analysis (Derry et al., 2010) which included reviewing AI-generated transcripts, time-indexing and content-logging video, analytic memos, and collective viewings for refining our understanding (c.f., Engle et al., 2007) about the co-constructed meaning of the SRL framework.

Findings & discussion

"Making space" as a framing tool

To review, "making space" worked as a framing component of classroom practice wherein teachers made moves to engage in "equitable sensemaking—collaboratively constructing knowledge with students' diverse epistemic resources" (Bell et al., 2021). The following assumptions surfaced repetitively in teachers' discourse about making space: 1) students' "ideas are valid" because of background experience and knowledge; 2) students need opportunities for "ownership of their learning/knowledge"; 3) students can recognize and leverage each other's thinking with representations; and 4) representations "help students notice changes in their own thinking." In short, the teachers came to the SRL framework with *shared assumptions about the importance of children's scientific thinking*. Teachers' relatively sophisticated noticing practices, framed through "making space," may have made it more likely that the SRL framework became a meaningful axiological tool to name what they value. Next, we provide evidence that SRL functioned as an axiological tool by identifying three values that repeatedly surfaced across our PD activities, previously mentioned.

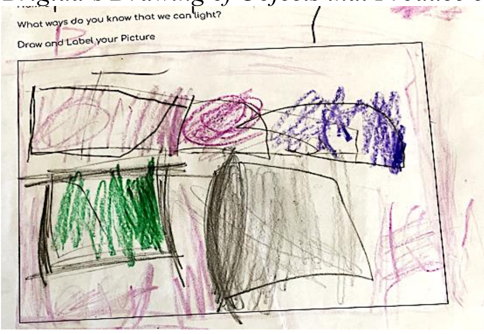
Value #1: Children as capable sensemakers

While teachers knew how to make space for children's sensemaking, the SRL framework helped them refine their practices to support changes in student thinking (*recognizing*), and to build on and use students' ideas as resources (*leveraging*). Teachers became adept at recognizing their students' brilliance even if children's ideas were not expressed in canonical ways. For example, while discussing Brigida's work from a lesson where students identified classroom objects that produced or reflected light, first-grade teacher, Katie reflected:

> I asked her, 'What is this?' She says, 'That.' She points at our smart board [as something that produces light.] 'And then these things [Katie points to top of drawing]? What are those?' And she goes, 'Oh those!' [Katie points to lights above]. *I was impressed with her picture*. (Figure 1)

Brigida, whom Katie described as a student "figuring out English more than other students," redrew her picture on a chart hung on the classroom whiteboard, and Katie also placed her idea on a summary chart. This example illustrates how SRL functioned as an axiological tool: 1) Katie was knowledgeable enough about the child's drawing to recreate and help our group interpret the scientific thinking in the drawing. She valued the scribbles as meaningful; 2) Brigida's drawing was "impressive" even though it may not have been considered artistic or representational in a normative sense; 3) Brigida's ideas were *surfaced* through drawing (versus written English), gesturing, and talk, *recognized* as important by including it on the class's chart, and included on the summary chart for *leveraging* in subsequent lessons.

Figure 1
Brigida's Drawing of Objects that Produce or Reflect Light



Value #2: Teacher risk-taking toward student risk-taking

Risk-taking was a value that worked for the teachers on multiple levels. Not only did teachers use SRL to describe their own risk-taking, they explained how students took risks in their learning, too. In a post-observation interview, Soren, a kindergarten teacher, used the SRL framework to explain how making space allowed her to *surface* student ideas, then take risks to *recognize* and *leverage* what they contribute by "accept[ing] what [students] are saying, and then figur[ing] out what [the teacher] can do…to acknowledge how great it is or how it connects." Soren also described her own participation in the research project as doing activities out of her "comfort zone," then by extension, she offered a rhetorical question: "I've loved that I took that risk…the amount of growth I've had…if that's beneficial for me, why would I not make that available for my students?" Specifically, then, Soren described how she took a risk during a phenomenon-centered lesson involving a melting snowman. When asked what a snowman was made of, the kindergarten students offered potentially risky ideas ("salt and water together will make a snowman," and "soap and water will make a snowman"). Then, rather than shut them down, Soren "wrote all these ideas down" and made a (risky) pivot to follow student inquiry and experiment with these ideas in the classroom the next day. For her, this "was a totally different change from the plan." Soren embraced what the representation of the melting snowman surfaced, wrote down student ideas to recognize their contributions, and leveraged their ideas for scientific inquiry. From these instances, SRL coupled with ideas about making space provided us with a shared language and framing to acknowledge and critically reflect on the value in risk-taking for teaching and learning.

Value #3: Collective knowing for teaching and learning

SRL facilitated reflection on the value of students collectively building knowledge. Reflecting on a video where Katie made space for students to build on each other's ideas about what produces light, Soren commented: "At the beginning [in Summer PD] I felt like leveraging was, like this *ultimate* thing, right? But it doesn't have to be. It can be as simple as what *you're* doing. You're taking what they said and leveraging it. You've recognized it, you're leveraging it to help them take the next step up." Soren doubled down in later reflection:

> More so than ever is if a child is saying something that at first seems incorrect…I asked for someone to build on their thinking…in the hopes that someone will add to it, take it and go with it in the right direction. So I think the building piece…is a really important part of any classroom…If you don't know what to do with what a child has just said, maybe the kids do…Even in kindergarten, they will do something pretty amazing.

In reflecting on Katie's video, Soren saw how SRL enabled collective knowledge building, and in reflecting on her own practice she articulated how recognizing students' ideas and inviting others to build on and leverage them supports a "group thing"—collective knowing.

Ongoing tension: Reproduction of hierarchies while recognizing students' brilliance

So much of teachers' learning through our PD demonstrates anti-deficit noticing (Louie et al., 2021) but, unsurprisingly, there are tensions. One such tension is the continued use of institutional ways labeling children as "high kids" or "low kids" (Horn, 2007). Teachers often identified children in this way at the same time they delighted in children's thinking and reasoning. For example, Katie discussed Brigida (above) as "one of my lower ELs" and "on my other end" compared with a boy who is "technically an EL, but he's like a three or something. He's high." These are tensions to confront as we continue to refine the intentionally incomplete SRL framework.

Significance & implications

The NASEM's (2021) *Brilliance and Strengths* consensus report recommends that elementary teachers, who have few opportunities for sustained professional learning in science, are supported in "developing the ability to recognize and value their learners' conceptual, linguistic, and cultural resources" (p. 248). The report also "urges that research be conducted to understand and support how learning science…can contribute to equity" (p. 250). We use SRL as an axiological tool for this purpose. Drawing on Louie and colleagues' (2021) anti-deficit noticing framework, we noticed how knowledge hierarchies are so easily reproduced, even when the framing of the PD ("making space") centers the value of all students' ideas. Even with a nearly ideal professional learning arrangement—teachers committed to strengths-based perspectives in long-term, job-embedded, collaborative PD—there is still work to be done.

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Making Sense of Modes in Collective Embodied Science Activities

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Abstract: In this paper, we explore how students navigate collective mixed-reality embodied science activities in two contexts. We analyzed students' interactions using a mediated discourse analysis approach by creating bubble maps that captured modal density: the modal complexity (frequency and number of modes) and modal intensity (how much attention participants give to each mode) during embodied modeling and how these maps highlighted participants' engagement with science. We found that the content of the models shaped the modes that were relevant for participation and how the modelers interacted with each other.

Introduction and framing

In education, there has been increasing interest in understanding the role of bodies and movement in learning. We are particularly interested in supporting students' learning through *collective* embodied science modeling, or activities where students coordinate their actions in order to create an embodied model and to learn about complex science phenomena (Danish et al., 2020). In our work, students participate in these activities in mixed-reality environments; as they move around the classroom, they see themselves and their classmates projected as avatars on a screen. To an outside observer, these modeling sessions often seem messy and chaotic. They require that students move around and collaborate in a physical space, while also paying attention to how their actions influence the projected model. It is important to understand how students make sense of these activities in order to support their noticing of and engagement with target science ideas.

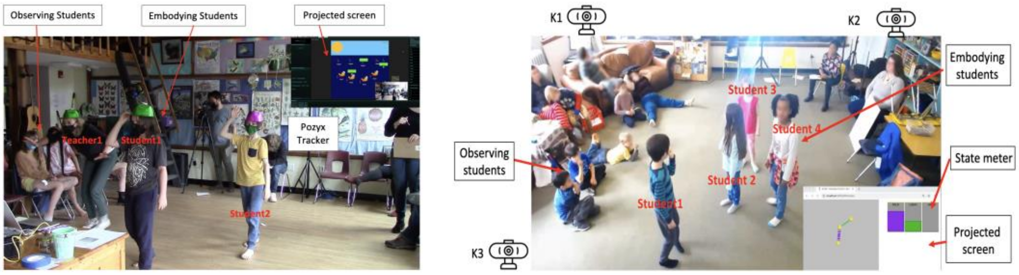
We explore these activities through the lens of mediated discourse analysis (MDA; Scollon, 2001). MDA is a framework that considers what actions are happening in a given site of engagement, and how discourse contributes to those actions. In MDA, the unit of analysis is a mediated action, or the things that people are able to do in a moment using available cultural tools. Central to this focus on mediated actions are modes, or systems of mediated action that "are part of the action that the individuals perform with others, the environment, and objects within" (Norris, 2016, p. 142). Wohlwend (2021) offers a modal categorization scheme, in which modes can be considered embodied (e.g.. gaze, speech, movement), environmental (e.g. color, layout, proxemics), or designed (e.g. image, music, shape). She argues that researchers may overlook meanings that children create because they are focused on fixed speech or print, rather than on actions in lived spaces. Mixed-reality embodied play activities are modally complex; they require students to coordinate multiple modes to be successful. In this paper, we explore how mapping the modal density of modelers' interactions, that is their modal intensity (how foregrounded or backgrounded a mode is for each modeler) and their modal complexity (how intertwined modes are with other modes), can inform our understanding of students' actions during embodied activities. We ask: how do students and teachers navigate modally complex multi-reality embodied play activities, and how does this impact what they notice and their participation in scientific modeling? We explore this question across two contexts where students engaged in embodied science activities: 5th and 6th grade students (ages 10-12) embodying energy transfer in aquatic ecosystems, and 1st and 2nd grade students (ages 6-8) embodying solid, liquid, and gas particles. In putting these contexts next to each other, we do not intend to compare them directly, but to explore the value of modal density for understanding modelers' participation across contexts.

Methods

Participants and data sources

Data for this analysis comes from two iterations of our projects on embodied science modeling: Science through Technology Enhanced Play (STEP) and Generalized Embodied Modeling: Science through Technology Enhanced Play (GEM-STEP). In these projects, students embody various agents (e.g. energy, particles, fish, worms, bees) in order to model complex systems. As they act as these agents, their movement is tracked and projected on a screen (Figure 1). Students generally model in small groups, while other students watch and make observations.

Figure 1
Students embodying energy in GEM-STEP (left) and students embodying particles in STEP (right)



Context 1: 5th and 6th graders embodying energy transfer in aquatic ecosystems
The first modeling activity occurred in the GEM-STEP environment, a platform that supports students to move between cycles of embodied and computational modeling (Danish et al., 2022). This iteration of the project took place in a 5th-6th grade mixed age classroom in a private school in the Midwestern United States. The students engaged in six one-hour long class sessions to learn about energy transfer within aquatic and garden ecosystems. The lessons were taught primarily by the research team, although the two classroom teachers were present and helped to facilitate, participating in the activities alongside students, and providing feedback on the lessons throughout the implementation. Data sources that were collected included video of the classroom implementation, screen recordings of GEM-STEP, and pre and post tests and interviews for each student. Because MDA relies on multimodal data, we focused on classroom video and screen recordings.

Context 2: 1st and 2nd graders embodying solid, liquid, and gas particles
The second modeling activity occurred in the STEP environment, a predecessor of the GEM-STEP that leverages students' embodied play as learning resources to understand scientific phenomena. Students' movement was tracked by three kinect cameras (labeled as k in Figure 1) and simulated as water particles on the screen. The present analysis focuses on an implementation of the particle curriculum in which 22 first and second-grade students from the Midwest participated in seven thirty-minute class sessions to learn about the behavior of particles in three states of matter (Danish et al., 2020). Three researchers, one classroom teacher, and student observers watched the embodied modeling and offered in-time feedback and questions. Previous analyses have shown that students made significant learning gains from the pre/post tests (Tu et al., 2021) and that the collective embodied modeling activities developed their mechanistic reasoning (Zhou et al., 2022). This current analysis uses multimodal interaction analysis to investigate how students' multimodal resources played out in their coordination and emergent scientific understanding.

Analysis

We engaged in multimodal interaction analysis (Norris, 2004) to understand how the modelers navigated the complex mix of modes and meanings as they engaged in a round of embodied activity. To begin, we selected one clip from each context that contained complex interactions between multiple modelers because we wondered about how modal density could shed light on the modelers' collaboration. In context 1, two students and one teacher embodied energy in an aquatic ecosystem in a 130-second-long round. The model included the sun, five algae, and five fish, which students could bring energy between. We selected this clip because we were struck by the sharp contrast between the way that the teacher used the mode of gesture, as she acted out energy, and the students' lack of engagement with acting, even though it was encouraged by researchers. In context 2, four students each represented a particle and explored how their speed controlled different states of matter in a 190-second-long round. We selected this clip because we were interested in how students worked together as they planned, tested, and refined an idea.

Next, we made bubble maps of modal density for each modeler (Norris, 2006; Wohlwend, 2021). To do so, we segmented each clip into ten second segments, and coded each segment for the modes that were present and absent for each modeler (frequency of modes). Next, we assigned values for which modes were foregrounded and backgrounded (attention), that is, which modes required conscious attention, based upon discussion among the authors. In this process, we included embodied modes (gaze, speech, movement, posture, gesture, haptic) due to our interest in modelers' embodiment, as well as proxemics (proximity to others) because we were interested in the modelers' collaboration with each other. We noticed that gaze was present and foregrounded for the majority of both clips, and so we split gaze into gaze towards the screen, gaze towards other modelers, and gaze towards the community (including observing students and teachers) in order to better understand this mode. Speech referred to anytime the focal modeler spoke, movement to their movement through the space, posture to a modeler standing still, gesture to hand movements that conveyed meaning, haptic to moments when touching something (like the hats) and/or other modelers was relevant, and proxemics when modelers seemed aware of or navigated around other modelers in the space. After creating these bubble maps, we explored the implications of a particularly foregrounded or backgrounded mode for participation. In context 1, we noticed that movement was foregrounded and frequent for all the modelers, so we tracked how each modeler's movements corresponded to their engagement with the science model. In context 2, gaze was heavily foregrounded but in different ways across students, and movement was foregrounded for everyone except for student 4, which was surprising in a modeling activity about speed. Thus, we rewatched this clip iteratively to understand how those modes informed students' coordination.

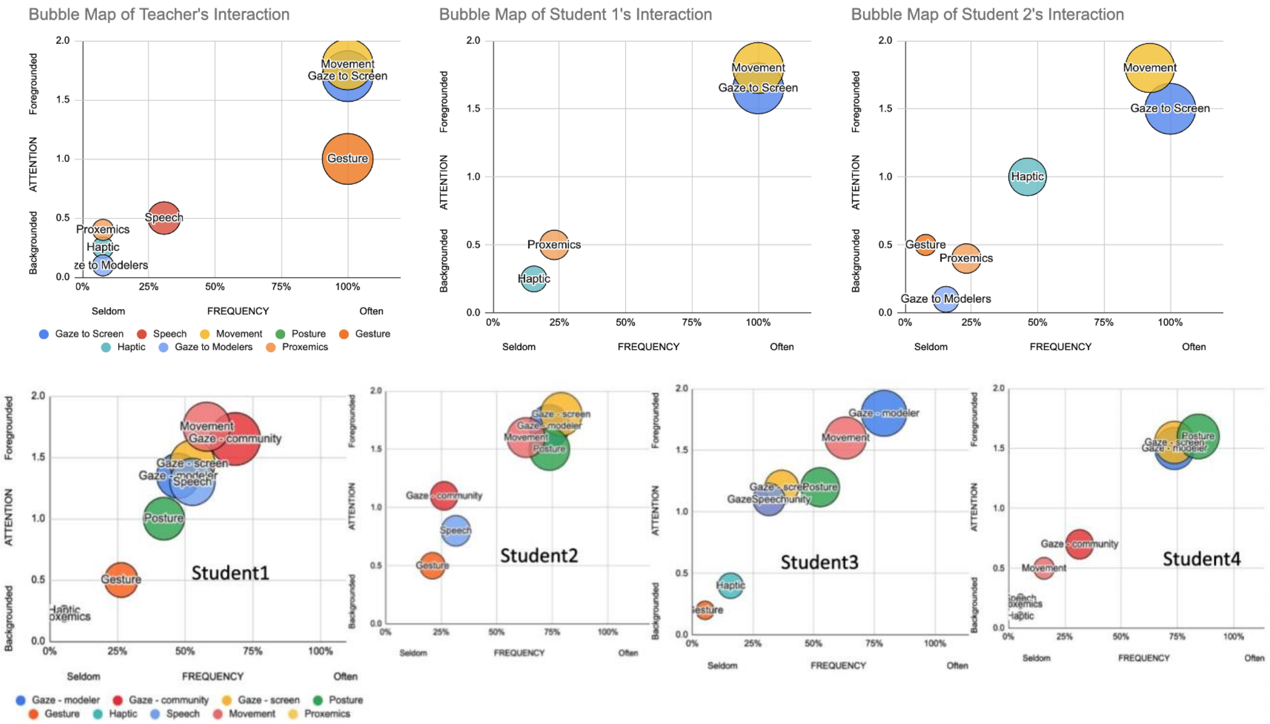
Findings and discussion

Context 1- 5th and 6th graders embodying energy transfer

The bubble maps for each modeler demonstrated that both movement and gaze to the screen were modes that occurred often and that modelers explicitly attended to as they made meaning (Figure 2). The modelers' actions were characterized by an intense, constant gaze towards the screen: they rarely looked at each other, yet only had a few close calls in terms of bumping into each other. There were distinct differences between the teacher and the students' modal interactions. The teacher used speech to coordinate with students: "talk to me people, who do I need to save?". She also engaged playfully through her hand gestures, a mode that drew negative attention from observers: "you look ridiculous". Instead, students seemed more focused on modeling through movement. Even though movement was frequent and foregrounded for everyone, they attended to the model through movement in different ways. The teacher often traveled far distances, ensuring that the fish and algae furthest away from the sun received energy, while the students attended to the fish and algae closest to them. However, they all seemed aware of which agent needed energy, as indicated by a red or orange energy bar, and only brought energy to an agent with a green bar once. All of the modelers were in nearly constant motion as they moved between the sun, algae, and fish. They attended to all of the agents, engaging in what looked like parallel play.

Figure 2

Bubble maps of modelers' modal interactions during a modeling round in Context 1 (top) and Context 2 (bottom)



Context 2- 1st and 2nd graders embodying particles

While gaze and movement were also foregrounded for the modelers in this context, they varied in where their attention was directed most often (Figure 2). Student 1 predominantly focused on the community, student 2 on the screen, student 3 on other modelers, and student 4 on both the screen and other modelers. Rewatching this clip iteratively as a team, we noticed that each student's bubble map related to their roles in the cycle of initiating/planning a goal, enacting/refining the plan, and starting a new plan. Student 1 initiated the modeling plan and addressed questions about the goal from the community, thus directing his gaze there. He assigned each student to move at still, slow, and fast speeds to correspond to the three states (solid, liquid, and gas). Student 2 was initially assigned to be a still particle and complied (as seen by foregrounded posture in the bubble map). Student 4 joined the modeling late and was not assigned a speed. As a result, she was often still and movement was backgrounded. Thus, students collaborated in this context; each students' modal density highlights their role (or lack of role) in the model.

Implications

The bubble maps helped us to attend to how each design necessitated and benefited from different modes. In particles, students needed to collaborate with each other to be successful: as such, their gaze was divided between other modelers, the screen, and the community. In energy transfer, students gazed almost entirely at the screen to make sure the algae and fish did not die, perhaps limiting collaboration. Using bubble maps to attend to these differences in gaze helped us to understand how the content areas and model designs facilitated different modes, leading to different ways of collaborating and engaging. Attending to different modes also seemed to afford different opportunities for engagement and learning. For example, proxemics were backgrounded for all of the particle modelers: students attended to speed and its relationship to the macrostates and had not yet determined that distance to each other mattered. In energy transfer, modelers' intense gaze to the screen enabled their movements to hold meaning– they moved intentionally between agents as they embodied an energy cycle. While we focused on the foregrounded modes in analysis, the backgrounded modes point to actions that may be important but are beneath notice, or to which participants are centralized or excluded from activity. Differences in bubble maps across participants also may indicate differences in experience, like the teacher's gestures during energy transfer or student 4's lack of movement in particles. Future research can explore how to design embodied activities that support specific kinds of modes and engagement.

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The Influence of Informal Transdisciplinary STEAM Programming on Adolescent Cultural Learning Pathways

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Abstract: We lack adequate longitudinal accounts of learning and becoming across settings and pursuits, especially with respect to how out-of-school learning experiences might productively shape extended life pathways and civic engagement. This ethnographic longitudinal study examines how transdisciplinary, out-of-school STEAM programs in Ireland and the U.S. contribute to adolescent cultural learning pathways, with an emphasis on how young people come to transform their worlds. We found these out-of-school programs helped youth deepen their engagement with STEAM practices and gave youth material, ideational, and relational resources, all of which youth used to pursue their imagined futures in other settings (e.g., school, work). This research informs our understanding of the variegated cultural learning pathways traversed by adolescent youth (Bell et al., 2012; Nasir et al., 2020) across developmental timescales after their participation in STEAM program experiences.

The longitudinal study of STEAM learning

In this paper, we apply the framework of a cultural learning pathway to the longitudinal cases of three adolescents to better understand how out-of-school STEAM learning experiences can help young people fight for their desired futures for themselves and their communities (Arada et al., 2023; Sequentials Volume 2, Issue 1: Learning to Engage, 2021). Our focal research question was: How does participation in transdisciplinary programs shape adolescents' subsequent participation in other learning settings?

Conceptual framework

To approach this question, we leverage the conceptual framework of cultural learning pathways, incorporating research on youth civic engagement and transdisciplinary learning. We see learning as developing repertoires of cultural practices within communities (Gutiérrez & Rogoff, 2003; Lave & Wenger, 1991). As they learn, young people reorganize possible futures for themselves and their communities as they imagine themselves and the world as if it were otherwise (Gutiérrez & Jurow, 2016; hooks, 1994; Uttamchandani, 2020). At the same time, youth are constrained by the histories, structures, and powered relations within which they act (Holland and Lave, 2019).

Therefore, we take up the framework of cultural learning pathways to analyze individual learning and identity shifts over extended periods of space and time. Cultural learning pathways consist of personally consequential activities and sensemaking over time and across settings; they are shaped by cultures, social practices, and values (Bell et al., 2012). For example, Ma et al. (2020) use the learning pathways framework to illustrate the interplay between one young person's peer relationships and his statistical reasoning about national LGBTQ+ presence. Through analyses such as these, researchers and practitioners can better understand how to design learning environments that help youth from historically marginalized communities navigate their learning pathways and advocate for their desired future selves and worlds.

This project studies transdisciplinary programs, specifically those that blend practices from traditional science, technology, engineering, and/or mathematics fields (STEM) with practices from the arts. We define transdisciplinarity as a co-equal blending of disciplines, in which epistemic practices from different historically constructed disciplines are interwoven, hacked, or repurposed, creating new integrations of knowledge and new practices, such as defining a problem space or exploring materiality (Bevan et al., 2019; Mejias et al., 2021). We take up transdisciplinary learning as a strategy to support culturally sustaining education, countering colonially constructed disciplinary divisions (Bang & Medin, 2010; Simpson, 2017).

Methods

To better understand how transdisciplinary learning can shape youth cultural learning pathways, we conducted longitudinal ethnographic case-studies of three participants in four transdisciplinary programs for adolescents.

Transdisciplinary out-of-school STEAM program designs

This study draws on case studies from participants in four STEAM programs that were part of an NSF-funded research-practice partnership: (1) Science Gallery Dublin's OPEN MIND Studio, a week-long program of workshops and activities in Ireland; (2) ListoAmerica Clubhouse, which focuses on creative use of technology in the United States; (3) YR Media, a youth journalism and digital media program in the United States; and (4) WAC Arts' digital music production program in the United Kingdom, though no case studies from WAC Arts are featured in this paper. These programs share intertwined design elements (also described in Hurley et. al., 2022), which we hypothesize shape participant learning.

1. **Investigating and developing solutions to personally and locally consequential problems.** All programs in our study support learners to leverage their interest, knowledge, and experiences to investigate problems that they and/or their communities find consequential, such as the interplay between AI and privacy. Youth engage in ethical deliberation around these problems and collectively envision solutions. Programs and facilitators give youth social and material support for individual and/or collective action, e.g., brokering opportunities to join existing social movements.
2. **Building a collaborative community of learners.** Programs in this study desettle traditional hierarchical structures in learning settings. Facilitators use icebreakers to build community. More experienced youth often take on mentor roles, while adults act as near-peers.
3. **Sequencing practices to support transdisciplinary investigations.** In all programs, youth engage in transdisciplinary learning and practices. Disciplinary practices are used as steppingstones to support eventual engagement in transdisciplinary learning. For example, at Science Gallery Dublin, youth began with the engineering practice of building circuits, which ultimately prepared them for the transdisciplinary design challenge of storytelling via electronic dioramas.

Longitudinal study of cultural learning pathways and case selection

As part of our research-practice partnership, we employed cross-setting research techniques—ethnographic interviews, participant artifacts, autoethnographic data sources, and participant observation when possible—to build case studies of the cultural learning pathways of adolescent youth (Yin, 2008). Interviews were conducted annually over the course of three years with 37 youth from the four study sites described above.

Participants ranged in age from 11 to 22 at the start of the study and had been involved in the focal program for as little as one week to as many as nine years. This report shares data from three annual interviews with youth, begun in 2019 or 2020 and running through 2023. We conducted theory-driven purposeful sampling based on the cultural learning pathways of youth, selecting cases in which young people made direct claims about connections between the STEAM programs and subsequent learning in relation to their activist identities.

Three cases of out-of-school STEAM and cultural learning pathways

The following section offers three case studies, followed by our findings about this data set when considered as a whole. These case studies represent a range of cultural learning pathways, practices, and STEAM programs.

Grace, Science Gallery Dublin, and environmental activism

Grace (she/her) attended Science Gallery Dublin's week-long OPEN MIND Studio during her transition year (10th grade equivalent). When she attended, the art-science program was focused on human uses and disposal of plastics. Youth formed small groups to propose technology- and art-informed actions to help combat this environmental issue, then presented their ideas to peers and facilitators, who offered suggestions and feedback.

The next school year, Grace joined her school's environmental club, the Green Committee. The school's new principal solicited this club for ideas for environmental actions to take in the school. In her first interview, Grace recounted, "Because I knew all the stuff that I learned in this course [at Science Gallery Dublin], I felt like it was a lot more easy to engage with her," indicating that she felt the program had given her epistemic resources, such as the practice of defining the problem space, that supported her in this environmental activism.

Nuri, ListoAmerica Clubhouse, and social justice activism

Nuri (they/them) was a Latinx student who had been a member of ListoAmerica Clubhouse for six years when they were first interviewed at age 17. Nuri's high school had a large Latinx population, but Nuri said they felt a lack of Latinx visibility in school activities, interactions with faculty, and advanced classes. As a result, Nuri helped launch a high school club called Teens for Justice (pseudonym), which focused on raising awareness about racial and economic inequality and advocating for an ethnic studies graduation requirement.

In their interview, Nuri described how they had asked ListoAmerica Clubhouse facilitators for support with Teens for Justice. In response, ListoAmerica Clubhouse offered everybody in the club licenses to the Adobe

Creative Cloud software. Mentors at the nonprofit also offered graphic design lessons to Teens for Justice club members, which the club used for its advocacy work over social media.

In high school, Nuri had been a member of the Science Olympiad with future plans to be an engineer. By the time of their second interview, Nuri was attending a college with two robotics clubs–one club that built battling robots and another club that built food-delivery robots. Nuri chose to join the latter club specifically because they saw potential social good in the project — delivering food to people with limited mobility. This indicates that they continued to engage with transdisciplinary practices to solve community and civic problems even after leaving ListoAmerica Clubhouse.

Ben, YR Media, and building a just music production community

Ben (he/him) was 20 years old at the time of his first interview, and was passionate about music, especially playing the saxophone and digital beat making. He had joined YR Media specifically because of that interest in music, which he said he deepened in the program by creating and editing a music video series. In his second interview, Ben described a new endeavor: a new studio and production company, called The Town Sound (pseudonym). Ben found his business partner through DJ shows he did with members of his YR Media social network. Ben said he wanted The Town Sound to reimagine the relationship between audio production studio and artists, describing it as “almost like a label, but not exactly like a label, because we don't really want to have ownership over people. We just want to partner with people,” rather than own the rights to artists’ music.

Ben said his work at YR Media had been key to starting The Town Sound. He related, “What was really helpful was learning about all the other technological stuff that could assist me outside of music or within music” like graphic design of a concert poster or music video editing. This experience helped Ben communicate with people in these related fields, such as describing his preferred website design for The Town Sound.

Findings

With this project, we sought to better understand how participation in focal programs shapes adolescents’ subsequent participation in other learning settings. These findings are tied to youth engagement in programs with particular design elements, specifically that they engage youth in investigating and developing solutions to personally and locally consequential problems, build a collaborative community of learners, and sequence practices to support transdisciplinary investigations.

Cross-case thematic analysis resulted in the following interpretations and findings. Each case illustrates all three findings, but for the sake of brevity, we only give one example for each finding.

Finding 1: Youth deepened their engagement with STEAM practices

Youth continued to deploy and refine epistemic practices learned in STEAM program spaces within other pursuits over time. For example, Grace drew on her experience with the STEAM practice of defining the problem space at Science Gallery Dublin when she discussed possible new activities for the Green Schools Committee with her principal (Bevan et al., 2019). Participation in all programs in this study helped young people deepen and expand their engagement with transdisciplinary STEAM practices (Bevan et al., 2019).

Finding 2: Youth combined STEM / STEAM practices with community changemaking

The design of these programs helped youth see their practice-linked STEM or STEAM identities as connected to community changemaking. ListoAmerica Clubhouse encourages youth to use the organization’s resources to solve community challenges, such as building a teen mental health app. Participating in this model may have helped Nuri to imagine ListoAmerica Clubhouse as a possible resource for Teens for Justice, particularly as the teen activist group sought to engage in the STEAM practice of audiencing (Bevan et al., 2019). Nuri’s use of STEAM practices to pursue imagined futures is further illustrated when they said they chose the meal delivery robotics club because they saw it as having a social purpose.

Finding 3: Youth gained material, social, and ideational resources to shape desired future communities and relations

Throughout these cases, young people used the resources they gained in out-of-school STEAM programs to make changes in other settings. For example, Ben began The Town Sound with a musician he met through his YR Media social network, an instance of a social resource affecting his learning pathway. Additionally, at YR Media, participants collaboratively decide on products. Mentors are also paid for their work, affording them a level of dignity not offered at many jobs for teens. We argue that being a part of this community offered ideational resources to Ben about how an organization like The Town Sound might operate with a flatter structure.

Discussion and conclusions

With this longitudinal ethnography, we hope to better understand how out-of-school transdisciplinary programs can be designed to help youth advocate for their desired future selves and communities. By proposing solutions to issues that are meaningful to themselves and their relations, as part of a community of learners engaged in transdisciplinary practices, these three youth STEAM identities become enmeshed with community-engaged activist identities. Cultural learning pathways are not linear trajectories; they meander and shift, as people manage different priorities, struggle to find available time, fight for recognition and resources, and engage in ongoing identity work. By better understanding how these programs can foster youth dignity and how youth can be connected into ongoing systems and communities of support, we hope to continue efforts to build transformative learning experiences for youth both in and out of school.

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“These Two Worlds are Antithetical": Epistemic Tensions in Integrating Computational Thinking in K12 Humanities and Arts

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Abstract: While advocates for interdisciplinary learning have voiced risks of separating out disciplinary learning into discrete silos, studies of contact between heterogeneous disciplinary perspectives in both pedagogical and real world professional settings point to other risks that educators may need to consider. As such, designing for interdisciplinary learning does not simply require addressing functional problems such as teacher professional learning and time in the school day, but rather implicates complex epistemological navigations that must be taken into account. This manuscript explores potential epistemic tensions between Computational Thinking (CT) and humanities and arts disciplines based on a Delphi study with experts from three humanities disciplines—language arts, social studies, and arts. We analyzed how experts talked about epistemic tensions between CT and their disciplines and how they saw possible resolutions for those tensions. Our analysis found 5 epistemic tensions: contextual reductionism, procedural reductionism, epistemic chauvinism, threats to epistemic identities, and epistemic convergence.

Introduction

There have been recent calls for the field of the Learning Sciences to attend to learning processes in contexts that cross disciplinary boundaries (Herrenkohl & Polman, 2018), such as cross-disciplinary collaborations (Edwards, 2005), interdisciplinary learning ecologies (Damşa et al., 2020) and classroom curriculum that promotes epistemic heterogeneity (Pierson, Brady, Clark & Sengupta, 2022). Simultaneously, there have been increasing efforts to overcome the way the typical school day is organized around the norm of disciplinarity by designing learning environments that directly integrate disciplines together (e.g. Finch, Moreno & Shapiro, 2021), or that help learners make connections and appreciate distinctions between disciplines (Stevens, Wineburg, Herrenkohl, & Bell, 2005). These directions of scholarship have generated important questions for the field such as how learners draw across epistemic practices as they navigate complex problems, and how learning environments can be better designed to support learners' development of meta-epistemic fluency (Damşa et al., 2022; Stevens et al., 2005).

Yet, these questions cannot be fully answered without adequately attending to the tensions that emerge when heterogenous epistemic disciplines come into contact—tensions that can lead to missed opportunities and/or harms in the learning process. For example, in K12 classroom settings, such as the life sciences, teachers and students using epistemic approaches that map onto 'settled' Westernized practices (such as classifying nature into taxonomies) have actively silenced students who use epistemic perspectives that draw on non-Westernized approaches (such as viewing nature in terms of ecological relationships) (Warren, Shirin, Rosebery, Bang, & Taylor, 2020). In another example, in the context of the professional setting of public policy, data-driven cost-benefit analysis has dominated humanistic epistemologies, resulting in an elevation of values of efficiency over those of equality in policy construction (Berman, 2022). As such, considering differences across, and tensions between, epistemologies is critical for scholars and designers of interdisciplinary learning if they wish to effectively prepare students to not just address societal challenges, but avoid reinforcing them through a lack of meta-epistemic fluency.

Unfortunately, the phenomenon of epistemic tensions is understudied, and there is little guidance for educators on how to recognize epistemic tensions, and to support learners in productively navigating them. Utilizing the context of pedagogical integration of computational thinking (CT) practices (Grover & Pea, 2013) within the context of K12 language arts, social studies, and arts instruction, this manuscript presents findings from an empirical study of expert perspectives that surfaced epistemic tensions between CT and humanities disciplines, and potential avenues for resolution of these tensions. Identifying the epistemic tensions within the context of CT integration in K12 humanities disciplines is particularly timely given growing nation-wide efforts to implement comprehensive computing education under the banner of Computer Science for All (Vogel, Santo, & Ching, 2016), which is often inclusive of efforts to integrate CT directly into the humanities (Neumann & Dion, 2021)

Methodology

Our study aims to address two research questions. RQ1: Within the context of interdisciplinary pedagogy, what potential tensions exist between epistemologies of K12 humanities disciplines—social studies, language arts, and arts—and those associated with computational thinking? RQ2: What possibilities exist for resolution of these epistemic tensions within interdisciplinary pedagogical contexts? In order to address these questions, we conducted a Delphi study (Linstone & Turoff, 1975) to utilize expert consultation as a means to gather judgments on the intersection of CT and K12 humanities disciplines, assess and compare across expert perspectives that are not currently documented in extant literature, and generate new ideas (Franklin & Hart, 2006).

We collected qualitative data from each of the 43 participating delphi experts who ranged in institutional role (10 classroom teachers, 10 instructional specialists, and 23 education researchers), focal discipline (Arts=13, Social Studies=14, and Language arts=16), and pre-existing expertise in computational thinking (21 with, and 22 without). Study data included ~26 hours of video recordings and transcribed audio of whole group and small group discussions across six delphi focus group sessions (two for each of the three focal disciplines), and 312 written annotations of varying length by experts sharing their perspectives on the potential intersection of computational thinking and their focal discipline.

We analyzed data using a coding scheme aligned with the conceptual framework of Expansive Learning (Engeström, 1987), whereby contradictions experienced within and between activity systems, in this case epistemic tensions (RQ1), become focal points for advancing beyond the current limitations of existing systems and generate previously unconsidered solutions, in this case, resolutions to said tensions (RQ2) (Engeström & Sannino, 2016).

Findings

In considering possible relationships between epistemologies of computational thinking and those associated with K12 disciplines of social studies, language arts, and arts within integrated learning, participants in our study repeatedly surfaced five epistemic tensions (Table 1), as well as three potential resolutions (Table 2).

Table 1
Epistemic tensions expressed by delphi study experts related to integration of computational thinking into humanities and arts disciplines

Tension	Definition
Contextual Reductionism	Losses of nuance, particularity, and ambiguity around, for example, historical events or pieces of literature that could result from CT’s valuation of abstraction, quantification, modeling, pattern recognition, and prediction practices.
Procedural Reductionism	Problematic reduction of complex epistemic practices into sets of tractable steps. This tension was often expressed in relation to what was seen as inappropriate application of algorithmic logics to knowledge production.
Epistemic Chauvinism	Elevation of CT epistemologies at the expense of those related to a focal discipline in ways that devalue existing ways of knowing within a discipline. For example, some experts raised concerns that interdisciplinary approaches under discussion would end up foregrounding computational tools in ways that would supersede ways of knowing connected to their focal disciplinary values.
Threats to Epistemic Identities	Concerns that cultural and historical identities associated with humanities and arts epistemologies—their epistemological ‘ways of being’, so to speak—could be under threat during integration of computational thinking epistemologies. Some arts experts, for example, expressed concern about alienating ‘art kids’ who identify less with epistemologies that center logic and deductive reasoning.
Epistemic Convergence	Concerns that overlaps and similarities in epistemologies associated with CT and those of a focal discipline could lead to superficial semantic shifts and “reskinning” of existing practices, rather than substantive extensions into authentic interdisciplinary learning.

Table 2

Possible resolutions to epistemic tensions expressed by delphi study experts related to integration of computational thinking into humanities and arts disciplines

Resolution	Definition
Educator meta-epistemic assessment of CT applicability	Suggestions that educators actively reflect on the specific pedagogical context and associated epistemic learning goals of their core discipline in order to determine benefits and tensions of integrating CT practices into said context (e.g. a particular unit of study, particular students). In this process, educators would actively define ways in which CT might be grounded in their core disciplinary epistemology, and how to avoid integration approaches likely to result in epistemic tensions.
Student exploration of epistemic affordances and limitations of CT	Suggestions that educators highlight epistemic affordances and limitations present in integrations of CT and their core disciplinary epistemology within interdisciplinary learning settings, centering contradictions as a site of inquiry and student learning about deployment of varied epistemic practices.
Embracing epistemic pluralism	Suggestions that educators actively highlight the value of differences between CT and core disciplinary epistemologies for students, instead of shying away from them. For example, a social studies educator could use abstraction to look at patterns across historical events alongside epistemic practices of historical analysis that examine the nuance between those situations. Experts viewed combining these two perspectives as a way to new opportunities for learning.

Conclusion

As the Learning Sciences field turns its attention to designing and studying contexts that span disciplinary boundaries, fundamental questions need to be addressed such as: what kinds of epistemic tensions emerge when multiple disciplines are brought together? Further, what harms might these tensions cause? Further still, how can educators effectively design and implement interdisciplinary learning environments that support learners to productively navigate these tensions?

We see it as critical to actively attend to these issues as the field of computing education considers further work bringing its ways of knowing and doing into humanities and arts disciplines in K12 contexts. Our analysis works to put into conversation contemporary trends occurring within the computing education community that see interdisciplinary integration as a key site of implementation in K12 (Neumann & Dion, 2021; Weintrop et al., 2016) with the voices and perspectives of those that have expertise within disciplines that might be sites of integration.

More than any specific tension in and of itself, the study's findings demonstrate that the dynamics implicit in integrating computational thinking into K12 humanities and arts pedagogies are not merely limited to implementation challenges such as availability of instructional time, technology, and teacher capacity, but rather also operate on the fundamental level of epistemic commitments, identities, cultures and histories of the disciplines in question. This space of epistemic interaction between CT and existing disciplines is one that, ideally, would be attended to *prior* to addressing more "classic" implementation challenges in classrooms and schools in order to ensure that various harms are avoided, and opportunities for interdisciplinary enhancement are centered.

While this study is limited in that it did not directly examine epistemic tensions *in situ* within interdisciplinary learning environments, we see the expert perspectives surfaced here as advancing broader scholarship on interdisciplinary learning. Especially given possible risks, consulting experts and exploring tensions that can arise during contact between disciplines provides important starting points for both future scholarship and intentional design of impactful interdisciplinary learning.

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Narrative Construction Game as Consent Knowledge Assessment

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Abstract: Sexual assault rates on American college campuses remain high, despite students' ability to accurately describe consent policies. Therefore, conceptual change in consent knowledge is needed, specifically for concrete knowledge to become more complex. In this case study, I examined how constructing a narrative through a card game revealed concrete consent knowledge in 21 undergraduates. I argue if colleges devoted more time to consent education, narrative construction could show if student understanding becomes more complex.

Introduction

There is a disturbingly high prevalence of sexual violation on American college campuses (Cantor et al., 2015) despite recent consent education efforts. Programs tend to focus on teaching a concrete understanding of consent—*only yes means yes*. While this is important, it is insufficient for developing the expertise necessary to produce any noticeable decrease in campus sexual assault rates (Cantor et al., 2019). Campus hook-up narratives held by undergraduates show their current understanding of sexual consent; reducing campus sexual violence will require students to change their conceptual understanding. In this paper, I describe *The Hook Up Game*, a card game for constructing consent narratives, and the ways that playing it revealed the consent knowledge of 21 students at a large university in the Midwestern United States. Through analyzing the results of this case study, I argue the efficacy of narrative construction through gameplay to assess conceptual understanding of consent. Furthermore, such gameplay can theoretically assess conceptual change of sexual consent in students over time.

Conceptual change in consent knowledge

Conceptual change research has traditionally addressed learning in physical science disciplines, where experts largely agree on explanations of the natural world. More recently, research of conceptual change in history has shown what it looks like for novices to begin thinking more like experts in areas where multiple perspectives are inherent. Rodríguez-Moneo and Lopez (2017) argue that conceptual change in history involves learners progressing along two different continua: shifting from concrete to complex knowledge, and shifting from seeing only isolated events to seeing them situated within systems. Conceptual understanding is embedded in a learner's narratives, and conceptual change is evidenced by shifts within them (Lopez et al., 2015). While this assumes an individual cognitivist perspective, the cognition necessary for successfully engaging in a complex social activity occurs within "the interactions among people, tools, and task" (Hutchins, 1993, pp. 36-37). When young people cognize sexual consent, they do so in a distributed manner, using tools like socially constructed narratives and the perspectives of others.

The model of conceptual change in history, through a distributed lens, provides a framework for studying conceptual change in sexual consent. Conceptual change in any discipline involves transitioning from novice toward expert understanding. While it may be odd to use *expert* in relation to sexual consent, my purpose is to examine consent learning as disciplinary learning. Experts view novel problems in ways that are quite different from novices (Chi et al., 1981). Consent novices concretely interpret sexual encounters: Was everyone sober, and did everyone say *yes*? This simple conception fails to account for the complexities of campus culture. Learners who develop consent expertise, however, understand both the nuances of a specific encounter and the ways the encounter exists within complex systems. They see the sexism and heteronormativity in the typical sexual script: man initiates, woman coyly refuses, man persuades, woman agrees (Hust et al., 2017). If they follow it, they do so critically aware of the differences in refusal and token resistance. Further, consent experts appreciate the differences in hooking up while binge drinking at a party and doing so after a glass of wine on a date. However, a novice would say any alcohol negates a *yes*. This is not to minimize the role alcohol plays in sexual assault, rather to suggest telling students to fully abstain from either sex or alcohol does little to deepen understanding.

Methods

I worked as a consent educator for a decade, facilitating in-depth discussions with nearly 10,000 young people. These conservations influenced my design of *The Hook Up Game* and interpretation of how students played it.

Description of the Hook Up Game

The Hook Up Game is a collaborative social game where players co-construct a story of an intimate or sexual encounter between two characters. In addition to my consent education experience, constructionism (Papert, 1980) and the theory of transformational play (Barab et al., 2010) informed the design. Players use four types of cards to construct their narrative: character, setting, action, and dialogue. As shown in Figure 1, the story emerges through the order in which people play the action and dialogue cards. Character backstories and settings provide additional context. Players can “tinker” with their construction (Flannery et al., 2013) by adding, eliminating, changing, and reordering these cards, resulting in dynamic relationships between the players, their knowledge, and the narrative context. Players also have a *Woah there!* card to use if the story becomes non-consensual.

Figure 1
Layout of game play

Participants

I recruited 21 participants for this case study by demonstrating the game in undergraduate classes at a large university in the Midwestern United States and asking for volunteers. Convenience sampling is appropriate for this study, as consent learning is relevant to all undergraduates. These efforts yielded three play groups, each with seven players. The participants in each group were over age 18. Table 1 shows the composition of each group.

Table 1
Demographic composition of gameplay groups

Group	Player pseudonym, gender	Academic standing
1	Alice, Beth, Cindy are cis-women; Devon is a trans-man; Elliot, Freddy, Gil are cis-men	Juniors
2	Heather, Isa, Jo, Kelly, Lauren, Megan, Nora are cis-women	Sophomores
3	Oscar, Pete, Quinton, Raj, Sam, Tom are cis-men; Uma is a cis-woman	Sophomores

Data collection

I reserved a room on campus with couches and a coffee table for playing the game, and I provided snacks to create the atmosphere of a game night. Each play group met for roughly one hour, playing the game for 20:00 minutes and discussing their experiences for the remaining time. I facilitated these discussions as semi-structured group interviews. I video recorded each session to capture the conversations and the cards played. I made jottings throughout each session. I told participants ahead of and at the start of the session that the game included explicit descriptions of sexual activity and possible references to sexual violation, and they could stop at any time.

Data analysis

This case study examined one question: How might narrative construction through a card game assess undergraduates’ conceptual knowledge of sexual consent? By examining the potential of this game to reveal participants’ consent knowledge, I aim to suggest possibilities for narrative construction games generally. To do this, I analyzed the sessions at two levels by writing and coding two sets of field notes after watching the videos multiple times. At the first level, I analyzed the constructed narrative, and at the second, how players discussed it.

I coded the first set of notes inductively (i.e., identified themes that emerged), resulting in 27 codes. I then collapsed them into five codes (Table 2). I coded the second set of notes deductively, looking for examples of concrete or complex consent knowledge and examples of group agreement or disagreement. This coding scheme (Table 3) came from the conceptual change framework described earlier.

Table 2
Narrative codes

Code	Description	Example
Performance of gender; social power	Typical sexual script; behaviors expected in a social situation	Giving a woman alcohol at a party
Female character initiation/aggression	Counternarrative to the typical sexual script	Female asking male partner for sex
Aggression/violation; manipulation/coercion	Physical or verbal tactic to extract sex from partner	"Why do you think you're here?"
Affirmative consent; explicit boundary	Verbal communication of desires or boundaries	"Just hands, ok?"
Mutuality; assumed consent or boundary	Non-verbal communication of desires or boundaries	Freely kissing back; pushing away

Table 3
Consent knowledge codes

Code	Description	Example
Concrete	Knowledge that closely aligns with formal consent education	Any alcohol negates consent
Complex	Knowledge of the complexities of social systems and relationships	Awareness of sexism's impact
Agree	Multiple members shared an interpretation	
Disagree	At least one member disagreed	

Results

Group 1 created a hook-up between a non-binary pansexual character named Mars and a cis-gender lesbian named Erin. The narrative did not contain any elements of the typical sexual script. The power dynamics constantly shifted, with Mars and Erin taking turns instigating greater sexual intimacy. There were numerous examples of mutuality, where kissing or touching by one character was reciprocated by the other. There was one sexually aggressive action where Mars tore Erin's underwear, prompting Erin to explicitly state a desire to "keep our underwear on." Erin later disregarded her own boundary by explicitly asking Mars to have sex, and Mars responded with assumed consent by "putting a condom on their partner."

While little in the story was obviously problematic, the group seemed unsure if it was consensual. Beth said the ending "took a weird turn," alluding to Erin's decision to rescind her own boundary. Elliot thought the characters were "off all night," referring to multiple shifts in instigation. Everyone agreed the characters should have more explicitly discussed boundaries. This reflects concretely understanding consent as always being verbal. However, they demonstrated emerging expertise at a few points. Gil, Freddy, and Beth discussed the power that setting can wield, suggesting Erin had additional power by being in her own apartment. Elliot and Beth explained reciprocating actions can show consent, prompting Devon to say these can be misinterpreted when people do not know each other well. Beth agreed, adding people also misinterpret what it means to go home with someone.

Group 2 created a hook-up between a fraternity member named Trevor, and a first-year student named Mariana. It was not consensual. Mariana did not want to have intercourse but was open to oral sex. She explicitly expressed this boundary several times, saying things like "What if I just go down on you?" and "I don't want to go all the way." Each time, however, Trevor responded with manipulation, trying to extract a *yes*. This closely follows the typical sexual script. He then got Mariana drunk, and she vomited. When Trevor asked explicitly for sex at this point, Mariana said yes and put a condom on Trevor.

In discussing this story filled with sexual violation, the group agreed it was not consensual. However, Jo said it "wasn't really rape." Several members said they needed to use their *Woah there!* cards more often, but Lauren lamented "we just treat this like it's normal." The group showed concrete knowledge of consent by pointing out that Mariana was too drunk to meaningfully say *yes*. They held Mariana responsible for drinking, though with more complex knowledge they would have situated this individual action within the broader systems at play during a fraternity party. There were hints of emerging expertise when players acknowledged that the story was "complicated," suggesting they knew their current conceptualization of consent was insufficient for understanding the story completely.

Group 3 created the most consensual hook-up. Callie and Jake were on a first date in a restaurant. Over a glass of wine, Jake said he was "hoping to get lucky." Thwarting the typical sexual script, Callie responded by removing her own underwear. They mutually kissed each other a few times, Callie said she did not think she should drive home, so they headed to the bathroom. Jake explicitly asked Callie if she wanted to have sex, and she replied, "yes please!" During sex, Callie said it was painful, so Jake offered to perform oral sex on her instead.

Most professional sexual assault advocates would identify this story as completely consensual, as would many feminist scholars. Callie's removing her underwear at the table was a bold assertion that she was as interested in having sex as Jake. When she said the sex was painful, he immediately stopped. Instead of making her feel bad for delaying his pleasure, he prioritized hers. However, because of their concrete knowledge, the group did not see consent. They said the verbal communication was insufficient. Raj called Callie's *yes please!* "hazy," and Sam agreed, noting the wine. They thought when Callie said she should not drive, it meant intoxication. While there was little evidence the characters were too drunk to consent, four participants thought Callie would feel violated and think her interactions with Jake were "a drunk mistake."

Discussion

The sexual narratives constructed through this gameplay became objects to think with. Students used their consent knowledge to interpret the sexual encounter. Unsurprisingly, these interpretations showed the undergraduates held mostly concrete knowledge of consent. Groups 2 and 3 showed the most concrete knowledge, possibly because they completed their consent education online due to the Covid-19 pandemic. While the members of Group 1 also had a largely concrete understanding, they showed more ability to recognize the complex systems in which an individual hook-up occurs. This could be due to an in-person consent education, an additional year of in-person college, or—most likely—a combination of these and many others. Research has shown that concrete knowledge has not reduced sexual violation. Though it has also shown that long-term, multimodal education can deepen students' consent knowledge (Ortiz & Shafer, 2018). If the purpose of consent education is to reduce sexual harm, then colleges—and high schools—need to devote far more time to it, and educators need a way to meaningfully assess consent learning. Narrative construction through gameplay can provide one way for such assessment.

Limitations

This study is limited in the following ways. First, the small sample size does not represent the knowledge of all undergraduates. Next, I constructed the interpretations alone, without the benefit of other's lived experiences. Further, this iteration of *The Hook Up Game* did not allow for bystander intervention, something included in most consent education. The next version will enable the introduction of additional characters, providing the option for bystander intervention and adding to the elements of consent knowledge that the game can assess. Finally, more research, conducted in a variety of settings, is needed to understand the full assessment potential of these games.

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Changing Task, Changing Talk: An Analysis of Whole Class Discussions of Literary Texts

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Abstract: This work examines two lessons implemented one year apart by the same 11th grade English teacher. The lessons occurred at the same time of year and were around the analysis of the same passage from a novel. However, the task structure and the way the teacher mediated the discussion differed. The findings detail the consequences of these differences for students' engaging with each other in building literary interpretations and arguments. Implications for the design and implementation of literary tasks and discussion are considered.

Introduction

Design-based research (DBR) is a hallmark of the learning sciences. The reflection phase is particularly important for understanding what worked for whom and implications for redesign. This paper examines how redesign impacted classroom discussion of literary works in a first as compared to second design iteration. The design encompasses the text choice, the task and its structure, the activities in which students engage, and the teacher's instructional moves during implementation. Laboratory research has shown that task structure, texts, and activities impact student's literary interpretive reasoning (McCarthy & Goldman, 2015). These studies have not looked at the mediating role of teachers' instructional moves. Classroom-based studies also indicate that the task and its structure impact the intellectual work and discourse that students engage in during classroom discussions (Jackson et al., 2013; Kang et al., 2016). These studies did not explore the reflection phase of DBR and the resulting redesign of tasks, texts, and activities across DBR cycles. This paper examines two iterations of a DBR cycle in an 11th grade English classroom focused on literary interpretation to explore how the redesign following iteration one impacted students' engagement with literature and each other during whole class discussions.

The design work was informed by the nature of literary reading and interpretation. Literary texts portray the human condition through messages beyond the literal words (Langer, 2011). "Going beyond" the literal includes constructing interpretations that incorporate literary knowledge with personal, real-life experiences (Goldman et al., 2015; Lee et al., 2016). Interpretations can be particularly difficult for literary novices and thus require support from teachers (Levine & Horton, 2013). Lee and Goldman (2015) discuss factors that contribute to complexity in designing a learning environment to support students' development of requisite skills to engage deeply with literature. Teachers must understand the text and challenges that it might present students, as well as the demands of the task they ask students to engage in. The given task can vary in its level of cognitive demand from literal questions to questions about how the author uses the language and structure of text to convey meaning (Hillocks & Ludlow, 1985). As literary texts allow readers to explore the personal, cultural, and social aspects of human experience, individual readers can be expected to vary in their interpretations. Literary reading values this multiplicity and variety of perspectives on text. One way that teachers can support students in literary reading and interpretation is by creating opportunities for social interaction and exchanges of ideas around readings of the texts. These forms of argumentation encourage deeper exploration of author's use of language as well as connections to the everyday worlds of students (VanDerHeide et al., 2023; Lee & Goldman, 2015). Instructional moves during classroom discussions can support students sharing ideas and perspectives on text and make student ideas the center of classroom discussions (Howe et al., 2019; Nystrand et al., 2003).

The study reported here compares students' interpretive reasoning about literary works in the context of classroom discourse across two design iterations implemented by the same teacher, Ms. Edwards. Reflection on the first iteration (Year 1) led to changes in the task and teacher instructional moves for the second (Year 2).

Method

As part of a larger multi-year project focused on literary reading as multi-text evidence-based argumentation, Ms. Edwards designed and implemented a year-long curriculum focused on gender and power as manifest in several short texts and two novels. She taught 11th grade English in a large urban high school serving a diverse student population (47.9% Black, 43.1% Hispanic, 3.8% White, 1.9% Asian, and 3.3% mixed race; 87% free and reduced lunch). The teacher is White and was in her second year of teaching at that school when she joined the project.

The present paper draws on classroom observation video from two successive iterations of the year-long curriculum when students were reading *A Thousand Splendid Suns*, a novel by Khaled Hosseini that traces the stories of two women in Afghanistan. The two observations that constitute the primary data for this study were selected because the focus and content of the instruction was the same across iterations. The focus was on a passage that depicted the relationship between a husband and wife (Babi and Mammy). However, the task and set-up (instructions) for the task were different as were the teacher's moves during the class discussion.

In the first iteration (Year 1), the teacher gave the students the passage and asked them to "perform a close reading," annotating for power and agency. Students worked for about six minutes individually and then shared what they had noticed in the passage during a whole class discussion. In the second iteration (Year 2), the teacher put the passage up on a screen and told students to write four sentences in response to the question "Does this passage confirm or challenge your thinking about Babi's power?", reminding them that in a previous discussion they had decided Babi was powerless. She emphasized the importance of backing up their claims: "What evidence is showing you that it either confirms that he is weak or challenges that he is weak?" Students wrote responses individually for about four minutes and then discussed the passage as a whole class.

Data sources for this study are field notes and video and audio recordings of the two classroom observations. Each video was segmented into Interactional Units (IUs) independently by two coders. An interactional unit was a set of utterances that were "interactionally related and connected" (Smith, 2008, p. 81). The two coders agreed on the boundaries for the majority of IUs. Disagreements were resolved through discussion. Each interactional unit was analyzed for teacher moves and students' disciplinary practices, including the types and substance of the claims, the resources they used to make sense of the text, and the ways their contributions related to those of other students (e.g., building on others, challenging or disagreeing with others).

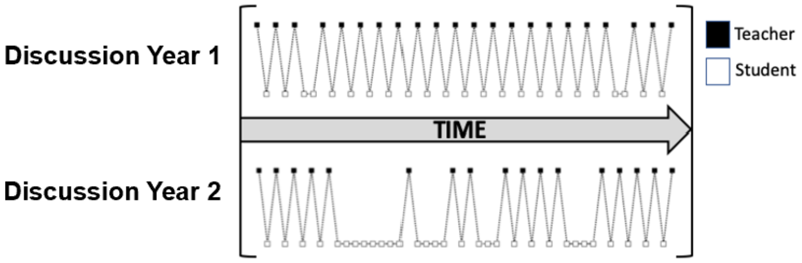
Findings

Our analyses of the discourse revealed differences across the two iterations in the teacher-student turn-taking interactions and students' disciplinary practices during whole class discussions. These differences can be traced to differences in the set up for the discussion as well as the teacher's instructional moves during the discussion.

The Year 1 discussion (~12 minutes) included 45 talking turns—22 by the teacher and 23 by students. Figure 1 depicts the distribution of talking turns in both discussions. The distribution of turns in Year 1 was almost entirely back and forth teacher-student. However, the Year 2 discussion (~12.5 minutes) was different, with 48 talking turns—17 by the teacher and 31 by students. Although the teacher did intervene in the second discussion, unlike the first discussion, we see chains of student-to-student talk moves that did not involve the teacher.

Figure 1

Distribution of Teacher and Student Talking Turns Over the Two Class Discussions



The Year 1 discussion was set up as a share out of annotations focused on agency and power from a close reading of the passage, and students did just that: They shared their annotations, all students agreeing Mammy had power (Babi was weak) until the teacher played "devil's advocate" to prompt them for alternative viewpoints. In contrast, the Year 2 discussion posed a question that had multiple viewpoints, and students provided those in their responses. Of eleven students, six claimed Babi was weak, three claimed he was strong, and two said he was both weak and strong. This represents a difference from the first discussion in the variation among student claims.

The Year 1 discussion began with the teacher asking students to share what they said in their annotations of the passage for power and agency. The first student asserted that Mammy had power. Several more students supported this idea and elaborated on Mammy's motivations. The teacher then asked the students to raise their hands if they thought Mammy was in power. Most students raised their hands, indicating that they agreed with the first student's statement. The teacher then stated: "I want to play devil's advocate for a minute and push us a little bit on this. What if I were to tell you that I don't agree?" Only after the teacher raised the possibility of a different interpretation of the text did students begin to argue about Mammy being in power. One student shared his thoughts "…he (Babi) wants to leave, but then like, she wants to stay so he actually goes by her agreement even though he is the male figure…I think he's more, like, devoted to his family's feelings than what he wants."

This interpretation uses Babi's actions in the text to counter the interpretation that Babi is weak and Mammy is in power. The teacher picked up this claim and directed students to compare Babi to the other male figures from the book, guiding them towards thinking about the multiple forms that power can take in different characters and situations. Towards the end of the discussion, she asked students to take another look at the passage: "See if you can pull some kind of reading that makes this kind of power structure less clear." The pattern and content of teacher talk moves, although it built on the initial student's interpretation, directed the students to what she wanted them to discuss (i.e., the complexity of power relations among the characters) rather than inviting students to respond to the initial claim. The teacher's moves likely reflect her realization during the lesson that the task set up ("annotate for power and agency") did not lend itself to literary argumentation and multiple viewpoints regarding power relationships. This realization may have triggered teacher moves intended to direct students to specific comparisons to surface this complexity. However, the directed teacher prompts also likely inhibited student-to-student talk moves and the free flow of ideas because students were looking to the teacher for direction.

After reflecting on the Year 1 implementation, the teacher re-designed the task and its structure for Year 2. She set it up as an argument from the beginning by directly posing multiple viewpoints in the central question: "Does this passage confirm or challenge your thinking?" Multiple students' hands shot up after she initiated the discussion with this question. The first three students who contributed to the conversation stated that they thought Babi was weak because he did whatever Mammy wanted. Without prompting from the teacher, a fourth student spoke up and said, "I disagree with all of them because they are lookin' at it the Afghanistan way, …cause some men, they don't wanna make a scene or wanna react to it cause they feel like that's not being manly. Cause like my momma when she at her house, you know, and my daddy just sit there like he doesn't want to say nothing because it would be a conflict…what I'm trying to say is like he got power, but he probably don't wanna use it on her, like what's the point of doing it?" The next student jumped into the conversation and said he also disagreed that Babi was weak. "Basically, just like [student] said …she might tell him to stop talking and shut up, and he might stop talking… [but] I feel like it doesn't change because I still feel like he's the smart one, he's the calm, like the brain of the household." Following these two contrasting viewpoints, another student stated, "I agree with both sides. Sometimes he is kinda weak, but sometimes he is strong…" The idea that someone can be both weak and strong represents the complex nature of the characters and of power relations both in the text and in the world, an understanding students came to by discussing and arguing varying viewpoints with each other. The Year 2 set up obviated the need for the teacher direction in the Year 1 discussion. The Year 2 task set up and the teacher's initial talk move were sufficient to support students arguing with one another, arguments that were grounded in the literary elements of the book.

Discussion

These two discussions demonstrate turn-taking structure and substantive differences that we claim are in large part the result of the redesign of the Year 2 task setup and teacher instructional moves. In Year 1, students mostly responded to the teacher with similar claims and rarely spoke to or referenced each other's ideas. In contrast, the Year 2 discussion consisted of varied claims and students directly disagreeing (and agreeing) with each other's ideas. The teacher staged the task as part of an ongoing discussion of power relations and character development over time, prompting students to decide whether new textual evidence "confirmed or challenged" their previous ideas. This problematization set the task up as an argument for which there could be multiple points of view. The design of the Year 1 discussion did not explicitly open space for multiple points of view and resulted in more summarizing annotated ideas than exploring multiple perspectives. In addition, the teacher stepped in and directly guided the Year 1 discussion, whereas in Year 2, she positioned herself out of the picture and let students build on and counter each other's ideas in a rich literary discussion.

These two discussions involved the same teacher, passage, and point of time in the year's curriculum, but the redesigned elements – the task set up and the teacher's mediation – made a profound difference in students' disciplinary reasoning during the discussions. Of course, we cannot rule out differences in the Year 1 and Year 2 students as contributing to the observed differences. However, the demographics of the classrooms across the two years suggest that such differences were minor compared to the differences in task structure and teacher mediation.

The present findings have implications for efforts to support teachers in engaging in instruction that provides opportunities for students to engage in literary argumentation and reasoning as well as in disciplinary argumentation in other disciplines. Teacher professional development often focuses on better lesson planning and designing of curriculum and instruction. It less often focuses on student learning that occurs when these designs are implemented. Professional learning activities that enable teachers to reflect on instruction, often facilitated by video records of instruction, indicate that such reflection leads teachers to greater awareness of their own instructional practices and how they are impacting student learning (e.g., Hall & Goldman, 2022; van Es & Sherin, 2010). Other efforts open up the classroom to teacher/research co-instruction through Learning Labs (Kavanagh et al., 2022; Kazemi et al., 2018). During Learning Labs, instruction is put on hold momentarily for reflection on what is happening. Reflection both after and during instruction leads to greater teacher awareness of the relationship between what teachers are doing and what students are doing. Increased teacher awareness is a powerful lever for change not only in designing instruction but in how teachers interact with students during instruction to support them in the intellectual work of the discipline, productive disciplinary discourse, and deeper learning.

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Imagining Generatively Together: Exploring Strategies for Deepening Problematizing in Design Thinking Towards Justice-Oriented Futures

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Abstract: The remarkable capacity of the human mind to travel through time and space enables us to think about our futures often. However, when analyzing complex problems towards justice-oriented futures, our methodological toolbox still has limitations. We draw from the processes of design thinking as a way to address wicked problems entangled in higher education injustices and inequities. In design thinking, the 'problem' phase is arguably one of the most challenging, yet critical phases. If a problem is ill-defined, then ideation of any possible future is constrained. We explore two innovative strategies to generate deeper problematizing for design thinking with multidisciplinary university students: an anti-goal strategy and the '7-problems-with-problems' strategy. In this preliminary analysis, we discuss the potential implications of the two strategies on design principles to support generative processes of problematizing for justice-oriented futures.

Introduction

'Design thinking' (DT) has been purported to be an effective approach to creative problem-solving, particularly for addressing *wicked*, or complex, real-world, problems. DT as a methodology has a multitude of approaches rooted in design theory (see Johansson-Sköldberg et al., 2013). Despite the common critique of its lack of conceptual clarity (Panke, 2019) and theoretical grounding (Micheli et al., 2018), DT has been increasingly adopted as the approach to support society-focused, human-centered, equity and justice-oriented, sustainable problem-solving (e.g., Wolcott et al., 2021), including as a key method of solving complex real-world problems in curricula of multiple disciplines (McLaughlin et al., 2022). Thus, we sought to explicitly problematize the methodology of DT, particularly that of one of the most influential DT approaches, the Stanford d.school method (Hasso Plattner Institute of Design at Stanford, 2020). The d.school method puts participants into contexts that support them to think and work like a designer across a series of phases. Each of these phases (i.e., empathy, problem definition, ideation, prototyping) encompasses a complex set of design cognition, each of which iteratively affects the efficacy of the next phase and, ultimately, the proposed 'solution(s)'. Empirical research on design cognition focusing on phases of DT (e.g., prototyping: Jobst & Meinel, 2014; empathizing, Svilha & Kachelmeier, 2022) elucidate nuance in emergent design cognition, supporting informed design-making for researchers and practitioners alike when using DT, such as *whether* design thinking as an approach does indeed support the intended outcomes, and importantly, *how* designers might optimize their collaborative approach toward creative, future-oriented problem-solving as intended through DT.

In this paper, we focus on the *problem definition* phase in DT. The problem definition phase follows the empathy phase, where designers use knowledge from empathizing to generate the identification of the problem(s) they are trying to solve. This stage is a critical step in the design process; inappropriately defined or misidentification of problems will lead to unviable solutions (Abdulla et al., 2020), or even the perpetuation of systemic injustice or tokenism (Ortiz Guzman, 2021). Thus, we investigated possible approaches to support design cognition for problem definition in DT with university students and staff collaboratively working towards possible justice-oriented future(s) of higher education. In two participatory workshops, we explored two innovative strategies to generate deeper problematizing in design thinking: an anti-goal strategy (van Lamsweerde et al., 2003) and the '7-problems-with-problems' strategy (Ortiz Guzman, 2021).

Methodology

Overarching methodology and methods

This paper is part of a larger study addressing epistemic diversity and equity when learning how to learn in college (Alhadad et al., 2021; GU ethics 2020/600). The broader research study brought together 20 university students across various disciplines (e.g., information technology, psychology, environmental science) and year levels (2nd-year undergraduate to masters' levels) to unpacked research from 'the science of learning' with the view to re-design research translations for students whilst centering equity. This program officially lasted eight weeks, however, it continued informally for another year and a half. This broader research was underpinned by participatory design research (PDR; Bang & Vossoughi, 2016) and social design-based experiments (SDBE; Gutiérrez & Jurow, 2016), centering students as the community of focus for equity-based futures in knowledge participation at the university. The use of PDR and SDBE as the overarching methodology allowed us to strongly anchor the program with deep roots of justice-making, disrupting power, and with strong attunement to our diverse identities, historicities, and positionalities as we collaborate to enact change. DT was employed as an analytical method within the broader research to support an equity-focused critique of the science of learning research translations. As part of this broader program, we conducted optional participatory workshops intended to support students to deepen their application of the design thinking processes in a defined topic (e.g., disability, future-focused curriculum, etc.). Two of the participatory workshop sessions focused solely on imagining justice-oriented futures of higher education, which the current paper will focus on. To activate thinking about social and epistemic justice in higher education, we began both sessions by discussing a current issue covered in the media (e.g., the presence/ absence of Indigenous ways of knowing in schools, current issues impacting critical race theory socio-politically). The sessions were conducted eight months apart. Each workshop ran for two hours, with most of the students overlapping across the two sessions (student $n_{session1}=10$; $n_{session2}=8$). One staff member participated in the first session (anti-goal strategy), while four staff participated in the second session (7-problems-with-problems strategy).

The two strategies: The anti-goal strategy and the 7-problems-with-problems strategy

The *anti-goal strategy* (AG) instructs participants to consider the worst possible outcomes or scenarios that can be imagined or experienced in relation to the design aims. Initially a strategy used in engineering (van Lamsweerde et al., 2003), the AG strategy has shown potential to support students' insights as they work to strategize ways forwards for their everyday wellbeing (Dresser et al., 2021). An AG can be thought of as the antithesis or negation of what is considered the desired goal. Its utility is suggested to support the generation of desired goals by focusing on things they might dislike or want to avoid the most. In the case of justice-oriented higher education futures, as in this study, this means that participants in the first workshop collaboratively generated problematic goals that cause or lead to injustices or inequity, thereby creating a list of behaviours, practices, or activities that would reliably achieve the anti-goal of ensuring injustice in higher education. The second strategy, the *7-problems-with-problems strategy* (7PwP), was created by Ortiz Guzman (2021) through a series of industry-wide workshops and extensively critiqued the problem with problems for equity-focused design work by supporting participants to *understand* what these problems might be before going into problem identification and definition collaboratively. Some examples of the problems with problems identified are that the problem articulated is "just a symptom but treated as a root cause" (P4) or is "described at the level of individuals, absent institutional, systemic, or ideological factors that are also at play" (P5). In the second workshop, participants were briefly familiarized with the 7PwP statements before collaboratively generating problems of injustice and inequity in higher education.

Evaluating the problem statements

To evaluate each problem statement, collaboratively generated across the two workshops, we used the 7PwP rubric developed by Ortiz Guzman (2021). This rubric provided seven criteria to evaluate how these problem statements can better address social injustice (Table 1). Each statement was scored against each criterion, from 1 to 3, where a score of one means "Needs work", two means "Getting there", and three means "Close to the goal". Statements from both workshops were combined in the same spreadsheet, and their order was randomized, so the researcher doing the scoring could not identify the strategy used to generate each statement.

Table 1
Scoring criteria using the Seven Problems with Problems

Code	Definition
P1	Is your problem stated as the absence of a solution you wish to implement?
P2	Is your problem statement missing specific references to people?
P3	Does your problem implicitly or explicitly blame those experiencing the problem as having caused or being responsible for it?
P4	Does your problem treat a symptom as a root cause (unintentionally)?
P5	Does your problem focus on the problem at the individual or interpersonal level and miss the institutional, systemic, or ideological aspects?
P6	Does your problem statement forget to acknowledge the historical context of the issue?
P7	Are you trying to solve the problem for everyone or trying to solve all the problems at once?

Data analysis

To compare the difference between the distribution of the scoring of each criterion, for the AG and 7PwP tasks, we conducted a multinomial test. We tested the equality of the distributions considering the frequency of scoring of the AG task as our null hypothesis. We conducted Bayesian analysis, using the statistical software JASP (2022), with default priors. The strength of evidence for the null (H_0) or alternative (H_1) hypothesis was measured using Bayes Factors (B_{01}). A high value for B_{01} suggests stronger evidence for H_0 (here that there was no change between the distribution of scores from the two workshops), and a small value suggests stronger evidence for H_1.

Findings

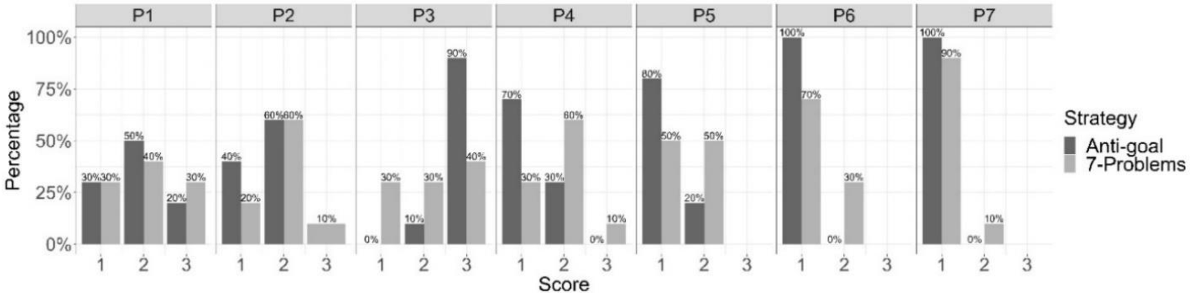
The results from the multinomial test show that there is moderate evidence that the distribution of the scores for the 7PwP has similar distributions to the scores of the AG strategy for P1(B_{01}=4.2), while there is very strong evidence that both have different distributions for all other criteria (B_{01}< 1/30). Overall, the problem generated in both strategies needed to be improved for criteria P5 to P7 (Figure 2). The 7PwP have slightly better performance overall, with a higher percentage of statements being classified as "Getting there" (2) or "Close to the goal" (3), in most criteria, except P3, where it is outperformed by the AG task. As an example, a statement that was scored for P4 (symptoms or root cause) as "needs work" is "unpaid internships as a requirement in the degree is the actual worst and so unfair in many ways" compared with a "close to the goal" statement scored example was "learning about our histories are sometimes truncated/ only get to learn part of an erased or amended history". The statement with the highest score (18, summed scores across the seven criteria) was from the 7PwP session:

> How we assign value to students as an entity in society: racism, and all other forms of prejudice as intersecting and disproportionately imposed in this. e.g., students as activists (climate strike, Black Lives Matter) - a form of surveillance, and assigning values, and expectations to those. (sic) And for some students are deemed problematic, but not others (e.g., racialized super surveillance) this happens to White allies as well as they 'take sides'. An attack on anything that might challenge the status quo.

The quote above was scored as "Close to the goal" (3), for P1 to P4, and as "Getting there" (2), for P5 to P7. In contrast, the statement with the lowest score (7) was from the AG: "introducing these issues early on in academic careers and not simply at the end of an undergrad class or something to opt-in." This statement is not a problem but a solution (P1) and also failed to address the other problems with problems, thereby scoring as "Needs work" (1) for all criteria.

Figure 2

Distribution of scores for each criterion, for the AG (46 problem statements) and the 7PwP (35 problem statements) tasks.



Discussion

Both the AG and the 7PwP strategies as a nuanced method to generate deeper problem statements in DT showed promise, while also indicating limitations as conducted in this study. Even though we used the 7PwP as *scoring criteria*, the 7PwP *task* did not produce deeper problem statements overall. Both the use of the AG and 7PwP strategies provided practical directions to generate problem identification, as well as further developing the articulation of the problem statement. We found that even though both strategies required improvement with the articulation of the problem statement in addressing the 7PwP criteria, the use of the 7PwP strategy slightly improved the depth, complexity, and quality of the problem statements, in particular, not treating the symptom as the root cause (P4). However, the AG strategy was more effective in avoiding attributing people experiencing the problems as being responsible for them (P3; 90% of AG statements, compared to 40% of 7PwP statements). This might be because of the nature of the AG strategy, which encouraged the focus on issues participants wanted to avoid or deny, which inherently meant overt consideration of the people impacted. The counter effect to this was that the AG strategy failed to generate problem statements that identified root causes, but rather were of symptoms.

Within two hours, the AG strategy was able to elicit a brainstorming style of problem definition. However, given the extent to which the AG generated inappropriate or misidentified problems, this strategy limits the depth and quality of problem definitions. This lack of depth was also observed in the 7PwP session, albeit less severe, suggesting that with more time, participants may further refine the problem statements in ways that address the 7PwP rubric more closely to the ideal statement. Thus, we suggest that following a brainstorming phase, there is a need to prioritize and expand the problem statements through deeper discussion and reflection. Combining elements of these two strategies may support the generation of more equity-focused problem statements that are less problematic for design thinking. Further, we observed that the problem statements generated in the AG session tended to exclude staff perspectives, unlike those in the 7PwP session. This suggests that an important design consideration is to ensure a diverse representation of the community involved in the context of the wicked problem so that the problems articulated include the multiple vantage points of people most proximate to the entangled problem. This is particularly important as we observed that if we only worked off the very student-centric AG statements, some of the proposed solutions might create additional burdens for other people in the same complex system of higher education (e.g., disability staff, academics), thus inadvertently creating or perpetuating further inequity and injustice. Whilst the two strategies used in this study continue to highlight the challenge of supporting people and communities in problematizing for speculative justice-oriented futures in their contexts, they offer some ways to deepen the process of justice-focused design thinking that much further.

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International Society of the Learning Sciences

Building Teachers' Digital Competence Through a Self-Reflection Process

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Abstract: Teachers' digital competence is a key element of the digital transition and transformation of education for quality teaching and learning. Education systems are seeking meaningful and effective professional development to support teachers build their digital competence. We propose a self-reflection process for teachers' professional learning and an online tool to facilitate this process. The SELFIEforTEACHERS tool uses the DigCompEdu framework as the conceptual reference for educators' digital competence. Personalised feedback generated by the tool can help teachers design their professional learning paths, while anonymous aggregated data can support plan professional development programmes. We implemented a pilot study to test the tool validity and reliability and collect preliminary data on its use. We are currently conducting a qualitative study to explore how the tool can be used effectively for the self-reflection process. This paper presents the conceptual approach of the project, while empirical results will be shared in future papers.

Introduction

Digital transition and transformation of education for quality teaching and learning has been a high priority in national and regional strategies. The COVID-19 health crisis revealed what research had already shown: not all schools and teachers are ready to use digital technologies to provide quality online and remote learning (OECD, 2021). According to the Teaching and Learning International Survey (TALIS) in 2018, only 43% of the participating teachers felt well or very well prepared in the 'use of ICT for teaching' (OECD, 2019). The teaching profession requires educators equipped with the necessary competences to respond to rapidly changing demands for teaching and learning. Thus, there has been an increasing need to find ways to support teachers' professional development to harness benefits and opportunities, as well as deal with challenges that digital technologies present to education.

To provide meaningful and effective professional development, learner-centered pedagogical approaches are emerging. Boeskens et al. (2020) use the term 'professional learning' to distinguish more active and contextualised forms of learning, with emphasis to the teachers' active role and own agency as reflective professionals. Reflection is perceived as a "personal process that can deepen one's understanding of self and can lead to significant discoveries or insights" (Desjarlais & Smith, 2011). It can trigger self-assessing one's capacity in order to improve it. Important aspects of successful self-assessment incorporate the measurement against a model, which can provide a benchmark for identification of further development priorities, as well as acting upon the results (Hillman, 1994). In our case, we used the European framework for the Digital Competence of Educators (DigCompEdu) as the conceptual reference for educators' digital competence (Redecker, 2017).

In this short paper, we present a comprehensive approach for building teachers' digital competence, encompassing self-reflection as a learning process and an online tool to facilitate this process. We will share empirical results of the proposed approach in future papers.

Conceptual approach

In the recent European Commission Education Action Plan 2021-2027 (DEAP), digital competence is considered a core skill for all educators that should be embedded in all areas of teacher professional development (European Commission, 2020). The launch of an online self-assessment tool for teachers based on the DigCompEdu has been foreseen in one of the actions.

Taking into consideration the DEAP, the research team endorsed two posits: first, that self-reflection as a process can support teachers' professional learning; second, that DigCompEdu framework can serve as the conceptual framework to benchmark educators' digital competence. The goal is to address the need for effective professional development to foster digitally competent primary and secondary teachers across Europe, by developing an up-to-date, valid and reliable online tool for teachers, based on DigCompEdu. The tool is an integral part of a comprehensive professional learning process based on self-reflection.

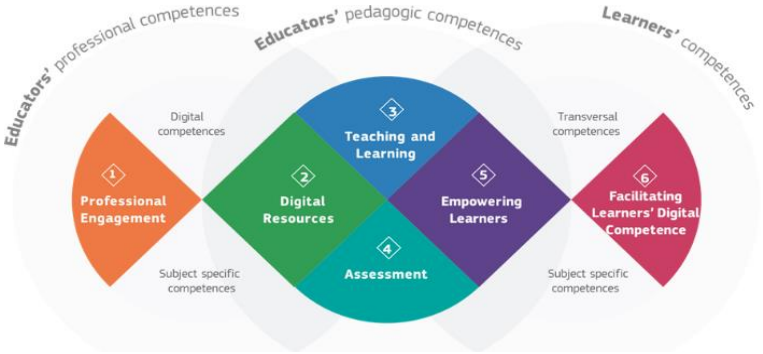
To achieve our goal we: analysed existing self-assessment tools based on conceptual frameworks; explored self-reflection as a learning process for teachers' professional learning; performed a content analysis of DigCompEdu in relation to up-to-date pedagogical trends literature; adapted DigCompEdu content to primary and secondary teachers' professional practices; designed and developed an online tool to guide teachers' self-reflection, providing personalised feedback with suggestions how to level up; suggested a process to support teachers' designing their professional learning; ran a pilot study to test the tool validity and reliability; are investigating how the tool can be effectively used at both process level and outcomes level; will analyse aggregated data to measure the tool impact; and will explore the adaptation of the tool to other education contexts.

DigCompEdu

Digital competence is one of the eight key competences for lifelong learning and is approached as a combination of knowledge, skills and attitudes, for "confident, critical and responsible use of, and engagement with, digital technologies for learning, at work, and for participation in society" (European Council, 2018, p. C189/9). To describe educator-specific digital competences, the DigCompEdu framework has been developed. It is the result of work at the European Commission, which brought together experts from across Europe to reach a common understanding and provide a comprehensive model for describing educator-specific digital competences (Redecker, 2017). DigCompEdu has been widely used by educational systems, researchers and education stakeholders to support national frameworks and strategies, assessment tools, education and training programmes, and educational resources.

DigCompEdu describes 22 educator-specific digital competences in six areas, with emphasis on the pedagogical competence of using digital technologies to enhance teaching and learning. It involves educators' digital competence in their professional context and their competence to facilitate the development of their learners' digital competence (see Figure 1). The framework proposes a progression model with six stages through which an educator's digital competence typically develops for each of the competences.

Figure 1
The DigCompEdu framework (Redecker, 2017; CC license)



Several self-assessment tools have been developed to help measure teachers' competence. For example, the MENTEP TET-SAT (1), a tool developed as part of a policy experimentation project and the CheckIn tool (2), an experimental tool based on the DigCompEdu framework, used, adopted or adapted in various research projects, as in work with teachers in Germany (Ghomi & Redecker, 2019), Portugal (Lucas et al., 2021), Morocco (Benali et al., 2018), Switzerland (Cattaneo, 2021), and Southeastern Europe (Petrovic, 2021). SELFIEforTEACHERS advances beyond the CheckIn tool, enriching its content with current trends and validating its internal and external validity with a pilot study.

The self-reflection tool and process

To design and develop the self-reflection tool the research team performed a content analysis of DigCompEdu to adapt it specifically for primary and secondary education teachers in Europe. The framework 22 competences were studied and deconstructed through their descriptors and activity examples provided. They were then transformed into statements with examples relevant to teacher practice to facilitate their understanding of the framework and guide their self-reflection (Economou, 2023). The tool comprises 32 self-reflection items (corresponding to the framework competences, parts thereof, or emphasising aspects of teachers' digital competence based on emerging educational needs) (see Figure 2). Each item provides an introductory statement describing what the corresponding competence is and six proficiency level statements - based on the DigCompEdu progression model - from which teachers can choose the one that best captures their competence level. The tool also generates a personal report for each teacher with results and feedback with suggestions on how to level up.

Figure 2

Tool self-reflection items and competence areas

PROFESSIONAL ENGAGEMENT

- 1.1 Organisational communication
- 1.2 Online learning environments
- 1.3 Professional collaboration
- 1.4 Digital technologies and school level infrastructure
- 1.5 Reflective practice
- 1.6 Digital life
- 1.7 Professional learning (through digital technologies)
- 1.8 Professional learning (about digital technologies)
- 1.9 Computational thinking

DIGITAL RESOURCES

- 2.1 Searching and selecting
- 2.2 Creating
- 2.3 Modifying
- 2.4 Managing and protecting
- 2.5 Sharing

TEACHING AND LEARNING

- 3.1 Teaching
- 3.2 Guidance
- 3.3 Collaborative learning
- 3.4 Self-regulated learning
- 3.5 Emerging technologies

ASSESSMENT

- 4.1 Assessment strategies
- 4.2 Analysing evidence
- 4.3 Feedback and planning

EMPOWERING LEARNERS

- 5.1 Accessibility and inclusion
- 5.2 Differentiation and personalisation
- 5.3 Actively engaging learners
- 5.4 Blended learning

FACILITATING LEARNERS' DIGITAL COMPETENCE

- 6.1 Information and data literacy
- 6.2 Communication and collaboration
- 6.3 Content creation
- 6.4 Safety and wellbeing
- 6.5 Responsible use
- 6.6 Problem solving

Through guiding self-reflection statements, teachers identify strengths and gaps in their digital competence. Upon completing the session, they are prompted to take action for further development. As critical self-reflection can lead to engaging in strategies for continuing personal, professional and career development (setting goals for example) (Cheng et al., 2015), teachers are encouraged to design their own professional learning paths to further develop their digital competence.

SELFIEforTEACHERS aims to involve teachers in self-reflection at three stages: reflect on their professional practice and self-assess their digital competence guided by the tool items; reflect on their results and the tool feedback to plan their professional learning paths; and reflect on the whole process and their progress.

The self-reflection learning process suggests a spiral of six steps: (1) Complete a self-reflection session; (2) Analyse the personal feedback report; (3) Design professional learning path; (4) Implement the learning path (e.g. participate in a training course, join a community practice); (5) Apply new competences in professional practice; and (6) Repeat the self-reflection to monitor progress.

Tool validation

To validate the tool we implemented a pre-pilot with 795 teachers in two countries (Italy and Portugal) during December 2020 and January 2021, and a pilot study with 3218 teachers in five countries (Estonia, Italy, Lithuania, Portugal and Ireland) in April 2021. Psychometric statistics verified the competence areas and progression levels as proposed by the DigCompEdu framework, and the validity and reliability of the 32 items for each of the areas. A follow-up study, using quantitative and qualitative methodologies, explored user perceptions about the tool and the self-reflection experience.

The pilot study confirmed that the SELFIEforTEACHERS tool is valid and reliable for primary and secondary teachers to self-assess their digital competence. Factor analysis confirmed a good fit for the suggested six-factor model of teachers' digital competence. Confirmatory Factor Analysis (CFA) did not suggest any changes to the dimensionality (factor structure) of this construct; all items had good - or at least satisfactory - factor loadings. Correlation analysis did not reveal significant overlap between any two items in the self-reflection tool and none of the item pairs correlated highly with each other.

The follow-up study analysis confirmed that a large majority of participants were satisfied with the self-reflection experience, the online tool user-experience, the items, the help texts and the feedback report. Analysis of qualitative data showed that participants found the tool relevant to their job and professional development and felt motivated to proceed with planning professional learning based on the tool feedback report.

Discussion and future directions

The study proposes a comprehensive approach to support building teachers' digital competence. It entails an online tool and a self-reflection process to empower teachers' active engagement and agency in assuming a central role in their professional learning, by capturing their current digital competence and initiating and designing their learning pathways. They are empowered to take ownership of their professional learning and development and act as reflective practitioners, identifying their own training needs and mapping out their learning pathways in a context of autonomous lifelong learning (European Commission, 2007). At the same time, it provides policy makers, teacher educators and trainers, and school leaders with a tool for teacher professional development programmes as well as anonymised aggregated data to support policy planning.

The online tool developed is valid and reliable. At the current stage of the study, we are investigating how the tool can be effectively used. Through a network of experts across Europe we explore in various *use cases* how the tool can help different stakeholders support building teachers' digital competence. We are also designing twelve cases studies in six countries to investigate the factors that can play a role during the tool use, and how participating teachers' digital competence might change. We will then analyse the aggregated data to investigate what impact the tool may have on teachers' digital competence.

Through the whole process, we also expect to identify contextual factors, such as systemic, institutional, cultural and personal, that might have an influence on the tool use and how, contributing to research on teachers' digital competence in relation to personal and contextual factors. Based on the study results, we will explore the adaptation of the tool to other education sectors and different contexts (e.g., specific teacher groups based on subject matter, regions, and roles).

Endnotes

(1) MENTEP TET-SAT, http://mentep.eun.org/tet-sat
(2) DigCompEdu CheckIn tool, https://joint-research-centre.ec.europa.eu/digcompedu/digcompedu-self-reflection-tools_en

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Toward A More Comprehensive Definition of Collaboration: Scholarly Literature vs. Practitioners

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Abstract: Collaboration is a core component of collaborative learning. However, the definition of collaboration still lacks consensus and differs across disciplines. Therefore, this study aims to provide a comprehensive definition of collaboration that is generalizable across different contexts. We gathered the definitions of collaboration from 52 scholarly articles and 22 focus group interviews with 87 practitioners. We found some alignments and gaps between scholarly articles and practitioners regarding the collaboration definition. The study underscores the need for bridging gaps in defining collaboration between research and practice to provide a complete picture of collaboration in collaborative learning environments. A comprehensive definition of collaboration creates opportunities for the development of transferrable assessments, rubrics, instructional supports, and technology.

Introduction

Collaborative learning is a commonly used instructional approach across various domains of work. Research has found that collaborative learning has the potential to improve learners' conceptual understanding, motivation to learn, and metacognitive skills (e.g., Hatami, 2015). Regardless of the potential positive impact of collaborative learning, many scholars have agreed that the core component of collaboration still lacks a coherent definition. Thomson et al. (2009) argued that this coherence issue is due to the varied definitions of collaboration across disciplines. Patel et al. (2012) echoed such a concern that "for a concept so widely used in everyday language, there is a surprising lack of a clear understanding of what it is to collaborate, and of how best to support and improve collaborative working" (p. 1). Bedwell et al. (2012) contended that, etymologically, collaboration is a vague and elusive concept. It stems from the Latin word *collabore* referring to "to labor with or together" (Lewis & Short, 1879, p. 365), which can be interpreted in many ways across disciplines. Sundaramurthy and Lewis (2003) added that many collaboration definitions do not include a description of what the process of collaboration looks like. Therefore, when different definitions of collaboration are translated into classrooms and workspaces to build professional skills and support learners, educators and practitioners do not operate from the same conception of collaboration and therefore demonstrate varied implementation approaches.

The lack of a common collaboration definition may be due to the gaps between scholarly literature on collaboration and how practitioners define and implement collaboration. Identifying these gaps is crucial to bridging discrepancies and ambiguities. It may also aid in moving toward a more comprehensive definition of collaboration that is applicable across disciplines. Therefore, this study aims to investigate such gaps by conducting a systematic literature review of scholarly articles and interviewing individuals across different fields to gather data on how they define and operationalize collaboration. The following research questions guided this study: (1) How does scholarly literature define collaboration?, (2) How do practitioners define collaboration?, and (3) What are the intersections and gaps between scholarly literature and practitioners' definitions of collaboration?

Methods

This study employed a grounded theory approach to develop an in-depth and comprehensive understanding of collaboration definitions across different disciplines (Strauss & Corbin, 1998). We conducted a systematic literature review and a series of focus group interviews to gather data on how scholarly literature and practitioners define collaboration (1). For the systematic review, we started with a keyword search in the ERIC database using the term "collaboration" from any papers published in any journals and any disciplines (e.g., humanities and social science, medicine and health, and STEM) (Gough & Thomas, 2012). This search resulted in a total of 6400 publications. We then used random and theoretical sampling approaches to collect any definition of collaboration from the papers. We adhered to two exclusion criteria: papers that 1) cited others' definitions of collaboration, and 2) restricted access to full papers. We collected and qualitatively coded the data. We reviewed 52 papers and we did not find any new categories until reaching theoretical saturation.

We also recruited 87 participants (22 groups with three to four members each) for the focus group interviews. The participants represented a wide range of ages, races, and occupations. The focus group participants were students and professional practitioners that use collaboration in their educational and professional interactions. The mean age was 32 (*SD*=10). Participants identified racial groups included 43% Asian/Pacific Islander, 17% Hispanic/Latinx, 37% White, and less than 1% Black/African American and other. Participants' occupations varied and included fields such as academia (e.g., students, teachers, researchers), corporate (e.g., business analysts, attorneys), and technical fields (e.g., engineers). The participants engaged in an hour of collaborative activity and were subsequently interviewed for approximately 15-20 minutes. Focus groups were recorded and transcribed verbatim.

We used open and in-vivo coding processes (Creswell & Poth, 2018) to analyze the definitions of collaboration from scholarly literature and transcriptions of focus group interviews. Three researchers were involved in the qualitative coding process and modifications and generation of the initial and final coding scheme. Table 1 presents the modified coding scheme consisting of elements of collaboration that were used to define collaboration.

Table 1

Elements of Collaboration Definition (Note: % = percent of papers and focus groups for each element)

Element	Sub-element	Description	% Papers	% Groups
Input	Joint/group effort	More than two individuals jointly working.	81%	91%
	Complementary expertise	Everyone brings their expertise to ensure efficiency (e.g., knowledge and experience).	21%	77%
	Task/problem solving skill complexity	The tasks or problems faced require multiple skills, knowledge, or experiences.	4%	18%
Process	Knowledge/ resources sharing	The process of information exchanges.	23%	0%
	Workload decomposition	The process of decomposing tasks and workload for efficiency.	0%	23%
	Conflict negotiation and resolution	The process of exploring and resolving differences.	8%	45%
	Shared decision-making	The process of collective conclusions or solutions for problems.	19%	14%
	Layered decision-making	The process of evaluating the conclusion, including monitoring and regulating the shared knowledge and/or outcomes.	6%	0%
Norms	Shared goals	Belief in achieving or solving one or multiple common goals.	63%	68%
	Reciprocal engagement	Everyone actively contributes to all processes and interacts with each other.	19%	14%
	Responsible and accountable	The degree to which members can justify any roles/actions/decisions they are assigned to.	13%	14%
	Mutual trust and respect	Everyone believes in each other's strengths.	21%	9%
	Non-hierarchical (shared power)	Involving a shared power and authority, or everyone is considered equal.	17%	5%
	Voluntary participation	Everyone has the willingness to contribute/participate.	6%	14%
Output	Quality outcomes	The end goal is to produce better or different solutions/outputs than working alone or gain new knowledge and skills.	6%	45%

Findings

How does scholarly literature define collaboration?

Based on the findings of the systematic literature review shown in Table 1, we found that most papers included *joint/group effort* and *shared goals* within the elements of Inputs and Norms when they defined collaboration.

This is not surprising since a common definition of collaboration is working together toward a common group goal. In addition to this definition, many papers proposed more extended definitions of collaboration to include Processes and Outputs as elements of collaboration. For example, Friend and Cook (1992) defined collaboration as:

> …a style for direct interaction between at least two co-equal parties voluntarily engaged in shared decision making as they work toward a common goal… [and has characteristics of] voluntary, individuals who collaborate share a common goal, requires parity among participants; includes shared responsibility for decisions; share accountability for outcomes among individuals; includes sharing resources; emergent characteristics. (p. 5)

Although this definition is robust, it omits various sub-elements from Norms, Processes, and Outputs, such as *mutual trust and respect*, *conflict negotiation*, and *quality outcomes*, that other papers included in their definitions of collaboration. For example, Scoular et al. (2020) defined collaboration as involving "perseverance, contributing to team knowledge, valuing contributions of others and resolving differences… a division of labor with participants who are engaged in active discourse that results in a compilation of their efforts" (p. 2). Still, this definition does not cover sub-elements other scholars consider necessary when defining collaboration.

We also found that very few papers (*n*=3) included sub-elements *quality outcomes* of collaboration and *layered decision-making* as elements of collaboration. In summary, there was no clear consensus on how to define collaboration. Each paper provided a different definition of collaboration with emphases made to different sub-elements, as shown in Table 1.

How do practitioners define collaboration?

Based on the findings of the focus group interview analysis shown in Table 1, we found that when defining collaboration, most groups emphasized three sub-elements: *joint/group effort*, *complementary expertise*, and *shared goals.* These sub-elements are seen in Groups 5 and 15's definitions: "two or more people who are working together towards a common objective" and "help(ing) each other to get a better advantage, especially understanding the different group members' strengths and weaknesses and how can you, like, supplement each other…. [to] accomplishing the same goal." Furthermore, we found that some groups emphasized *task/problem solving skill complexity* and *workload decomposition* as sub-elements. For instance, Groups 3 and 2 stated that collaboration should include tasks that require collective efforts and a process of "many people try[ing] to reach the goal altogether, dividing on the task, and make the load easier for each member of the group." In addition to *workload decomposition*, participants mentioned *conflict negotiation and resolution* as important for collaboration. Unlike the scholarly literature, many groups mentioned Output when defining collaboration. Specifically, they identified *quality outcomes* as being a collaboration product.

Although, the focus group participants defined collaboration using all the elements of collaboration, we found that many sub-elements were not mentioned. For instance, none of the groups described *knowledge and resource sharing* or *layered decision-making* as sub-elements to Process. Additionally, very few of the groups touched on some of the sub-elements to Norms, like *mutual trust* and *non-hierarchical (shared power)*.

What are the intersections and gaps between scholarly literature and practitioners' definitions of collaboration?

Based on the intersections of various definitions of collaboration, Figure 1 shows the concept of collaboration bringing together elements of Input, Process, Norms and Output. We brought ideas from research papers and focus group practitioners together to construct a description of collaboration: *A complex process through which a group of individuals interdependently and constructively explore ideas to search for solutions and construct new knowledge. As individuals work interdependently, they create a socio-cognitive space where goals, ideas, beliefs, and plans are collectively generated and shared among the members in the group. The socio-cognitive space includes the sharing of tools and promotes learning that extends one's own limited vision to create high quality products.*

Figure 1
Integrated concept of collaboration.

Discussion and Significance

Our findings show that while there are intersections of how research and practitioners define and operationalize the concept of collaboration, they also show that there are gaps between research and practice. Research literature and focus group participants generally agreed on the Inputs and Norms of collaboration and varied on Process and Outputs of collaboration. Research literature emphasized *sharing knowledge and resources* while focus group participants emphasized *conflict negotiation and resolution* and *quality outcomes*. Perhaps practitioners are more interested in a functional production of artifacts while researchers may be more interested in gaining new knowledge and making intellectual contributions to their fields. Our study helped us put together a definition of collaboration that incorporates multiple elements of collaboration that can be used across disciplines and in various settings, like in online collaboration and face-to-face collaboration. Having a comprehensive definition of collaboration creates opportunities for the development of transferrable assessments, rubrics, instructional supports, and technology. Future work would require an expanded analysis of additional practitioners, until saturation is reached more broadly.

Endnotes

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International Society of
the Learning Sciences

“So, They Said Harder Math, Right?”
Youth Pedagogical Development in Youth Teacher Debrief Sessions

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Abstract: This study explores how young people, aged 14-22, employed as facilitators of math learning for younger children in an out-of-school time organization, talk with each other about their experiences as they participate in a routine known as “debriefs.” Debriefs occur between facilitation sessions and allow opportunities for youth to discuss mathematical ideas and understand their roles as facilitators. They also provide space for youth to begin planning the next facilitation. Through interaction analysis of one typical debrief session, we offer implications for understanding how debriefs contribute to the unique ways that young people develop their pedagogical approaches—a process we call “youth pedagogical development.”

Introduction

This study takes seriously the idea that young people can be effective intellectual leaders in formal and informal STEM learning contexts, among others. As facilitators of STEM learning, young people learn to teach and develop positive identities as leaders and as STEM doers. We call these processes of identity development and learning that occur while youth are engaged in disciplinary teaching *youth pedagogical development* (Yu et al., 2023). In this case, we analyze how young people reflect on their facilitation of mathematics learning for other young people during debriefs, and how debriefing contributes to youth pedagogical development. The near-peer teaching program we discuss in this paper, The Young People’s Project (YPP), is a grandchild of the organizing practices of the Student Non-Violent Coordinating Committee (SNCC) (Moses et al., 1989). In SNCC practices, organizing is carried out in collaboration with, and eventually led by, the hands, hearts, and minds of the people who will be most impacted by the goals of that organizing. It is grassroots and collaborative. Leadership is decentralized. Likewise, the debriefs we describe below are learning and organizing tools rooted in the freedom movement in 1960s Mississippi and elsewhere.

Literature review

Taking various forms, teacher reflection practices are often studied in teacher education as ways to improve teachers’ pedagogy (e.g., Liu & Ball, 2019). An important component to engaging in reflection is for teachers to be able to identify and make connections between events and pedagogical principles, and notice contexts in which events occurred (e.g., van Es & Sherin, 2021). In preservice settings, opportunities for collaborative reflection have been shown to be crucial to preservice teachers’ development and self-perceptions as facilitators and future classroom teachers (Jao et al., 2020)..Our study explores reflection among multiple youth who all taught together, as opposed to groups of people debriefing one person’s pedagogy as is the case in many schoolteacher reflection sessions. We pay particular attention to how youth at YPP take up their own configuration of semi-structured verbal debriefs regarding their teaching of mathematics to elementary school-aged children. We orient to the exploration of young people’s engagement in debriefs through an emerging framework, detailed below, that we call *youth pedagogical development* (Yu et al., 2023).

Theoretical framework: Youth pedagogical development

Youth Pedagogical Development (YPD) helps explain how youth learn to teach as they engage with disciplinary ideas and attune to pedagogical strategies that support learning and engagement for others. Youth’s engagement also transforms the ways in which they come to identify as teachers, learners, and doers of, within, and across academic disciplines (Tucker-Raymond et al., 2016). We conceptualize development as the socially, culturally, and historically situated processes through which individuals learn together in joint activity and, in so doing, transform those processes (Vygotsky, 1978). To further theorize YPD, we highlight its interrelated components—identity; learning and doing; teaching; and disciplinary ideas, literacies, and practices. At the core of YPD are identities. Identities are situated within specific social practices and developed over time as part of social interaction with others (Nasir & Cooks, 2009). Oftentimes, young people employed as facilitators in informal environments are not experts in whatever it is they are supposed to teach. In YPD, teaching and learning are explicitly interrelated processes in which there is a short period of time between the time when young people learn about and engage with disciplinary ideas, practice what they are going to teach, and then teach others. Therefore, new youth teachers, leaning on more experienced ones, learn alongside the children they are supposed to be "teaching." This component of YPD disrupts normative distinctions between "teacher" and "learner." Finally, in YPD, disciplinary ideas, literacies, and practices, are thought of more expansively than in schools. For instance, the mathematics in this study is solely taught and learned through games. Pedagogical goals are concerned with *familiarizing* learners with ideas and helping them feel comfortable exploring them. It is important to note that YPD will look different in different youth teaching contexts because the relationships between the commitments, practices, and engagements of each unique organization and the youth teacher participants will be different.

Research question

How does participation in a YPP debrief session contribute to youth educators' pedagogical development?

Methodology

The data in this paper come from a multi-year study of youth teaching in three organizations, including YPP. YPP employs predominately students of color from local high schools and colleges to serve as Math Literacy Workers (MLWs) and College Math Literacy Workers (CMLWs), respectively (collectively, C/MLWs). The C/MLWs work together to design mathematics workshops for elementary- and middle-school aged students in local public schools and camps during the academic year and summer. After outreach workshops for younger students, the C/MLWs engage in a reflective practice called a "debrief." The C/MLWs in this paper were part of a smaller group at YPP that visited a summer camp for children ages 4-13 run by a community organization. These C/MLWs provided an hour or so of programming two times a week. The group included two CMLWs, both of whom had been MLWs, and eight MLWs, all of whom were in their first year at YPP. These C/MLWs were tasked with introducing a game to the campers called Flagway™. Flagway (see typp.org) is a timed, competitive game in which participants categorize numbers based on characteristics of their prime factorizations and then run a physical course based on their answers. Activities leading up to the final Flagway game are meant to break down into parts the mathematics ideas needed for the final game.

Data for the larger project were collected through participant observation and interviews during Summer 2021 and Spring and Summer 2022, for a total of roughly 200 hours across sites. We identified 31 instances where our data sources from YPP mentioned "debrief" or "reflection." For this paper, we focus on illustrative examples from one, approximately 15-minute-long debrief. This debrief occurred after the third visit to the summer camp. We engaged in an interaction analysis protocol as a team of seven (Jordan & Henderson, 1995). We created themes based on our noticings and discussions while listening to the audio file and reading the transcript of the debrief. Our ongoing analysis had clued us in to how debriefs reflect the four tenets of YPD (i.e., identity, teaching, learning, doing). Therefore, in our deductive coding, we highlighted moments in the transcript that demonstrated one or more of these tenets. We then wrote analytic memos for each of the themes that emerged as most prominent. Two of these themes are presented here due to limited space. Each member of the team checked and edited the analytic memos.

Findings

During the last 15-20minutes of their summer workday, the C/MLWs typically debriefed that day's workshop in some detail. The debriefing process at YPP served as both reflection of the day's teachings in meeting the learning goals as well as planning for the next outreach lesson. Debriefs were not only opportunities to think about what worked with participants, but also to debate ideas, including mathematics, for themselves. At the debrief that is the focus of this paper, the C/MLW team sat together in a room while one CMLW acted as notetaker on a chalkboard. As the MLWs shared pluses, minuses, and deltas (i.e., changes to make), the CMLW wrote their responses on the chalkboard. As was typical, CMLWs led the conversation, facilitated MLW contributions, and then made contributions based on their own observations of the outreach activities. Next, we share illustrations of young people learning to teach at YPP during one debrief. We focus on two themes: 1) learning and teaching mathematics ideas as interdependent processes, and 2) learning to decenter the self in favor of collective responsibility. The excerpt begins with conversation among a few MLWs while Adri (CMLW) is at the front of the room getting organized to facilitate the debrief.

1 Nate: They wanted, like, something harder.
…
3 Garvey: Do multiplication then!
4 [Laughing from elsewhere.]
5 Nate: Yeah, no, we did multiplication. They wanted something, like, more than that.
…
9 Garvey: Do some factor tree races. That's… if we struggle with that, 9th graders struggle…

10 Nate: They're actually smart like… some of the kids are just smart
…
14 Adri: So, they said harder math right?
15 Nate: We could do, like, factor tree races 'cuz, like, aren't we supposed to teach them Flagway?
…
21 Adri: They wanted… they wanted multiplication.
22 Josiah: Yeah.
23 Nate: I mean, factor tree races are basically multiplication.
24 Cesar: It is. But it's also division, too.
25 Nate: But like that's the same…

In the beginning of the conversation two MLWs, Nate and Garvey, discussed different possibilities for mathematics activities they could use with the workshop participants the next time they went to that site for outreach. This time, they had played games related to finding and sorting prime and composite numbers. The conversation beganresponsively, when one MLW noted that the participants "wanted something harder." They then engaged in a brainstorming of how "harder math" might be embodied in different activities. As they debated which mathematical activities might be "harder," they also recognized themselves as learners, "if we struggle with that." That is, the debriefing offered them an opportunity to reflect on their own mathematical learning by juxtaposing it with that of the younger participants, all while recognizing the students in asset-based ways ("they're actually smart").

In [14], Adri responded to the talk among the MLWs. As Nate and Garvey were talking, she overheard some of what they were saying and used it to direct the conversation. She then affirmed that factor tree racing was a good activity because it was next in the sequence of ideas in which they were engaging participants to learn Flagway. As the experienced CMLW, she had a sense of the larger scope and sequence of activities, rationalizing the choice as serving the larger pedagogical purpose, not just making it harder. Nate and Cesar in [23] and [24] discussed whether factoring is multiplication or division, if multiplication and division are the "same thing," and whether that suffices to meet the needs of the students they were serving who requested "harder math" [14]. Being positioned as teachers pushed them as learners to grapple with relationships between mathematical patterns in multiplication, division, and factoring. In the following excerpt from the debrief conversation, two CMLWs in the group, Adri and Dion, emphasize learning to decenter the self in favor of collective responsibility.

35 Adri: Anything else? I think the transitioning inside [the community center] to outside [in the adjacent park] didn't work very well. Everybody wanted to go back inside. [MLWs: Yeah.] It was hot outside, everybody wanted to go back inside.
36 Dion: That's another thing. CMLWs, MLWs, it's hot outside, we know it's hot outside. Kids don't want to be out there just as much as you don't. So, there should be no reason you're like, "Oh, it's hot outside, I can't participate, I don't want to participate." We're all on the same page on that one.
37 Adri: Transitions. Oh yeah. I'm thinking if we're trying to do—first of all, like to begin with, once y'all see the kids immediately you should be like gathering them to, to be in like a circle or something so that whoever's facilitating can start, right? So, like we saw all the kids coming out and going into the playground, you should have immediately directed them…even if it's not your activity, but we're all supposed to be circling up and so therefore it just makes it run smoother for whoever's facilitating, for everyone to be on the same page and everyone to get into the circle. And you can do that through modeling.
38 Dion: And then knowing what's being facilitated. All of us should know how to facilitate the activities.

Adri and Dion solicited ideas from MLWs regarding what they felt was significant about their time in the workshop and were now making their own suggestions about what they felt was important. As MLWs were learning to attune to critical self-reflection, the CMLWs called their explicit attention to identities-in-practice, identities that were collective as well as personal. Until they started facilitating workshops at YPP, most of the MLWs had been only students in learning settings. In outreach they were asked to take responsibility for the learning of others. It was their job. Dion signaled this shift in [36]. It was a shift in identities–who they were to be and to whom they were responsible (each other and the workshop children). Before the workshop they had created the lesson plan and assigned each other sections of the workshop so that leadership roles were distributed. Different people would lead the ice breaker, main activity, and the closing with the younger students. However, once in the workshop, Adri also drew their attention in [37] to how they could influence how the workshop went even if they were not leading a section. In [38] Dion emphasized collective responsibility again when he said that "all of us should know how to facilitate the activities." In part, this collective responsibility meant recognizing that what one might be feeling as an individual (e.g., "hot") is an experience that many other people are having. It also means not prioritizing oneself over group goals. In both of his statements, his use of "we" and "us" signaled his own and other C/MLWs' membership in that group. In doing so, he modeled his own responsibility to the collective in the debrief (Brewley, 2012).

Discussion

We highlighted two themes in this paper: 1) learning and teaching mathematics ideas as interdependent processes, and 2) learning to decenter the self in favor of collective responsibility. Through these two themes, we show how YPD is distinct from models of learning and development related to learning to teach in schools. Debriefs like the one analyzed here offer opportunities for youth to reflect on and plan for the ways they organize others to learn mathematics. Here, we emphasize the organizing aspect of YPP as distinct from traditional models of teaching. Within a typical school system, teachers organize students to do the learning. At YPP, young people organize themselves and others as both learners and as teachers. When participants are learners *and* teachers, authority is distributed, and identities are fluid. With multiple people to learn from and alongside, MLWs can find their own style of leadership and organizing without the high stakes of being solely responsible for workshop activities or children's learning. The collective offers a safety net for trying out roles and identities. C/MLWs are responsible for one another's success. Commitments like distributed authority and collective responsibility are orientations toward teaching drawn from the organizing practices of SNCC (Moses et al., 1989). Ultimately, YPP does not develop individual teachers. YPP develops practices of teaching and learning (e.g., debriefs) as key aspects of YPD.

Conclusion

Youth's identities as learners and teachers, their investment in their pedagogical improvement, and their commitment to understanding mathematics ideas are integral parts of YPP debriefs. These and other aspects of debriefs not highlighted here due to space constraints help us to characterize how young people learn to teach, what we call YPD, by connecting their development to organizational commitments and practices. Debrief sessions like the one described here offer opportunities for C/MLWs to socialize one another into YPP's commitments and practices. Distinct from teacher pipeline programs, YPP's main purpose is to help young people to organize themselves around mathematics, much in the same way SNCC helped people in Mississippi organize around voting rights. An implication for understanding identities and learning as part of YPD at YPP is not just that youth teachers are individuals becoming STEM doers and teachers, but that they are doing so for collective empowerment and movement building.

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“Where is the Z-Axis?”: Negotiating Understanding of Servo Rotation Through Gestures and Tools

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Abstract: Understanding abstract concepts in mathematics has continuously presented as a challenge, but the use of directed and spontaneous gestures has shown to support learning and ground higher-order thought. Within embodied learning, gesture has been investigated as part of a multimodal assemblage with speech and movement, centering the body in interaction with the environment. We present a case study of one dyad’s undertaking of a robotic arm activity, targeting learning outcomes in matrix algebra, robotics, and spatial thinking. Through a body syntonicity lens and drawing on video and pre- and post-assessment data, we evaluate learning gains and investigate the multimodal processes contributing to them. We found gesture, speech, and body movement grounded understanding of vector and matrix operations, spatial reasoning, and robotics, as anchored by the physical robotic arm, with implications for the design of learning environments that employ directed gestures.

Introduction

Within the growing literature on embodied learning in mathematics, gesture has been investigated as part of a multimodal assemblage with speech and movement (e.g., Alibali & Nathan, 2012), centering the role of the body in interaction with the environment. The use of directed and spontaneous gestures has shown to support learning and has been especially useful for grounding abstract concepts, which have continually presented as a challenge (e.g., Pier et al., 2019). Though extant work has focused on children’s use of gesture and its implications for mathematics learning (e.g., Abdu et al., 2021), few studies have explored students’ use of gesture as part of their sense-making process toward understanding of specific domain knowledge in mathematics within higher education. Engaging the body along with and beyond the use of gesture and speech, in interaction with physical artifacts, is another aspect of existing research that has been left underexplored, yet holds the potential to reveal much about students’ learning processes in mathematics (Robutti et al., 2022).

This paper is a case study of one dyad’s undertaking of a robotic arm activity targeting learning outcomes in matrix algebra, robotics, and spatial thinking. We designed the activity to assess participants' growing understanding of vector and matrix operations, spatial reasoning, and robotics, as they manipulated the robotic arm and calculated its end coordinates. This exploratory pilot study adopts a constructionist learning theory lens of body syntonicity and takes on a mixed methods approach to address the following research questions: *To what extent did the robotic arm activity inform student learning gains in mathematics? How did gesture, speech, and the body contribute to these learning gains across dimensions (i.e., vector and matrix operations, spatial reasoning, robotics)?* Two out of the four participating groups who observed the largest learning gains from pre- to post- test engaged gesture and the body in their sense-making. We selected one of the groups to theorize the processes that contributed to the observed learning gains, with implications for the design of learning environments that employ directed use of gesture.

Background

Within the literature on embodied learning in mathematics, extant work has considered the role of multimodal dialogue of small groups for learning mathematics (Abdu et al., 2021), the role of teachers’ gestural use in improving math understanding (e.g., Nathan et al., 2017) and increasing learners’ visual engagement (Farsani et al., 2021), and the design of technology-integrated tools to support embodied interactions in math learning (Abrahamson, 2009). With mathematical ideas inherently metaphorical (Lakoff & Núñez, 2000), gesture has been found to be especially helpful for grounding abstract concepts calling for higher-order thinking. For instance, Pier and colleagues (2019) investigated undergraduate students’ multimodal use of gesture and speech in mathematical reasoning, finding that the use of dynamic gestures (i.e., gestures “that depict and transform mathematical objects," p.3) correlated with the construction of valid mathematical proofs. Gesture has also been found to support problem solving reliant on spatial reasoning skills in particular (e.g., Chu & Kita, 2011).

To understand students' use of gesture in an embodied learning task in matrix algebra, we drew on constructionist learning theory (Papert, 1980), which puts forth the notion of "objects-to-think-with," that is objects in the physical or digital world that help ground mental models and help advance understanding of abstract ideas as learners interact with these objects. Papert further puts forth the notion of body syntonic learning, or a form of embodied learning, aligned with constructionism, where learners draw on their experience as a person with a body to imagine themselves in place of or in relation to the object they are interacting with. Learning thus emerges as a result of these processes of interaction between the learner and the physical object. Adopting a body syntonic lens supported our investigation of students' gestural use in interaction with the robotic arm and motivated our analysis of the ways in which specific gestures and speech grounded abstract concepts across the four dimensions previously discussed.

Methods

Set in the context of a graduate elective class at a 4-year minority-serving public institution in Southern California, this paper zooms in on a hands-on activity, which contextualizes a matrix math application within robotics. Before the activity, students assembled a robotic arm kit at home and viewed a pre-recorded 90-min lecture, introducing them to foundational concepts in matrix algebra and robot kinematics (e.g., degrees of freedom; vector and frame notation; matrix operations). For the activity, we positioned the arm in front of a grid and students selected how to rotate each of the three middle servos, marking the position of the end effector (i.e., the position of the arm's claw) and determining its coordinates. Students then created a diagram to visualize the servos' rotations and calculated the coordinates of the end effector, with facilitators available on Zoom and on site for guidance.

Participants were PhD or MS students in Education, Informatics, Engineering, or Computer Science and formed 2 dyads and 2 triads (Latinx = 3, Asian = 2, Multiracial = 2, and White = 3). We selected one of the dyads as an instrumental case study (Stake, 1995) to understand how students negotiate understanding of servo rotation, the z-axis, and their abstract mathematical representations. We selected this dyad because of their engagement in episodes of independent problem-solving and the high density of gestural content related to the discussed mathematical content. One student in the dyad, Miguel, had taken a linear algebra course as an undergraduate, while the other student in the dyad, Alex, had not (all names are pseudonyms).

We drew on pre- and post- assessment data to evaluate student learning gains, conducted before and after completion of the activity. The assessment consisted of 13 items, covering (a) vector operations, (b) spatial reasoning, (c) matrix operations, and (d) robotics fundamentals, which we evaluated on a 0–3-point scale. The first and third author established IRR with 20% of the assessment data (n=52 items, α=.97), before proceeding to code the rest of the data. We conducted paired-sample t-tests to evaluate the significance of the learning gains, and calculated effect sizes. After an initial pass of the focal dyad's video data from a 360-degree camera (a total of 1.5 hours), we selected 7 short clips with low facilitator involvement and high-density of pertinent gestural content for more in-depth analysis. In our iterative analysis of these segments, we identified and grouped student gestures, developing coding rules around them, and qualitatively analyzing representative moments.

Findings

Assessing learning gains and effect sizes

On average, participants increased their total scores on all four components, with our focal dyad observing learning gains well-above average for most categories (see Table 1).

Table 1
Average learning gains and effect sizes

	Max score	Range at pre-test	Range at post-test	Learning gains (avg)	Learning gains (focal dyad)	Cohen's *d*
Total score	30	1-16	4-21	4.11*	7	0.79
Vector operations	9	1-7	1-6	0.33	0	0.38
Spatial reasoning	9	0-6	0-7	1.78	2	0.65
Matrix operations	6	0-3	0-4	0.44	1.5	0.29
Robotics	6	0-1	0-5	1.56*	3.5	0.86

* $p < .05$

Hand gesture and talk ground concepts in spatial reasoning and vector operations

Purposeful use of hand gestures grounded the dyad's developing understanding of key concepts in spatial reasoning and vector operations (e.g., concept of a plane, vector components). The *drawing-in-space* gesture was a one or two-handed gesture aimed at the physical representation of an abstract construct through "drawing" and bounding the construct in space. For instance, Miguel used the drawing-in-space gesture to situate the Cartesian plane in the physical space through two cutting hand motions, one from top to bottom to represent the y-axis and one from left to right to represent the x-axis (see Figure 1). He named the vector components in the x- and y-direction concurrently, capturing the expanse of the Cartesian plane as constituted at the intersection of the two axes, *"That perfectly straight line is* n_y*. And that perfectly horizontal is* n_x*."* Alex followed what Miguel was doing, interrupting his notetaking to observe his gestures. The hand gestures Miguel performed were key in establishing common ground with Alex about the properties of the physical space. Miguel naming the vector components further signaled an understanding of a vector as being able to be broken into its respective components, in the horizontal x-direction and the vertical y-direction, and the importance of doing so in this context for calculating the end coordinates. Altogether, the drawing-in-space gesture established common referents for the dyad moving forward in a way that could be replicated when necessary, and established a sense of direction, needed when discussing servo rotation and the axis of rotation.

Figure 1

Miguel (left) using a drawing-in-space gesture to represent the x-axis, with a start in (a) and end in (b)

(a) (b)

Another type of hand gesture, *rotational gesture,* most directly informed understanding of servo rotation, what it looks and feels like, drawing on one's spatial reasoning to envision the rotation – and its specifics, such as the axis of rotation – in space. For instance, following the drawing-in-space gestures from above, Miguel modeled the rotation of the first servo by bringing his hands together at an angle and turning them counterclockwise, noting that the rotation is completed around the first angle, *"So this is rotated on* θ_1 *[froomph]."* Difficult to describe it in words, Miguel used utterances (i.e., "froomph") to signify when the gesture was completed. This rotational gesture closely followed the drawing-in-space gesture, so Miguel's right hand was still in the direction of the x-axis while his left hand was in the direction of the y-axis. Though the axis of rotation was not brought up until later, through the specific choice of how to orient one's hands and the direction and angle of rotation, Miguel represented the z-axis as the axis of rotation (see Figure 2). As it was not discussed explicitly, we termed this representation of the z-axis, "the invisible z-axis". Essential to understanding the servo rotation and its properties, the z-axis emerged as an inherent albeit not explicit component of rotational gestures, whose understanding, we theorize, contributed to the development of one's spatial reasoning competencies.

Figure 2

Miguel enacting a rotational gesture to represent a servo's rotation, with a start in (a) and end in (b)

(a) (b)

Body movement and utterances highlight nuances in robotic arm movement

Extending the traditional hand gestures, *augmented gestures* incorporated sound or shifts in body movement to emphasize the size of angle of rotation or the change in frame. For example, Miguel overlaid rotational gestures with sound, which increased in volume with the greater angle of rotation. He explained to Alex, *"The second part – this one - is rotated – [FROOMPH] in comparison."* To underscore the magnitude of the angle of rotation for the second servo, in relation to the angle of rotation for the first servo, Miguel augmented the rotational hand gesture with sound where varying volume levels correlated with the angle's magnitude. In the activity, it was especially important to understand servo rotation as a relative rotation with respect to a specific frame and we found that shifts in full body movement helped articulate the change in frame. To trace the movement of the first, second, and third servo, Miguel used rotational gestures, augmented with shifts in head and body movement and extending the gestures in space to capture the change in frame. When modeling the rotation of the second servo, we observed Miguel turn his body in the direction specified by the new frame (see Figure 3b) and yet again, when modeling the rotation of the third servo, with respect to another, new frame (see Figure 3c). Involvement of full body movement enhanced and grounded understanding of what is meant by a change in frame, otherwise difficult to grasp through hand gesture alone.

Figure 3

Miguel modeling the shift in frame for the first (a), second (b), and third servo rotation (c)

(a) (b) (c)

Discussion and implications

Drawing on constructionism and body syntonicity, in this paper, we presented an application of matrix algebra within robotics and investigated how gesture, speech, and the body contribute to learning gains in the case of the focal dyad. Though we observed statistically significant learning gains in total scores, the small sample size could have produced larger effect sizes, which is a limitation of the study. Qualitative analysis of the focal dyad's interactions with the robotic arm showed that gesture and the body complemented speech by providing a visualization of what is otherwise abstract and difficult to articulate through language alone (e.g., z-axis, servo rotation). Collectively, this study contributes to the literature on learners' unprompted use of gesture and the body to ground understanding in a specific domain (matrix algebra in context), as anchored in the physical "object-to-think-with". The paper has implications for the design of learning environments that use directed gestures to support specific learning outcomes as learners negotiate more challenging and abstract concepts in mathematics.

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Leveraging Computationally Generated Descriptions of Audio Features to Enrich Qualitative Examinations of Sustained Uncertainty

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Abstract: Prosodic features of speech, such as pitch and loudness, are important aspects of the social dimensions of learning. In particular, these features are likely related to sustained disciplinary uncertainty in collaborative STEM learning contexts. We present a case conducting an exploratory, descriptive analysis of sustained uncertainty in groupwork in a secondary mathematics lesson integrating computational and qualitative methods with audiovisual data. Results of computational audio feature extraction of loudness and pitch, combined with a transcript, were used to identify potential patterns between laughter and uncertainty.

Introduction

Qualitative research in the learning sciences has long relied on audio data as an important data source. This research has recognized the role that non-lexical features of utterances, such as intonation, pitch, and loudness in informing qualitative interpretations. However, the methods for capturing them in the transcript (see Hepburn & Boldin, 2013 for a range of examples) are time-consuming and typically useful for micro-analyses of single events. Computational tools such as voice activity detection (VAD) can be useful for quantifying features of audio data that transcript-based representations do not easily attend to but are often used for goals around prediction or automation (Slyman et al., 2021). This project seeks to explore potential uses of computational tools such as VAD for descriptive purposes within a qualitative methodological paradigm. In this paper, we present an in-the-weeds example exploring sustained uncertainty in collaborative student problem-solving in mathematics.

Background

Sustained uncertainty in problem solving in STEM

Exploration, inquiry, and modeling — important interdisciplinary processes that support student learning (NRC, 2012; NGA & CCSSO, 2010) — provide opportunities to make sense of disciplinary questions or problems. Productive engagement in these processes likely involves sustained uncertainty negotiated over time (Rosenberg et al., 2022; Watkins et al., 2018). However, uncertainty is often risky, devalued, and discouraged in schools, especially in science and mathematics classrooms (Archer et al., 2017). Previous research exploring disciplinary uncertainty from an interactional perspective has highlighted its complex and contextually-situated nature. For example, Watkins et al. (2018) identified a student repeatedly bringing up an idea until it evolved into a question that others picked up. Similarly, explicit expression of uncertainty may be a poor indicator of epistemic stance. For example, “I don’t know” might signal uncertainty in knowledge, but also “I don’t want to talk about this anymore,” or simply, “I am disengaged.” (Tsui, 1991). Attending to the prosodic features of speech could help tease apart nuances in these uses that are not apparent in the lexical (e.g., words used) features of speech alone.

Prosodic features related to uncertainty

The features of discourse relevant to communicating uncertainty have been examined both qualitatively and using computational methods. In both cases, it is common to look at the linguistic and semantic features of discourse. Qualitatively, these analyses have emphasized the social and rhetorical functions of uncertainty, such as how various linguistic features communicate epistemic stance to readers (e.g., Hyland, 2005); and how scientists’ discussions about different claims about data include a gradual softening of assertions (i.e., decreasing the certainty of claims) until they come into alignment with one another (Lynch, 1985). Computationally, these analyses have been used to detect when questions are asked (e.g., Hirsh, 2019) or what intonation speakers use (Hübscher et al., 2017). In addition to identifying questions, there are other linguistic features of semantic uncertainty, including adjectives/adverbs such as “probable, likely, unsure, perhaps”; auxiliaries such as “may, might, can, would, should”; conjunctions such as “if, whether”; and specific verbs and related nouns, such as "propose/proposal; question; investigate; consider;" etc. (Szarvas et al., 2012). These features have been used to detect uncertainty in speech automatically using probabilistic models (e.g., Jean et al., 2016).

Other studies have examined paralinguistic features such as intonation, as well as descriptive features of audio data such as the number and duration of turns. For example, Berger and colleagues (Berger & Calabrese, 1975) showed a correlational link between the amount of verbal communication in an interaction and the degree of uncertainty in the talk: as amount of talk increases, uncertainty decreases. Intonation is also an important marker for differentiating between uses of different types of question words (tag questions, wh- questions, inverted questions, and repetition questions) between speakers of different languages (e.g., Farais, 2013).

Methods

In this paper, we present an in-the-weeds example of how we are "layering on" automatically-detected non-lexical features of audio data in order to increase depth/complexity of descriptive qualitative analysis. We use a methodological approach integrating computational and qualitative techniques within a qualitative methodological paradigm focused on rich description. To do so, we use a single illustrative case or data episode, which allows us to deeply explore the potential features and characteristics of sustained uncertainty. We position this approach in contrast to prediction-oriented computational work, aiming to leverage large data to identify relationships among variables. Our goals and aim are to layer complementary perspectives about a common data episode to develop a descriptive account that incorporates a multiplicity of analytical perspectives spanning both computational and qualitative findings. Additionally, this analytical process involves placing these perspectives in conversation with one another to re-interpret findings with the addition and revision of layers of analyses, similar to the iterative hypothesis generation and testing used in qualitative analysis of video (Engle et al., 2007). This integration is guided towards a goal of rich multi-faceted description, rather than convergence on a single or simple characterization or label.

We selected an approximately 20-minute segment of video/audio of groupwork from a high school mathematics classroom, focusing on a single group. This data comes from a larger study, including video/audio recorded classroom lessons in high school mathematics from 10 teachers. The segment comes from a lesson on solving trigonometric equations as part of a math course for grade 10 and 11 students. This course and teacher, Mrs. Perry, was selected because the teacher used significant amounts of groupwork and previous research has documented that Mrs. Perry's teaching practice is responsive to student thinking (Dyer & Sherin, 2016).

The specific lesson and segment were selected to include a 4-minute episode of collaborative mathematical exploration among the teacher and students identified from previous qualitative analysis (Dyer et al., 2021). This analysis identified shifts in epistemic agency and authority among the participants, as well as sustained disciplinary exploration over several minutes. We selected this larger episode because we expected that exploration would involve frequent instances of disciplinary uncertainty and/or other forms of uncertainty that were not immediately resolved. The larger segment corresponded to the beginning and end of the first portion of groupwork in the lesson and thus included portions with the teacher present and not present. We hypothesized this would provide variation in the interactional patterns and structures of the group interactions over time.

To analyze the episode computationally, we use prosodic feature extraction audio analytics techniques from *openSMILE*, an open-source audio processing program (Eyben et al., 2010) in conjunction with a time-coded transcript of the episode. For prosodic feature extraction, we focused on pitch and loudness as two features we hypothesized would be related to uncertainty based on prior work. Both outputs are provided at the frame level, and thus, we created aggregate measures and displays for each turn of talk as a unit of analysis. These include the maximum value, minimum value, mean value, and smoothed line graph of values over time.

Findings

To facilitate the interpretation of our results, we first provide a short summary of the episode. The episode comes from a small group of four students working together on a task that asked students to solve the equation $-15=20\cos(30x)$. Across the episode, the students consider graphical and equation-based approaches to find different solutions. The first approximately 13.5 minutes of the episode involved the students discussing and working with one another, followed by the teacher visiting the group for around 12.2 minutes, and concluding with less than one minute of the group talking before the class transitions to whole-class student presentations (not included in the episode).

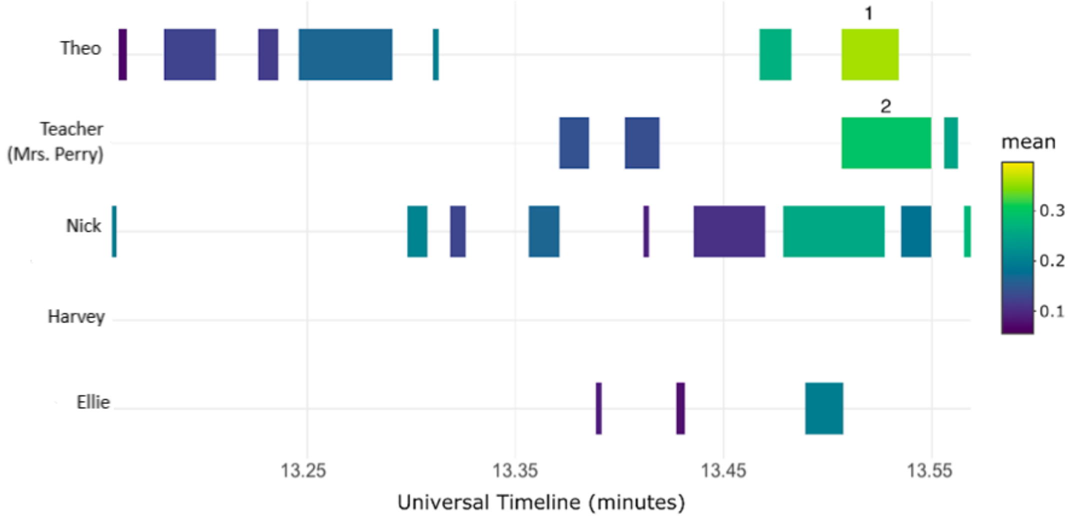
Case: Examining anomalous moments of loudness

We present here a case example that emerged from our explorations of the loudness of turns during the focal episode. Figure 1 shows the mean normalized loudness of speech by segment, with each row representing an individual speaker. Note the most yellow-appearing segment, located in the top-right of the graph and annotated with the number "1.". We can see that this utterance from Theo's had the highest average loudness. It also had the highest maximum loudness. The other speakers' turns during this time were also louder than the turns preceding it.

In examining the transcript, during segment 1, Theo said, "I know *((LAUGHTER))*! I still don't understand, though." During segment 2, the teacher said, "*((LAUGHTER)) And you still didn't get it ((LAUGHTER))*!"–the segment with the second-highest mean loudness. Examining the frame-by-frame measures of loudness within each turn shows that the loudest portions of each segment were not when the individuals were laughing. Instead, although laughter occurred *during* the segments with the highest mean loudness, the laughter was not registered as the loudest part of the segment.

Figure 1

The Mean Loudness Per Utterance During the Period of Sustained Uncertainty



These patterns suggest two things. First, laughter may accompany (or indirectly be the cause of) louder utterances. Perhaps students became louder when they laughed because their laughter represented an expression of relief or a breaking of tension caused by uncertainty. The words they spoke may have been louder in order to match the tension-breaking tone of the laughter. Alternatively, perhaps these segments were not exceptionally louder than average but were instead louder than the unusually quiet turns that preceded them—turns that were quiet because they were tentative or embarrassed about whatever it was that they were *still* not understanding (Theo).

Discussion and future work

We have presented an analytic case of leveraging computational tools in service of qualitative methods. Specifically, we used prosodic feature extraction (loudness) to initiate grounded hypotheses for future exploration. Rather than serving as an endpoint for prediction, the computational analysis instead functioned as an early pattern-detection tool. In our ongoing analytic work, we are expanding our analysis beyond the 20-min segment described to explore hypotheses generated within the segment. For example, how often does loudness correlate with laughter? How do moments of laughter (and/or loudness) reflect uncertainty, or other epistemic markers?

This example provides an initial demonstration for how prosodic features are helpful as accompaniments to intensive qualitative analysis—and not a replacement for such methods. Specifically, we found that the prosodic features of pitch and loudness are most helpful in a descriptive, rather than a highly inferential, manner. For example, the transcript allowed our team to identify the association between segments of high average loudness and laughter. Similarly, examining the pitch within segments led our team to interpret the role of laughter as a co-occurrence with loud speech rather than the primary driver of high average loudness.

Our future work will continue to leverage additional computational tools, such as automatic speech recognition, as an additional layer and visualize select components from that output (e.g., use of hedging words; use of question words) in conjunction with prosodic features such as loudness. Another feature under development is a way of representing the absence of speech, including pauses within turns, using voice activity detection (VAD) algorithms. Though unconventional and atypical, we encourage other researchers to creatively and critically leverage these tools for computational tools such as VAD for descriptive purposes within a qualitative methodological paradigm, rather than only for automated prediction.

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The Debate Between Inquiry Learning and Direct Instruction: What Should Count as Evidence?

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Abstract: In the ongoing debate regarding whether direct instruction or inquiry learning is superior, there exists a lack of clarity—even confusion—regarding the core features of each type of instruction. This paper argues that scholars advocating direct instruction have frequently misconceived core features of inquiry learning. The consequence of this is that many studies purporting to support direct instruction over inquiry learning fail to do so. We present three arguments for this claim, focusing on three essential features of inquiry learning environments: epistemic agency, community interaction, and complexity of inquiry learning environments. We call for and sketch a new approach to conducting research on the relative affordances of core features of these two approaches to instruction.

Introduction

For over five decades, educators have debated the efficacy of learning through inquiry and other constructivist forms of instruction versus learning through direct instruction (e.g., Furtak et al., 2012; Hmelo-Silver et al., 2007; Kapur, 2016; Kirschner et al., 2006; Shulman & Keislar, 1966; Tobias & Duffy, 2009; Zhang et al., 2021). Although a series of reviews in the 2010s by psychologists (Alfieri et al., 2011) and educators (Furtak et al., 2012; Kapur, 2016; Minner et al., 2010) argued for modest positive effects for guided forms of inquiry over direct instruction or traditional forms of instruction, subsequent reviews have argued for the greater efficacy of direct instruction over learning through inquiry (Stockard et al., 2018; Zhang et al., 2021). Empirical studies continue to argue for the relative advantages of direct instruction (e.g., Martella et al., 2020; Yaghmour & Obaidat, 2022).

In this debate, there is widespread agreement on one point: Direct instruction (i.e., telling students the answers they are expected to learn, typically followed by practicing use of what they were told) promotes more learning than pure discovery learning (i.e., learning environments in which students try to invent answers with little or no guidance). This point is conceded by most proponents of inquiry learning (e.g., Furtak et al., 2012; Hmelo-Silver et al., 2007). Proponents of inquiry learning argue instead that, in contrast to pure discovery learning, guided discovery or guided inquiry—in which students are given scaffolds to support their discovery processes—are superior to direct instruction (e.g., Hmelo-Silver et al., 2007). However, proponents of direct instruction continue to argue that direct instruction is superior to both guided and unguided forms of inquiry (e.g., Zhang et al., 2021). We will focus our discussion on the debate between direct instruction and *guided* inquiry.

Although many learning scientists strongly endorse instructional approaches grounded in inquiry (see chapters throughout Duncan & Chinn, 2021), some also endorse instruction more aligned with direct instruction, such as direct explanations of inquiry skills in history (Van Boxtel et al., 2021). Although the pages of *The Journal of the Learning Sciences* and *International Journal of Computer-Supported Collaborative Learning* seldom investigate learning environments grounded in direct instruction, the pages of many other journals include many papers investigating predominantly direct-instruction methods such as learning from worked examples and explicit strategy instruction.

In this short conceptual paper, we argue that much of the evidence that has been brought to bear on this debate—and especially evidence used to support the superiority of direct instruction—is in fact irrelevant to the questions about learning and instruction that are of primary interest to learning scientists and that should be of interest to educators more broadly. In this paper, we both critique the current evidential base used to argue for direct instruction and make suggestions for future research.

Clarifying the meaning of inquiry learning

One challenge that bedevils the debate is getting to a shared definition of these forms of instruction (Furtak et al., 2012). We begin by building on new work to clarify what counts as inquiry instruction. Recently, Duncan and Chinn (2021) edited the *International Handbook of Inquiry and Learning*. In their introductory chapter, Chinn and Duncan (2021) synthesized the many approaches to inquiry discussed in the volume and proposed six characteristics that these environments had in common: (1) Students find things out—developing at least some new ideas on their own. (2) They are actively engaged in finding things out by making inferences on their own.

This does not mean that they find *everything* out on their own, but they should work out some significant elements of what they are learning. (3) They use some kind of evidence (which can include empirical data, human testimony, prior experiences, etc.) to develop their ideas. (4) They have epistemic agency, which means they have the autonomy and authority to express their own ideas and develop their own conclusions. (5) There is some complexity in the reasoning involved—that is, the inferences students need to make are not trivial but substantive. (6) Students are engaged in these processes within communities; inquiry takes place in the crucible of social interactions. We would add a seventh commonality: Students are also given various scaffolds and other supports so that they are engaged in guided rather than unguided inquiry.

This analysis, which we refer to as the C&D analysis, has important consequences for how to evaluate and interpret the research base that has been used to try to adjudicate the debate between guided inquiry learning and direct instruction. Specifically, an entailment of the C&D analysis is that much of the research used to support direct instruction has little relevance to the question of whether direct instruction is more or less effective than guided inquiry as a method of instruction. This short paper does not permit an exhaustive re-analysis of the research base that has been used to support claims favoring direct instruction, so we will sketch our fuller analysis.

Limitations of the current research base in evaluating the efficacy of inquiry learning vis a vis direct instruction

In this section, we discuss implications of the C&D analysis of inquiry learning for adjudicating the debate between inquiry learning and direct instruction. Our overarching argument is that many of the studies that purport to address the debate mischaracterize inquiry learning when they set up their experimental conditions. Thus, researchers are not investigating effects of inquiry learning environments at all. We have three main arguments for this position.

First, the C&D analysis emphasizes that existing inquiry learning curricula are fundamentally social. Students engage in inquiry in communities. Discoveries are made within and by communities, not separately by each individual student. But this feature of inquiry environments has an important consequence: It is common in inquiry curricula for students to hear crucial ideas from their classmates instead of inventing those ideas themselves. For example, in a study by Rinehart, Duncan, and Chinn (in preparation; see Rinehart, 2017), students in a genetics inquiry environment collectively invented the core Mendelian idea that every parent has two alleles (students of course used their own terminology), one of which is given to offspring. But it was not the case that every student invented this idea individually. Rather, some students invented the idea, and then as they shared it, and debated it, other students eventually came to endorse and adopt it, as they came to see what it meant and how it best explained the evidence.

In guided inquiry environments, teachers or educational materials may even be the ones to tell students the critical targeted ideas. For example, a teacher might present three alternative models of photosynthesis to students, one of which is the scientifically accepted model, and students work with evidence to determine which is best. This is still inquiry learning because students must work out for themselves what they find most compelling, and they may be asked to further improve the best of the models.

Thus, the core element in inquiry environments is not whether students discover ideas themselves (as opposed to someone telling it to them). In inquiry learning, students often first hear ideas from others. The core element in inquiry learning is that students have the epistemic agency to make sense of the ideas and to decide if they are convinced by the ideas, in light of all the evidence they are considering. This is, of course, like how scientists collectively work; each individual scientist does not invent every idea. Scientists regularly evaluate, investigate, and explore ideas that their colleagues have developed.

Proponents of direct instruction typically misconceive that the core of inquiry environments is that students are *not told* the target ideas. For example, Zhang et al. (2021) praised controlled studies that "have compared teaching involving exploration-based investigations with forms of direct explicit instruction, including simply giving students answers, having students watch demonstrations and listen to explanations, directly reading answers from texts, etc." (p. 1165). Other scholars who have investigated direct instruction have defined the core difference in the same way (e.g., Klahr & Nigam, 2004; Martella et al., 2020). In short, these studies misconceive what the core difference between inquiry environments and direct instruction environments is. Accordingly, most of the controlled studies cited by Zhang et al. (2021) as strong support for direct instruction over inquiry learning simply do not bear on the issue.

A corollary of this observation is that investigations of the effects of inquiry environments need to examine whether students genuinely accept the ideas that they are taught. Given that inquiry environments give students opportunities to choose which ideas make sense and are convincing, measures of the effects of inquiry learning environments should assess the ideas that students really endorse. This requires measures that examine students' responses when they are not simply playing school—responses that reflect real understandings and commitments. Few, if any, controlled studies comparing direct instruction with inquiry learning have included such measures.

A second implication of the C&D analysis raises equally serious objections to many of the studies that purport to contrast guided inquiry with direct instruction. The C&D analysis emphasizes that guided inquiry learning occurs in communities. But when setting up controlled experiments, many studies investigate the learning of individuals alone (e.g., Klahr & Nigam, 2004; Martella et al., 2020). Or, if the researchers do have students work in groups, they do not encourage the kinds of interactions typical of inquiry communities (e.g., Zhang & Van Reet, 2021). These experiments thus compare direct instruction—conceived perhaps fairly as a mainly individual form of learning—with an individual form of discovery that strips away the essential community in which inquiry is supposed to occur. These studies do not speak to whether direct instruction outperforms guided inquiry learning.

By removing the interactions of the community from inquiry learning, these studies block the operation of one of the learning mechanisms posited by many scholars to be central to learning. Specifically, sociocultural approaches to learning emphasize the Vygotskian mechanism that much learning occurs when students "internalize language practices from a social, external plane to an individual, internal plane" (Reznitskaya & Wilkinson, 2015). For instance, students learn to anticipate various counterarguments and to construct better arguments on their own after they have experienced being confronted with similar counterarguments in social processes of argumentation. It is these social experiences that propel growth. Studying inquiry learning without the core driver of carefully curated social interaction is like studying the propulsion of cars that lack engines.

A third important implication of the C&D analysis of inquiry learning for the debate between inquiry learning and direct instruction arises from the fifth criterion, which emphasizes the role of complexity. In inquiry learning environments developed by learning scientists, communities of students typically engage in forms of inquiry that address complex issues and practices (Duncan & Chinn, 2021). For example, students engage in complex practices such as struggling to work out which expert sources are most trustworthy when the experts disagree (Barzilai et al., 2020), determining how to conduct experiments when it is not obvious how to measure outcomes or what variables need to be controlled (Ford, 2005), and how to determine what counts as plants flourishing (Manz & Renga, 2017). None of these practices can be reduced to simple algorithmic rules.

In contrast, many of the studies that contrast inquiry learning and direct instruction focus on very simple strategies that can indeed be reduced to algorithms, such as learning to control variables when there are three or four prespecified variables, most with two prespecified levels each (e.g., Lorch et al., 2014; Martella et al. 2020; Strand-Cary & Klahr, 2008). This can be performed algorithmically. But real reasoning—on topics in history, in science, and in the social world—cannot be reduced to such algorithms. Even if studies were to show that direct instruction can be more effective on these simplistic topics, it would by no means follow that direct instruction is best for learning more complex forms of reasoning. Indeed, Ford (2005) showed that direct instruction on teaching students to control variables promoted performance on assessments that could be solved algorithmically but not on more complex scientific reasoning tasks that required more complex judgments. Thus, a third problem with many studies featured in reviews that appear to support direct instruction over inquiry learning is that they use simplistic, toy tasks that are far from the demands of the thinking needed to thrive in the real world.

Discussion

Based on the C&D analysis of the characteristics of inquiry learning environments, we have argued that the studies that purport to show better outcomes for direct instruction than for inquiry learning are flawed. First, they fail to recognize that "telling ideas" is not the most critical difference between inquiry learning environments and direct instruction, and so experiments that manipulate "telling ideas" fail to capture the most relevant difference—which is the epistemic agency to choose what ideas to accept. Second, many studies test inauthentic forms of inquiry learning environments that strip away essential drivers of learning including social dimensions. Third, many contemporary inquiry learning environments aim to promote complex modes of reasoning and knowledge, whereas many studies contrasting inquiry learning with direct instruction target simple, algorithmic learning goals. These problematic features of many studies call the results of the studies into question.

A number of scholars have commented that the debate between inquiry learning and direct instruction should move beyond declaring which mode of teaching is better, and examine instead which mode is better for which students under which conditions (e.g., de Jong, 2022). Given that shows that students are told many things by many sources in inquiry environments, the critical questions become: What is best told to whom, when, and by whom (de Jong, 2022)? In real instruction, telling students things is constantly interwoven with opportunities for students to think for themselves. What is needed is a better understanding of how to interweave telling and inquiring, and what to tell (and what not to tell) as students are engaged in inquiry. Investigators should shift the focus of research away from broad questions about "which works better?" or "which works better for whom?"—

as if students should spend tracts of time engaged in one or the other. Rather, researchers should ask finer-grained questions about how telling and inquiring should be interwoven from moment to moment to best support learning of content and development of thinking.

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Understanding the Assemblage of Community Desire: Progress, Challenges, and Tensions in Establishing a Community-Based Health Justice Science Education Curriculum Collaborative

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Abstract: Community-engaged research partnerships are increasingly used in education research to promote equitable and relevant educational outcomes. One key challenge of such partnerships that is rarely documented is the pre-partnership relationship development phase. This methodological paper reports on the early partnership exploration and formation efforts of an interdisciplinary research team working to build a community-based curriculum materials collaborative for health justice science education in a rural Midwest town. We explicate how we have approached this phase through an epistemological orientation of *desire-centered research* by integrating methods and stances from community-engaged ethnography with commitments from community-based participatory research. We articulate three main activities shaping this phase of work: (1) Learning about communities' well-resourced networks; (2) Progressive refinement of project foci; and (3) Gauging, establishing, and negotiating trust and capacity. Our situated accounting provides an illustration of how interdisciplinary teams might draw from and navigate across multiple methodological traditions in context-specific ways in working towards equity in education research.

Introduction and motivation

Community-engaged research (CEnR) in education can lead to more equitable and relevant forms of research. Importantly, community-engaged research goes beyond identifying partners and instead emphasizes the importance of doing research that directly addresses the needs and well-being of the partnered community (Israel et al., 2013). Building and negotiating trusting relationships with partners is essential, especially given the unequal power dynamics between academic partners and community partners (Wallerstein et al., 2019). However, while there is documentation *that* these relationships are necessary for CEnR partnerships, as well as many tools to guide assessment and evaluation of them (e.g., Boursaw et al., 2021), descriptions of and guidance for how initial relationships come about and develop in the very early stages is relatively absent from this literature (c.f. Parker et al., 2019). These early-stage relationship-formation negotiations are an essential time in which partners establish the norms, structures, and power hierarchies that will shape ongoing project research and design work.

This methodological paper reports on the early partnership exploration and formation efforts of an interdisciplinary research team who came together over a common recognition of the need to conduct community engaged research. Drawing upon our expertise across science education, public health, epidemiology, medicine, and genomic biology, as well as a history of past community-based projects, we are building a community-based curriculum collaborative for health justice science education. We aim to utilize participatory co-design of locally relevant and impactful health justice educational experiences that center students', families', and community-based organizations' deep community knowledge and improve science instruction for students and health outcomes for local communities. Here, we present an illustration of how we have approached early-stage partnership exploration by integrating guidance from ethnographic research traditions (e.g, Mokos, 2022) with community-based participatory research (CBPR) principles including building on community strengths and resources, mutual benefit for all partners, and intentional action to reduce social inequities (Israel et al., 2013).

Methodological orientation: CBPR and desire-centered research

We draw on approaches from community-based participatory research (CBPR), which is broadly used in the health sciences to improve community health outcomes (Brush et al., 2020) and is grounded in a commitment to sharing power with community partners and engaging together in a research process that centers the needs and interests of the communities involved. To inform our early-stage relationship-building phases as community outsiders, we draw upon ethnographic traditions (e.g., sociocultural anthropology; activist and community-engaged ethnographies) that provide methodological guidance around considerations of power and equity, such as balancing the role of key informants with broad community perspectives (McKenna & Main, 2013; Mokos, 2022) and adopting a stance of interpretive reflexivity (Lichterman, 2017).

To epistemologically guide our synthesis of approaches, we draw on Tuck's (2009) call to shift from *damage-centered research*, or "research that operates, even benevolently, from a theory of change that establishes harm or injury in order to achieve reparation" (ibid, p. 413) to *desire-centered research* that aims to capture desire rather than damage by "understanding complexity, contradiction, and the self-determination of lived lives […] by documenting not only the painful elements of social realities but also the wisdom and hope" (ibid, p. 416). In applying a desire-centered epistemology to educational partnership-building, the focus on community thriving allows for complexity and heterogeneity. This has led us to shift from the common question to partners of, "What do you need?" towards questions more like, "What would thriving look like here?" We assume communities' responses will reflect an *assemblage of desire* – a multi-faceted, and sometimes contradictory, collection of values, goals, and imagined possible futures that a community holds (Tuck, 2009) – and aim to have it be the vision that shapes the focus and goals of what a health justice science education collective could be and do.

Context and methods

Description of focal community

This project is situated in the context of "Plainsview," a small community of about 12,000 people near (but distinct from) a major University town in the Midwest United States. Plainsview, while rural in geography, reflects many of the challenges faced by communities experiencing increasing diversification (by which we mean more ethnic, racial, and socioeconomic variety, rather than an increased presence of a single racialized group) and the struggle of communities marked by economic disinvestment. The median income of Plainsview in 2021 was $33,000, and 87% of students in the school district were designated as low-income. Demographically, Plainsview's population as reported on the 2020 Census is 60% white (12.5% Hispanic), 25% black, 2% Asian, 5% other, and 6% two or more races. In contrast, the students in the city's public school system report as 24% white, 30% black, 33% Hispanic, 13% two or more races. The school system often receives low scores on their state report cards. At the elementary and middle school levels, 6% of students received at least a "meets expectations" score on the state's standardized tests. They are currently rated as demonstrating "large gaps" with respect to disparities in academic outcomes across demographic groups. While the teaching staff are highly qualified and well-paid, they do not necessarily reflect the students who they teach: 87% are white, and many do not live in Plainsview but instead commute from the nearby college town or surrounding communities.

The distinct demographic groups in the Plainsview community also have distinct histories. Plainsview has long been a destination for migrant farm workers who travel primarily from the Texas borderlands to work for Monsanto detasseling corn. A strong network of family and community services for migrant families remains active. Gradually, migrant families have elected to stay in Plainsview permanently due to this network, the affordability of housing, and economic opportunities that were available for them in Plainsview. Of course, the Latinx population in Plainsview includes more than migrant farm laborers and their families; for example, there is direct recruitment of Puerto Ricans for factory labor as well as growing Guatemalan and Honduran populations.

The Black community also has a multifaceted history. Some residents have a long history in Plainsview spanning generations. The Black population also gradually grew as major public housing projects in Chicago began closing in the 1990s and early 2000s. Plainsview was a desirable location because of its relatively low crime rate and affordable rental housing. Black residents from other nearby towns have relocated to Plainsview for the same reasons. This varied history brings with it some familiar dynamics: the longevity of presence in Plainsview has sometimes made the concerns of the Black community less urgent to leaders, while the influx of residents from the Chicago projects has at times led to reinforced stereotypes about, and blame for, violence and crime.

Description of the team and history of relationships and work with the community

The current project team includes faculty members and staff who collectively have several existing and successful research-practice partnerships, as well as a wealth of experiences with long-term health outreach organizations. At the same time, the dual pandemics of COVID-19 and increasingly public racial injustice made clear to us the need to build relationships differently with the schools, organizations, and communities with whom we partner for health- and education-related efforts. The first three authors have done the majority of the relationship-building work thus far. The **first author** is a science education scholar whose research interests are in science and science teacher education. She is a white woman from a small town in the Midwest, though not in the same state as Plainsview. While the social and political dynamics of Plainview that have emerged from conversations are eerily familiar, she is also astutely aware of the implications of her "outsider" status within this context. The **second author**, a graduate student and former 6th-12thgrade science teacher, is a Black male and first generation immigrant from the Caribbean. He grew up in a large urban city in the same state as Plainsview. Being a Black man connected to the large nearby University affects conversations in different ways both positively and prohibitively, depending on who is involved. His research is focused on STEM equity and the design of informal afterschool programs. The **third author** is a cultural anthropologist/ethnographer who began carrying out health-related research in Plainsview in May 2020, after the first large outbreak of COVID-19 occurred among (mostly migrant) workers. With other members of the team, she worked to set up COVID testing in collaboration with local politicians and community activists. Also a white woman from the Midwest, she quickly became aware of the suspicions people from Plainsview harbor of university researchers. Most of her previous research has been in Central America.

Research approach: Activities, data collection, and analysis

Over the course of the 2022-2023 academic year, we proposed to engage in three phases of activity: (1) Identifying and assessing partner readiness; (2) Establishment of a collaborative; and (3) Action plan development. This paper presents on Phase 1, which has involved individual meetings and/or information-gathering interviews with leaders at local organizations. To date, we have held informational interviews with 10 individuals representing a range of community organizations and/or leadership or activist roles in the community. We began with existing relationships based on recent collaborations and then asked for additional names at the end of each interview. When we recognized that we were beginning to hear the same few names repeatedly, we explicitly began asking for names of people outside of the local Plainsville "circle of power" (a participant-generated phrase).

To make sense of our data, we debriefed any conversations at weekly project meetings. From these conversations we kept a list of emerging themes related to health and education; notes about social structure and other explicit or implicit political dynamics, including how we wanted to handle them moving forward; and our own individual reactions and reflections. We also kept detailed notes about existing efforts related to health, well-being, and/or education in the community, including how and why they were successful (or not). The first author synthesized notes every 5-6 weeks into a project update. This paper reports on these syntheses.

Findings

We present a description of three key activities shaping our work that we argue characterize the pre-partnership relationship-building phase: **(1) Learning about communities' well-resourced networks; (2) Progressive refinement of project foci; and (3) Gauging, establishing, and negotiating trust and capacity**. Notably, these are re-framings of the goals described in the project proposal for Phase 1, which were originally informed by current literature on establishing community partnerships: (1) Identifying potential connections to community organizations/schools with shared health justice education goals; (2) Identifying the assets and knowledge gaps of respective partners; and (3) Assessing potential for partnership. While these re-framings may seem like semantics, in our case they were the product of continual epistemological and ideological reflection. In the interest of space, we will briefly describe each activity and how the re-framing differs from our original goals.

In our own learning about Plainsview (**Activity (1)**), we identified organizations that had a general health or education component of their mission, then met with them to broadly understand the work they did, their successes and accomplishments, and the challenges and needs they saw. This orientation allowed us to begin to see ***how Plainsview is already a well-resourced network***—even despite its designation as an under-resourced community. Importantly, this "learning about" was deeply informative in terms of the social and political dynamics of the community. As we gained an understanding of these networks and resources, we also gained an understanding of the needs and multifaceted visions for thriving described in relation to them. This led us to *refine our understanding of what a relevant focus on "health justice science education" may look like for Plainsview* (**Activity (2)**). These refinements include (a) an expansive notion of "health" as ***promoting well-being***; (b) the necessity of ***wholistic (and potentially wraparound) programming***; and (c) critical consideration of the ***role the school system plays*** in the community. This has pushed even wider the definitions of "health," "education," and "curriculum" that those with which we began.

Finally, our conversations about "readiness" have been less like an assessment and more like praxis. We describe this praxis in terms of *gauging trust*, or the "dance" between what people say and what we say, how much they are letting us in vs. not; and *considering capacity*, both partners' and ours, for working with uncertainty and building bridges (**Activity (3)**). In terms of trust, a few key dynamics became important in shaping our negotiations. One involved how we talked about our project goals related to justice in a community that leans politically conservative. Early on, several participants asked us what "health justice" meant, admitting they had Googled it before our meeting. Another participant cautioned us that being "too up front" about race and racism might lead people to quietly shut their doors. This raised a central tension that still shapes our work: ***how do we***

maintain a focus on racial equity within a racialized but intentionally "colorblind" community? And ***how should we, as a majority white project team, orient towards these goals of racial equity?*** Relatedly, how much effort and education should we plan to take on in terms of facilitating conversations about the systemic causes of disparities in "well-being," vs. working with groups that already have a deep understanding of those causes?

Our ethnographic-leaning approach also had implications in terms of how we were thinking about capacity. Before beginning conversations about time and funding capacities—more traditional metrics of capacity—we were first developing an understanding of the role(s) that we *could* play in a potential partnership. The relatively powered position we are in as University-affiliated professionals was very clear within these interactions: as we began to ask people to envision what a partnership could look like more explicitly, many responses described us taking on a role as an advocate, often around issues that only tangentially aligned with our areas of expertise. While these requests communicated important ideas about what participants desired, it also led us to reconsider ***how we frame our own capacity for contributions*** and ***how we may need to bound our capacity*** in ways we did not expect.

Discussion and conclusions

This paper has explicated three key activities for early relationship-building efforts in the context of shifting to interdisciplinary, community-engaged research: **(1) Learning about communities' well-resourced networks; (2) Progressive refinement of project foci; and (3) Gauging, establishing, and negotiating trust and capacity.** These activities are distinct from early *partnership*-building activities in that they elaborate what "identifying ready partners" involves when it is guided by specific methodological and ideological commitments. In particular, we highlight how common challenges related to discussions of justice and navigating powered relationships have manifested in this context. Especially as the learning sciences continue to lean into the sociopolitical turn (Gutierrez, 2013; Mendoza et al., 2018), we hope our description of our efforts can serve to de-mystify the process of working to build community-based partnerships and raise critical considerations, especially for scholars who are, like us, relative "outsiders" to the communities with which we partner.

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Co-Constructing a Vision of High-Quality Mathematics Instruction With School Leaders Through a Classroom-Based Immersive Learning Experience

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Abstract: A vision of high-quality mathematics instruction is necessary for schoolwide improvement in mathematics. In the context of a research-practice partnership, we used a design-based research approach to create classroom-based immersive learning experiences (CBILE) for school and district leaders to co-construct a sophisticated vision. Qualitative analysis of design meetings and principal interviews explored how CBILE contributed to school leaders' vision. Findings suggest that school leaders' co-constructed vision reflects a negotiation between vision constructs defined by mathematics education research and the situated context of their realities.

Introduction

A shared sophisticated vision of high-quality instruction across a district is important to ensure coherence in professional development and instructional support (Cobb et al., 2020). This study is situated within the context of a research-practice partnership (RPP) (Farrell et al., 2021) focused on schoolwide improvement in mathematics. We examine the co-constructed vision that takes shape among district and school leaders through a classroom-based immersive learning experiences (CBILE).

Principals are important levers in improving student achievement (Grissom et al., 2021). They set schoolwide goals, organize professional learning, and cultivate a culture of teacher collaboration (Supovitz et al., 2010). To foster mathematics improvement, principals must support individual teachers through instructionally focused conversations around mathematics lessons (Grissom et al., 2021). These conversations necessitate content-specific knowledge and a vision for what counts as high-quality mathematics teaching (Schoen, 2010).

As researchers, we draw from existing bodies of literature to support our partners, however, our inquiry process must also attend to the specifics of the context in which our practice partners work. We operated from a vision of high-quality instruction defined by the mathematics education research community (Munter, 2014). We sought to understand how our partners negotiated that vision as ultimately their co-constructed vision will be what informs subsequent school improvement work. This study extends existing literature by exploring how school leaders interpret the notion of high-quality instruction and whether and how it is useful to their priorities. In this paper, we ask: *How did school leaders co-construct a vision of high-quality mathematics instruction through the CBILE? What aspects of this vision are shared with the research community? Which emerge as priorities for school leaders?*

Theoretical framing

Munter (2014) describes vision as the image of what is possible in a mathematics lesson, yet may not be currently enacted. For teachers, a sophisticated instructional vision is related to improved quality of instruction (Munter & Correnti, 2017) and to their knowledge for teaching (Munter & Wilhelm, 2021). Drawing from existing literature on high-quality instruction, Munter suggests a sophisticated vision includes the role of the teacher as a more knowledgeable other who shares authority with students. Classroom discourse should represent a mathematics discourse community. Mathematics tasks should support students in problem solving and the mathematics practices (e.g. generalization). While a principal's vision of mathematics instruction may not need to be the same as a teacher's, they do need enough disciplinary knowledge to support teacher learning and instructional improvement at their site. Without sufficient knowledge, principals give content-neutral feedback to teachers (Rigby et al., 2017). The CBILE were designed as an opportunity for school and district leaders to co-construct a vision of high-quality mathematics instruction by experiencing and debriefing together with the teacher through a series of lessons.

Mode of inquiry

Study context and participants

The RPP is situated in a mid-size district encompassing two cities on the West coast of the United States. The district serves approximately 19,000 students. 46.3% of the population identifies as Latinx and 41.2% identifies as White. While 30.9% of the student population qualifies for free and reduced lunch, the majority of those students are enrolled within schools in one of the two cities.

During the year in which the study took place, the district emphasized building instructional leadership capacity as a means to support their improvement goals. All elementary school principals engaged in monthly learning sessions around the Common Core State Standards in Mathematics which they could draw from in subsequent staff meetings at their site. From this work, a subset of principals and district leaders decided to engage further with the RPP. The practice partners in this group included six principals, an assistant principal, three district leaders and a mathematics coordinator. Five of the six principals lead a Title 1 school. At the time of the study, principals had between one and 16 years of experience in that role, though all were former classroom teachers and previously held other administrative positions. The research team consisted of an education faculty member and two PhD graduate students, all with experience in mathematics teaching and learning in the K-12 setting. Through a series of value mapping and goal setting activities, the RPP established the development of a shared vision of high-quality mathematics instruction among school and district leaders as the goal of joint work, due to the belief that a lack of shared definitions of quality instruction served as an impediment to schoolwide improvement in mathematics. Further meetings defined CBILE as the learning opportunities to co-construct a vision of high-quality math teaching.

Design of classroom-based immersive learning experiences

Four CBILE were designed by one district leader, the mathematics coordinator and the university researchers (the design team). School and district leaders were asked to learn alongside students and the classroom teacher. During the lesson, leaders sat with students to note aspects of their mathematical thinking. This intended to disrupt the leader-as- evaluator structure typical of many classroom observations. The classroom teacher participated in conversations before and after the lesson in order to make visible her instructional decision-making process and to shift the power dynamic between the leaders and the teacher. Additionally, the design team theorized that visits to the same classroom space would support school and district leaders to attend to specific practices rather than superficial aspects of the space (e.g. to attend to how students engage with each other, rather than to how the desks are arranged). Further, school and district leaders would be familiar with students and could see their growth and participation over time.

The mathematics coordinator planned each lesson with the classroom teacher who taught 4th grade. Each session emphasized an aspect of high-quality instruction which was specifically designed into the lesson and the facilitation of the pre- and post- lesson conversations. In between each learning experience, the design team met to incorporate what was learned in the prior session to the next session.

Data and analysis

Audio transcripts and field notes from the CBILE, field notes from design meetings, and artifacts created from both learning experiences and design meetings were used to document what occurred during the CBILE and how they evolved. Audio transcripts of the interviews with the six principals were used to understand their experience and takeaways. Each principal answered the question: *If you were asked to observe a teacher's math classroom for one or more lessons, what would you look for to decide whether the math instruction is high quality?* (Munter, 2014). Follow-up probes were used to expand discourse around each vision dimension. Additionally, principals were given two video clips to watch and were asked if they saw elements in the clips that reflected, or did not reflect, their instructional vision. Finally, principals were asked a series of questions about the CBILE and any connections they made to the work at their school site.

Each design meeting was summarized in an analytic memo. Qualitative coding of principal interviews began with deductive coding using rubrics created by Munter (2014), however emergent codes were recorded and themes summarized in analytic memos. Interrater reliability was established between two researchers. Patterns and themes were discussed with the larger research team. The findings represent themes from the principal interviews that were triangulated with patterns generated from design team meetings.

Findings

Vision grounded in detail

When articulating their vision of high-quality mathematics instruction, principals incorporated substantive details from the classroom space in which they were immersed during the learning experiences. When asked to reflect on how students engage in classroom activity, all principals focused on use of tools (manipulatives, visuals, or mathematical representations) as a means to support problem solving and to show mathematical reasoning. Further, five of the six participating principals detailed the teacher's role in eliciting and responding to student mathematical thinking in language that mirrored what had been observed in the learning experiences. As one principal articulated:

> The teacher is celebrating and recognizing assets in the room…[the] teacher is really thoughtful about who to bring forth in the classroom, to move the whole class, like who, so these students, like there's something I want to get to in my lesson. And these three students…how can I leverage what they have to move the whole class forward on this thing, and definitely the teacher thinking through beforehand, like, these are the ways that kids may do this.

Vision grounded in context

The collaborative, learn-alongside nature of the learning experiences shaped principals' vision construction. As one principal noted, "I thought it was also particularly powerful in hearing from my other colleagues, from other team members, about what they saw that was an example of high-quality instruction, because some of those things are like, oh, I did not pick up on that. So I'm able to pick up on the sharing of ideas around high quality instruction." Others noted that engaging with the teacher unveiled aspects of the lesson previously unknown to them, such as the depth and rigor of the content standards.

Throughout the learning experiences and during the interviews, principals narrated the demands of being both a site administrator and instructional leader within the context of their district. Principals appreciated the opportunity to step out of the rush of their daily work. As one principal explained, the experience allowed leaders to "remove ourselves away from the nuts and bolts and the demands of the school day and just talk about the craft of teaching [which] is incredibly beneficial." Similarly, principals articulated the obstacles they faced to instructional improvement efforts, including pushback from teachers and continued stress from the Covid-19 pandemic. Detailing features of high-quality instruction within the district's context allowed them to create new narratives about what is possible in mathematics instruction given the constraints they faced. Moreover, the CBILE pushed against deficit notions perpetuated in the district context, which can be seen in this principal's comment: "And if we're able to see some wonderful things happening in a classroom, within our district, which is a bifurcated district, and on the side of the tracks, where you might not anticipate the same level of thinking and achievement because of all the other confounding factors. I think it's a pretty good, a pretty good selling point."

Expanding notions of vision

While principals globally praised the experience of participating in the CBILE, tensions emerged that shaped the construction of their vision of high-quality mathematics instruction. The design team conjectured that returning to the same classroom space would support principals in ignoring superficial aspects of instruction and instead attend to the details that mattered. However, this may have caused a tension for principals who are tasked with supporting teachers across a range of grade levels and years of experience. As one principal noted:

> I felt, maybe one of the issues was …, there was a singular focus and maybe a narrow lens on one- on one specific teacher. Right? We went into her class again and again, many times... I think we all agree it's a great classroom, and it's got great rapport. Without looking at a larger, like buffet of different teachers and different styles, I question, well, what else is out there? What other–what other things is a high? Where, what might be some other options out there?

The above quote also reflects questioning that surfaced regarding the forms of high-quality instruction. The four lessons were distinct from each other, though they included classroom routines that were repeated across lessons. While the teacher always started with students seated on the floor engaged in a think-pair-share, the task itself differed based on content and mathematics practice standards. During interviews, principals questioned the forms of instruction more than content specific nuances. It is possible that consistent classroom routines were a limitation of our design, giving the impression that there are only a few forms of high-quality mathematics teaching. However, this design feature surfaced a difference between researchers and leaders' perspectives. For principals, understanding the range of forms of practices became salient to their vision construction, even though the research community prioritizes understanding the function behind those forms (Munter, 2014).

Moreover, while the design of the CBILE intended to focus on specific aspects of high-quality instruction, the conversation went beyond the details of the lesson. District and school leaders asked how to transfer what they witnessed during the lesson to their school sites. During interviews this tension surfaced, as one principal stated:

> Because the teacher shared with us what they were doing, I had an idea of what the teacher's intent was, and an idea of what the teacher was trying to achieve, which standard she was looking at, her level of knowledge in regard to the progressions, she would provide for us an idea of where the kids had been. So, when I came into the class, I had an idea of what, what we might see the kids doing, I definitely felt the freedom and opportunity to look at student work, to talk to students, to get questions answered by the teacher. And I felt like I could hear my colleagues and also hear their concerns, their concerns about how this might look at their school site.

Discussion

When designing the CBILE, we drew from definitions of vision of high-quality mathematics instruction as an idealized classroom space. Our practice partners negotiated that definition within the contexts and realities of their work as school leaders. From a design perspective, this meant that on the one hand, visiting a classroom space and engaging as learners with the teacher provided an opportunity for principals to co-construct a vision of high-quality teaching that included elements recognized by the research community. On the other hand, other aspects, close to our practice partners' priorities, also became salient and expanded our understanding of the intricacies entailed in crafting coherence around instructional improvement across the multiple layers of school systems.

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What Does High-Quality Math Instruction Look Like? Elementary School Principals' Noticing and Their Mathematics Instructional Vision

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Abstract: Mathematics instructional vision and teacher noticing play an important role in high-quality teaching and might be also central for instructional leaders, yet there is limited research on both constructs for principals. In the context of a research-practice partnership focused on mathematics instructional improvement, we investigated the instructional vision and noticing of six elementary school principals. Qualitative analysis of interview responses and video noticing tasks reveals that principals pay most attention to aspects of the teacher's role and classroom discourse. In addition, greater levels of sophistication in their instructional vision are associated with higher sophistication in how principals notice. The results contribute to our understanding of what and how elementary school principals notice and how this relates to their vision of mathematics instruction. We discuss implications for the design of professional development focused on instructional leadership.

Introduction

Research on teacher learning has highlighted both a vision for instructional quality and the ability to attend to and interpret student thinking as important for responsive instructional practices (Munter & Correnti, 2017; van Es, 2011). When considering instructional change in their schools, it is plausible that both vision and noticing are also important components of principals' competence.

Instructional leadership includes the role played by school leaders in supporting teachers to enact high-quality instruction in their classrooms (Hallinger, 2018). The work that leaders do to support teachers' mathematics instructional practices is informed by their vision of mathematics instruction (Munter, 2014). At the same time, principals' noticing has a potentially important role in supporting teachers' noticing and their instructional practices. Even though teacher noticing is a fundamental component of teacher competence (Santagata et al., 2021) and has been studied from different perspectives, little is known about principals' noticing practices. We conjecture that principals' noticing and their instructional vision might be related, hence we ask: *What do elementary school principals notice about mathematics instructional interactions in video observation tasks?; How does their noticing relate to their vision of high-quality mathematics instruction?*

This paper reports on the initial analysis of data collected as part of a research-practice partnership and seeks both to contribute to the limited research on principal noticing (Amador, 2021) and to inform the design of professional development for instructional leaders.

Theoretical framing

Munter and Wilhelm (2021) define instructional vision as the "discourse that teachers or others currently employ to characterize the kind of "ideal classroom practice" to which they aspire but have not yet necessarily mastered" (p. 343). Munter (2014) developed an interview-based instrument, the Vision of High-Quality Mathematics Instruction (VHQMI) instrument, and corresponding scoring rubrics, that seeks to model the developmental trajectories of the instructional vision of educators. The instructional vision characterized in Munter's rubrics derives from decades of research in mathematics education, usually referred to as reform-oriented instruction, which promotes the teaching of mathematics for understanding and sense-making guided by students' mathematical thinking. This is operationalized in three initial dimensions: (1) *role of the teacher*, (2) *classroom discourse*, and (3) *mathematical tasks*. For each dimension, the VHQMI rubrics describe levels of progression ranging from an initial state that does not incorporate elements of reform-oriented instructional approaches to the most advanced level where the teacher is conceived as a knowledgeable other, a discourse community is described, and high-quality mathematical tasks are considered. Munter incorporates *student engagement in classroom activity* as a fourth rubric that emerges from the data collected in his interviews. This rubric only has two levels.

Teacher noticing encompasses the ways in which teachers pay attention to and make sense of what happens in the complexity of instructional situations (Sherin et al., 2011). Reform-oriented instruction in mathematics requires the ability to make decisions based on student thinking, which is a central component of teacher noticing. In her Learning to Notice Framework, van Es (2011) includes a rubric for *how* teachers interpret the events they notice. Considering analytic stances and levels of depth, the rubric characterizes a developmental trajectory of four levels: *baseline, mixed, focused,* and *extended*. Although the original focus of the framework is on students' mathematical thinking, the rubrics have been widely used in several studies and constitute a valuable guiding tool to characterize levels of sophistication of noticing shown by educators when observing a multitude of aspects of instructional interactions in mathematics.

Methods

Research context and participants

During the 2021-2022 academic year we partnered with six elementary school principals who were leaders in schools serving predominantly Latinx students. The leaders had between one and sixteen years of experience as principals and varied previous experiences as classroom teachers. The broader research-practice partnership with the local district aimed to provide tools to leaders so they could better support their teachers' mathematics instruction. Toward the goal of developing a shared vision of high-quality math instruction, principals engaged in four monthly classroom-based immersive learning experiences in a fourth-grade classroom at one of their sites.

Data collection

At the conclusion of the experiences, each principal participated in a semi-structured interview aimed at documenting both their vision of instructional quality and their noticing skills. Principals answered the question: *If you were asked to observe a teacher's math classroom for one or more lessons, what would you look for to decide whether the math instruction is high quality?* (Munter, 2014). They also completed two video observation tasks answering the question *What do you notice in this clip?* Two clips (of 1 min 11 sec and 1 min 06 sec) from a project directed by Kersting et al. (2012) were used. The first clip shows an interaction between the teacher and one student who provides an incorrect answer to a low-cognitive-demand task. The teacher develops a correct solution strategy in the student's notebook. The second clip shows a teacher-led whole-class discussion where one student shares an incorrect answer to a higher-cognitive-demand task. Two other students explain an alternative solution and the teacher facilitates the interaction. Both interview questions were followed up by additional prompts to come to a better understanding of both principals' vision and noticing. The interviews were audio-recorded and transcribed.

Data analysis

Two researchers analyzed qualitatively the interview transcripts, double-coding reliably 20% of the data and holding periodic meetings to discuss difficult cases and come to a consensus. For the responses to the video observation tasks, two rounds of coding were conducted. First, to characterize *what* principals notice, we started with an inductive coding approach. Secondly, the Learning to Notice Framework (van Es, 2011) was used to characterize the level of sophistication of interpretation of the noticed events (i.e., *how* principals noticed). We assigned a score from 1 to 4 (1=baseline, 2=mixed, 3=focused, 4=extended).

Instructional vision responses were coded using VHQMI (Munter, 2014) four rubrics: role of the teacher, mathematical task, classroom discourse, and student engagement. A score between 1 (low sophistication) and 4 (high sophistication) was assigned for each of the dimensions (except for student engagement where the maximum score in the VHQMI rubric is 2). The mean across the four rubrics was calculated by substituting the student engagement score for the score assigned in nature of the talk (a sub-dimension of classroom discourse), following Munter and Correnti (2017)'s methodology. This mean represents the overall level of sophistication of each principal's vision of high-quality mathematics instruction.

Findings

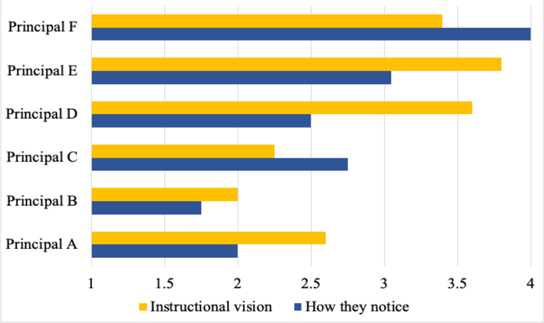
We first report on *what* principals noticed based on their observations of the two video clips. The focus of their noticing could easily be mapped onto three dimensions of Munter's rubrics: role of the teacher, mathematical task, and classroom discourse. Additionally, for the second clip, they also commented on culture and community, a code that emerged from the data. All participating principals made explicit comments about the role of the teacher for the first clip, identifying that the teacher took authorship of the mathematical ideas and did not elicit the student's thinking during the interaction, and the need for the teacher to further probe into the student's thinking. In addition, five principals noticed events related to the nature of the talk. They elaborated on the lack of student mathematical explanations, wondering how much the student did really understand. For the second clip, four principals characterized the role of the teacher as a knowledgeable other or a facilitator, and one of them talked about shared authority. In addition, principals focused on the patterns of the talk: five principals made explicit that it was a whole class/student-led discussion, where students shared their mathematical ideas.

Less attention was given to the mathematical tasks. None of the participants made comments about it in the first clip. In the second clip, only one of the principals noticed the mathematical intention of the task. Aspects of culture and community were highlighted only in the second clip. One of the principals noted that the students' thinking is valued both by the teacher and by students, and three other principals described the videotaped classroom as a space where students feel comfortable sharing their answers and helping their friends.

As mentioned above, we used the Learning to Notice Framework to score *how* principals noticed. We then adopted the VHQMI rubrics (Munter, 2014) to score their vision. Figure 1 reports noticing and vision scores for each principal (from 1 = baseline/low sophistication to 4 = extended/high sophistication), highlighting the association between the two.

Figure 1

Principals' instructional vision and how they notice



To illustrate these findings, we present excerpts from the responses of two principals representing different levels of sophistication. First, for the question about instructional vision, Principal F described an ideal mathematics classroom integrating fundamental notions of high-quality instruction with examples of practices:

> Well, the teacher is recognizing the assets of the students. So the teacher has some way of ideally recording and having a really good idea of what are the assets of the students. What are students able to do in math like, where are they on the progression. (Interview Principal F)

When observing the clips, principal F was able to highlight specific noteworthy events, using them as evidence to elaborate on and make connections to the implications they have for student learning:

> … and then she [the teacher] got it up on the board, she asked students to agree or disagree, which was good, give them opportunity to think through and own their own thinking. And then sure enough, the answer was in the room and kids use the tools. They have like, the one- the last girl talked about pizza, actually. So the pizza is her tool. And so she talks about- like- she had pizza, and sixths versus cutting it in thirds, is going to be much smaller if it's in sixths. (Interview Principal F)

This principal's responses were consistent across the two interview questions. The noticing task prompted an elaboration grounded in evidence from the video clips of ideas he shared about his vision. On the other hand, Principal A provides succinct answers that suggest beginning levels of sophistication. For the instructional vision question, she develops a generic description of her vision that in some passages is based on wonderings. This example is about the teacher's formative assessment practices:

> How's the teacher checking for understanding or changing on the spot if needed? Or bringing in different if it's too much? Or if it's too little? How are they shifting their instruction? (Interview Principal A)

In terms of her noticing, for the same clip principal F commented above, principal A briefly said:

> So that one was more of a student-led discussion. I mean, she [the teacher] wrote the answer in the board, and then there was discussion. (Interview Principal A)

Across both vision and noticing responses for this principal, we observe reference to general ideas (e.g., student-led discussion) without an articulation of the details present in the clip or of principles that guide a vision of high-quality mathematics instruction.

Discussion

Consistent with previous research (Amador, 2021), one of the predominant focuses of principals' noticing was the teacher's pedagogy. Secondly, principals' attention was placed on the students' involvement in the classroom discourse, with details of the mathematical work and thinking. One of the aspects that the principals did not comment on was the quality of mathematical tasks. This was surprising because, although the clips are brief, the task was described by the interviewer before playing each video. As Boston et al. (2017) argue, knowledge regarding the quality of mathematical tasks is essential for principals. These findings thus support the importance of intentionally incorporating in professional development for instructional leaders opportunities to consider the nature of mathematical tasks.

Noticed aspects of culture and community emerged when principals observed the clip that portrayed a whole-class interaction in the more reform-oriented lesson. This is important because high-quality mathematics instruction involves not only aspects of mathematical rigor and attention to students' thinking but also the affirmation of their culture, implementation of inclusive practices, and redistribution of mathematical authority, among other equity-related aspects. We are interested in exploring this further in our future analyses of the data, expanding our perspectives on principal noticing.

While instructional vision is understood as the discourse that is used to describe a dynamic vision of the future in terms of ideal teaching, noticing is a practice that involves attending to details relevant to mathematical learning that are happening moment-to-moment (in a clip or in live instructional situations). Not surprisingly, we found a positive association between the two. A vision for instructional quality is likely framing how principals make sense of what they notice. These findings suggest that creating opportunities to reflect on their instructional vision and refine their noticing practices might be a productive form of professional development for principals to support their instructional leadership skills.

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International Society of
the Learning Sciences

There is No "I" in Beans:
The Complex Organizational Structure of With-ness

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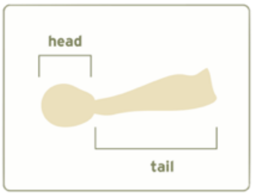
Abstract: While some learning scientists have begun to explore ensemble learning, the organization of shared activity across people and through time (Ma & Hall, 2018), little is still known about how groups develop the embodied instincts necessary to achieve such coordinated performances. This work explores the patterns and tools of social interaction that emerge in a group of university students learning advanced theatre movement techniques. Through the generative practice of increasingly difficult coordinated tasks (in this case, the act of throwing a sock full of beans in rhythm with each other), students begin to develop an instinct for and awareness of their body in relation to others in time and space. This study has implications for how individuals in groups achieve the embodied intersubjectivity necessary to learn as an ensemble.

Background

In recent years, the learning sciences have begun to theorize beyond the individual learner to include the interactions of such an individual in a group (Goodwin, 2017; Erickson, 2004; Kendon, 1990; Goffman, 1996; Meyer, Streeck & Jordan, 2017). Ensemble learning (Ma & Hall, 2018) in particular has opened the doors for examining how learners coordinate activity in a group that exists not as a collection of individual members, but as a collective *ensemble* that performs as one unit. Many learning scientists have begun to explore the markers of a "successful" ensemble, including the observed qualities of participating in or observing such coordinated groups (Barron, 2003). These are frequently theorized under the umbrella of "group flow" or "intercorporeality" defined as heightened consciousness (also known as *attunement*) emerging from full immersion in a group task (Sawyer, 2015; Stewart, 2010; Meyer, Streeck & Jordan, 2017; Leander, et al., 2023).

However, understanding how a group coordinates its actions can often be obscured by its own complexity, as participation in joint activity may change depending on various contexts or be lost in translation with a researcher who does not belong to the group (Ma & Hall, 2018). Similarly, given that ensemble learning necessarily occurs during group performance of a joint activity, little is known about how groups develop the embodied instincts necessary to achieve such coordinated performances. In theatre (i.e.: the craft, rather than the production of theat*er*), students are unique learners in that they must train themselves to intimately know where their body exists in time and space in order to adjust to the specifications of their role (Suzuki & Steele, 2015). As part of this training, actors practice ensemble-building so that they can prepare to perform coordinated movements with other actors. In a context that allows for the extracted study of the building blocks of *ensemble*, how do learners communicate and adapt their participation in order to achieve attunement?

Figure 1
Anatomy of the sock of beans (left) and exercise (right)



Round	Throwing & catching with	Part of sock
1	Both hands	Head
2	Dominant hand	Tail
3	Non-dominant hand	Head
4	Non-dominant hand	Tail

Methods

The following described exercise was observed as part of an ongoing ethnographic study of an advanced university theater movement class. During the exercise, 10 participating students were separated by the instructor into two groups of five, each group performing simultaneously. The researcher chose to focus on one group of five due to the vantage point of the camera, though analysis and findings were informed by observations seen in the corresponding group's footage. Interaction analysis (Jordan & Henderson, 1995) of the video data was conducted to reveal patterns of embodied communication. The data was also coded using V-note, a software that can track the duration of interactional events (here, throws and catches).

As a warm-up activity, five students are instructed to pass a sock full of beans in a circle. They are told to say each other's names as they throw the sock and are prompted by the instructor on when to change how they throw and catch the sock. During the activity, the instructor walks around the room observing and reminding the students to "focus on giving and receiving" in order to find their collective rhythm. They perform four rounds, each round increasing in difficulty relative to hand dominance and sock anatomy (see Figure 1).

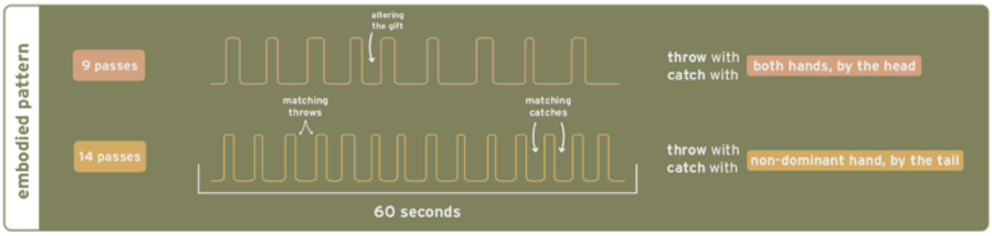
Findings

Overall, qualitative analysis revealed three major findings:

Finding One: As the task became more difficult, the group became more synchronized (see Figure 2). In the first round, where learners throw and catch the sock in a way that allows for the most control (two-handed, by the head), the actors prioritized adding their own flair to how they passed the sock over maintaining the group rhythm. Some actors choreographed unnecessary bows into their catches; others incorporated elaborate spins into their throws. Similar to Ma & Hall (2018)'s observed "tear", these were moments when the embodied flow of the collective was sacrificed. When actors changed the gifted tempo in order to add their own spin on the rhythm (see "altering the gift" in Figure 2) they disrupted the rhythm with which a throw was sent instead of continuing it. Despite the instructor's emphasis on "giving and receiving," these were moments when the actors focused more on "giving" (their contribution to the group) than "receiving" (listening to what the group suggested).

Figure 2

Coded patterns of throws and catches. Here, valleys represent time the sock was held; peaks represent time the sock was in the air; "altering the gift" indicates where a proposed rhythm was changed.

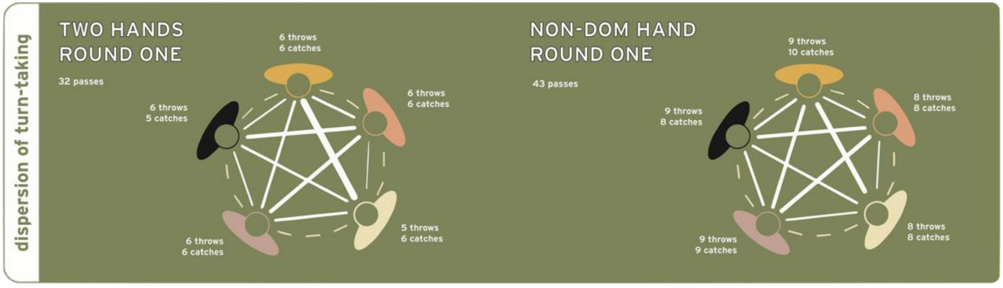


Note: "altering the gift" and "matching throws/catches" are not the only examples represented.

In comparison to the first round, the last round of the activity is much more difficult to execute with intentional control (non-dominant hand, by the tail). In these rounds, participants focused less on individual flair and more on executing the pass successfully, leading to an equal emphasis on the act of "giving" and "receiving." Throwers, less sure of their sock trajectory, entrained their body with the velocity of the sock so as to communicate how they intended to send it to their catcher. Catchers, in turn, entrained with the thrower to articulate how they planned to receive it. This embodied close listening between participants (see: Figure 4a and Figure 4c) allowed pairs to throw and catch with more regularity, as they were able to more clearly replicate the rhythm sent to them. This shifted the focus of participation from an individualized "giving" act to a coordinated *giving-receiving* act that involved both throwers and catchers.

Figure 3

Turn-taking across Round 1 & 3. White line width represents bi-directional throw/catch data.



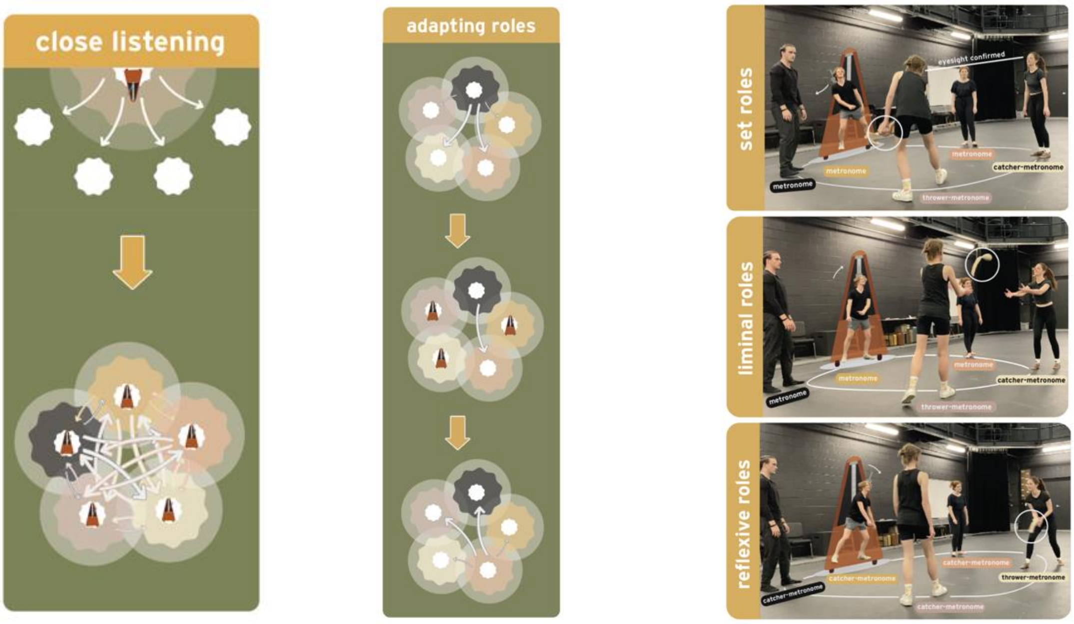
Finding Two: As the task became more difficult, the group shared turn-taking more uniformly across participants (see Figure 3). While the amount of throws and catches was shared well between participants across rounds (visible in the amount of throws and catches in both turn-taking webs in Figure 3), bi-directional throw/catch data revealed more prominent pass-relationships in rounds where participants had more control (two handed or dominant hand). In these 'easier' rounds where hand-eye coordination is less of a concern, actors could control to whom the sock would go, frequently favoring similar pass-relationships.

However, as the task became more complex (introducing non-dominant hand), the pass-relationships appeared more evenly distributed. In these rounds, participants focused less on *to whom* they were sending and instead on *passing* successfully. This required each member to remain in "receiving" mode, attuned to the adapting roles within the group and prepared to flex into what was needed (Figure 4b). This finding revealed a shift away from the group acting as a *collection* of individuals and towards the group as an *ensemble*: rather than determining a singular *who* is giving and *who* is receiving, the participants acted as a *collective* focused on a shared goal of *passing.*

Finding Three: The group achieved a flow state when they inter-determined their tempo based on shared attunement to the rhythm of passes instead of following the tempo set by one person. Rather than a 'conductor' to an 'orchestra' organizational system, each participant became their own metronome attempting to synchronize with other 'metronomes' in the group (see Figure 4a). This role negotiation was supported by the fact that regardless of role prominence in the group (e.g., thrower and catcher could be classically considered 'more prominent'), every actor participated in each exchange by embodying the rhythm of the passes so as to communicate how they all understood the rhythm (see Figure 4c for an example of this *metronoming* phenomenon). The more entrained individuals were to the rhythm of the sock passes– the more *metronome*-like their embodiment– the more responsive to the role outcomes of the activity they were. The more responsive the players, the more stable the group rhythm was.

Figure 4

(a) The interactional practice of close listening. Rather than a conductor model (above), the group regulated their tempo reflexively (below), (b)Embodied role adaption, where actors negotiate being thrower/catcher and continue to support the process by attuning to the sock rhythm, and (c) Example of adapting roles in the activity, including an actor who visibly attunes to the trajectory of the sock in a "metronoming" movement.



(a) (b) (c)

Discussion & implications

The three findings suggest a progression from a group of individuals to an ensemble. As the task became more difficult the group became: 1) more synchronized; 2) more even in their distribution of turns; and 3) more attuned to one another. A discovery like this may feel counterintuitive for actors, given that more skilled performers are often associated with more intentional control over their actions. However, this study demonstrates that in order to become an ensemble, the actors did not relinquish control, they *shared* it: they conducted complex negotiations of tempo through the embodied trajectory of the passed sock. Additionally, this study demonstrates that in order to maintain a successful flow, all participants in the group need to actively participate in those negotiations. It was not enough for a leader to set a rhythm for others to follow– each actor needed to know how to entrain and adapt their personal rhythm in advance of their turn to pass. Unlike collectives where individuals take obvious turns taking the lead, such as in a jazz ensemble, each participant had an equal hand in generating the emergent rhythm of the group. The rhythm arises as an emergent, entangled act where the actions of each part of the collective simultaneously influence the other (Barad, 2007).

Ultimately, ensemble learning and ensemble dynamics are still greatly understudied. While "tears" (Ma & Hall, 2018) in flow can be made visible to outsiders (here, “altering the gift”), how learners move from being a group (a collection of individuals) to being an *ensemble* (a collective, functioning as one unit) is less evident. Through the articulation of how the constraints of a task allowed individuals to transition into a collective “receiving” role with a unified goal, as well as the emergent *metronoming* phenomenon that arises as a result of the achieved flow state, this work attempts to shed light on some of the complex organizational structures in place for role bartering and balancing in small-scale ensembles. While the insights gained from observing students passing a sock full of beans alone cannot speak to all of the challenges that accompany collaborative learning, the understandings gained from how these actors learn to listen to and attune to each other holds great promise for advancing our understanding of ensemble dynamics and learning.

There is much more to group dynamics than how members of a group build on each other's contributions. Transactional accounts of interaction and knowledge building do not go far enough towards developing an understanding of the co-construction and interdependence of turns within an interaction (Erickson, 2004). This work shows that turns (and by extension the content of what we share with others) is also shaped by other people– what Goodwin calls recipient design (Goodwin, 2017). As groups become ensembles, they become attuned to each other and share agency in the construction of shared understandings. At least at the minute scale, it encourages us as learning scientists to expand how we think of participation: as an entangled act of *passing* rather than individual modes of *giving and receiving.*

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Perceptions Predict Problem Regulation? The Role of Homogeneous Problem Perception for Successful Regulation in Collaborative Learning

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Abstract: Collaborative learning does not always yield positive results. One problem might be that group members have different problem perceptions and fall short in homogenizing them. Yet, little is known whether a homogenous problem perception and an awareness of the homo- vs. heterogeneity of their problem perceptions enhance the regulation process. In this study, *N*=310 pre-service teacher students collaborated online in a problem-based leaning scenario. Afterwards, they answered an online questionnaire to measure their problem perceptions, their awareness of the homo-/heterogeneity of their perceptions, and different indicators of regulation success. Path models indicated that homogeneous problem perceptions enabled regulation success. Learners should thus be scaffolded to achieve homogeneous problem perceptions.

Problem background

Despite its theoretical potential (e.g., Chi & Wylie, 2014), collaborative learning does not always lead to success (Weinberger et al., 2012). One reason is that the collaboration process may be aggravated by a range of problems that need to be regulated by the group (e.g., Järvenoja et al., 2013). To do so, learners first need to identify the problem (Borge et al., 2018). In collaborative learning, though, each group member has their own problem perception, and these problem perceptions may either be heterogeneous (i.e., group members have different perceptions of the current problem) or homogeneous (i.e., group members have the same perception of the current problem). The homogeneity or heterogeneity may affect the regulation process within the group (e.g., Melzner et al., 2020), and thus be decisive for whether the problem is regulated successfully. This paper thus explores how a homogeneous problem perception during collaborative learning influences different learning outcomes.

Problem regulation and homogeneity of problem perception

Problem perceptions of the individual group members may be similar (i.e., homogeneous) or different from each other (i.e., heterogeneous). If all learners believe that a limited productivity is caused by insufficient prior knowledge, they perceive the problem homogeneously. If, however, one group member believes that the unsuccessful learning session is caused by a lack of knowledge, while another group member attributes it to an uninteresting leaning content, the learners have a heterogeneous problem perception, which might hinder the regulation process, as the different group members may use different, possibly incompatible regulation strategies to overcome the problem. A homogenous problem perception, in contrast, might benefit group learning, as the selection of appropriate regulation strategies may be easier (e.g., Borge et al., 2018).

Awareness of a homogeneous problem perception

However, even if group members have the same perception on occurring regulation problems, learners could be unaware of their homogeneous problem perception. The same holds true for learners with heterogeneous problem perceptions. Although one group member might believe that the unsuccessful learning session is caused by a lack of prior knowledge, while another group member may attribute the slow progress to an uninteresting leaning content, both could be convinced that the other group members perceive the situation the same way they do. It is still rather unclear how learners homogenize such a heterogenous problem perception. If, however, learners know that the problem perception differs within the group, they could deliberately try to counteract these heterogeneous perceptions. More specifically, if a learner realizes that his or her own perception is different from the perception of another group member, he or she can initiate regulatory activities to achieve a more homogeneous view (Borge, et al., 2018). Consequently, it seems more likely that learners who are aware of potential discrepancies in the problem perceptions choose regulatory activities to deal with this situation on a group level.

Homogeneous problem perception and regulation success

Homogeneous problem perceptions and awareness of a homogeneous problem perception should increase regulation success (e.g., Melzner et al., 2020), which can manifest in different ways. According to Hadwin et al.

(2018), for example, regulation occurs when learners individually, as well as in interaction with each other, adjust their cognitions, motivations, and/or their emotions. To arrive at successful regulation, a homogeneous problem perception appears to be a necessary precondition. In other words, regulation success would be high if group members successfully solved their problems and improve their learning experience and/or their knowledge gain to a satisfying level. In this paper, we differentiate between four dimensions of regulation success: (a) satisfaction with the group's collaboration process, (b) perceived success of coping with the group's regulation problems, and (c) subjective, as well as (d) objective knowledge acquisition.

Research questions

This paper focuses on the association of (1) actual homogeneity regarding the individual problem perceptions (IPP), and (2) the awareness of the IPPs with regulation success measured by (a) satisfaction with the collaboration process, (b) perceived success of coping with the group's regulation problems, (c) subjective knowledge acquisition, and (d) objective knowledge acquisition.

Since both homogeneous problem perceptions (e.g., Melzner et al., 2020) and an awareness of the group learning process (Borge et al. 2018) seem to be important for group regulation, we hypothesized that homogeneity of IPPs, and accurate awareness of the problem perception within the group would be associated with higher (a) satisfaction with the collaboration process (H1a and H2a), (b) perceived success of coping with the group's regulation problems (H1b and H2b) and, (c) subjective (H1c and H2c) as well as (d) objective knowledge acquisition (H1d, and H2d). For a deeper understanding of the regulation process, we further exploratively analysed video recall interviews, which took place about one week after the group session.

Method

Sample. Initially, N=405 pre-service teachers (M_{age}=20.61, SD=5.01, 77.28 % female) participated. We embedded the study as a learning exercise into the course content of 15 seminars. All students participated on a voluntary basis. N=310 students provided data for the main data collection (t1) and the post-test (t2). N=111 collaborative learning groups from which at least two group members answered the questionnaire were included in the analysis.

Procedure. During the first session, students collaborated in small groups online via Zoom in a problem-based learning scenario in which they had to analyse a case vignette that described a difficult classroom situation. Each group was video recorded. After the group session, participants answered an individual questionnaire. In the second session, one week after collaboration, participants completed a knowledge test. In four groups at least two group members agreed to participate in a post-hoc video recall interview, one week after the knowledge test. During the interviews, we showed each member from the same group one identical video excerpt from their group session and asked them to describe the respective situation and estimate whether they believed their groups members would agree with their problem perception.

Instruments and Analysis. Participants rated the extent to which 33 problems occurred during their collaboration, on a 5-point Likert-scale (3 items per problem, e.g., „Single/multiple group members lacked prior knowledge of the learning content"; on average α=.78). We selected these problems based on prior literature (e.g., Järvenoja, et al., 2013). Then, we calculated the difference of the individual problem ratings of each single group member from the average problem ratings of the rest of the group for each of the 33 problems separately. As a measure of *actual homogeneity of IPPs*, we used the average mean of these differences across all problems and multiplied it by –1 to get a measure of homogeneity instead of heterogeneity. To determine *awareness of homogeneity*, first, participants had to rate their perceived homogeneity of IPPs with six adapted items from Menold (2006; e.g., „I believe that my problem perception is different from the problem perception of the others"; α =.70). Next, we calculated the absolute difference between the z-standardized homogeneity of the IPP and the perceived homogeneity of IPPs and multiplied the score with -1 so that learners whose perceived and actual homogeneity aligned more received higher scores. We determined regulation success with: (1) *satisfaction with the group's collaboration process* which was assessed with five adapted items from Glaesmer et al., (2011; e.g., "I am satisfied with our group work.".; α=.92), (2) *perceived success of coping with the group's regulation problems*, for which we adapted four items from Engelschalk et al. (2016; e.g., „My group managed to successfully solve the problems that arose during group work."; α=.93), (3) *subjective knowledge acquisition* which was measured by 9 adapted items from Ritzmann et al. (2014; e.g., „I have the impression that my knowledge of Piaget's/Selman's/Kohlberg's theories has increased. "; α=.94), and (4) a multiple-choice test consisting of 36 statements (1 point for each correct answer) to assess *objective knowledge acquisition*. For analysis, we used the manifest scale means of the self-report measures and the percentage of correct answers for the multiple-choice test in addition to the homogeneity variables described above. We calculated a path model (see Figure 1) with a maximum likelihood estimator using lavaan version 0.6.11 (Rosseel, 2012*)*.

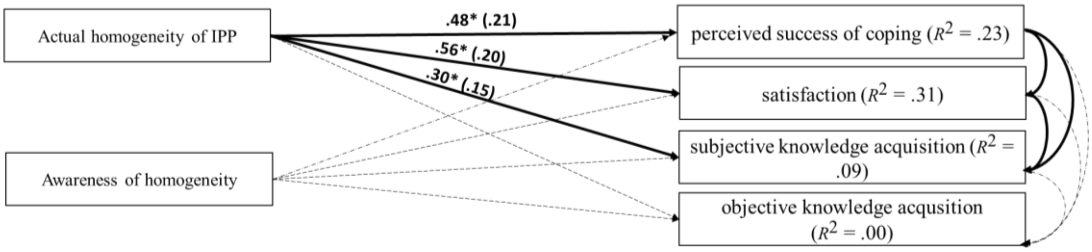
Results

Path model

The path model revealed that actual homogeneity of IPPs significantly predicted satisfaction with the collaboration process, perceived success of coping with the group's regulation problems, and subjective knowledge acquisition (see Figure 1). However, it did not significantly predict knowledge acquisition (H1d). Awareness of homogeneity neither predicted satisfaction with the group learning process, perceived success of coping with the group's regulation problems, subjective knowledge acquisition, nor objective knowledge acquisition (H2a-2d).

Figure 1

Path model with homogenous problem perception, awareness of homogeneity and regulation success



Note. Presented are only significant standardized coefficients (standard errors) *$p < .001$.

Interviews

For a deeper understanding of our results, we analysed two interviews of a group in which the group members had a rather heterogeneous problem perception based on the actual homogeneity of IPPs.

Excerpt from interview with group member A

> I: Then I would like to ask you: Describe, what just happened.
> L: I think we were unsure what exactly the task was, so we were unsure where to start working, how we could divide the group work, because we had no idea what exactly the goal was. (…)
> I: What do you think how the others perceived the situation? Do you think that their perception coincided with yours?
> L: Yes, I think so. Otherwise, somebody would have said something or helped me, or said whether we have to do it like this. But I think we as a group were on the same page.

Excerpt of interview with group member B

> I: How would you evaluate this situation?
> L: I think I evaluated it a little bit negative, because I had the feeling that the others had no real interest. (…) But I did not know, how to get these concerns across to the others or how to talk to them, to engulf them into a conversation that continues.
> I: Do you think that the other group members perceived the situation like you?
> L: I can imagine that it differed because everyone has different views and backgrounds, and I can only guess what they thought by the way they acted, but it is also possible that it is completely different.

Summary

The problem perception of the group members clearly differed. A mentioned that the group was unsure what exactly the task was. B, in contrast, expressed that the other group members did not feel like doing something. B realized that there might have been heterogeneous problem perceptions. However, he or she was still unsure how to regulate this situation. The group reported low regulation success compared to the overall sample (perceived success of coping with the group’s regulation problems: *M*= *3.42, SD* = 1.63, satisfaction with the group’s collaboration process: *M*= 3.40, *SD*=1.20; subjective knowledge acquisition: *M*= 3.00, *SD*= 1.20).

Discussion and practical implications

As expected (e. g., Melzner et al., 2020), actual homogeneity of IPP was associated with satisfaction (H1a), perceived success of coping with the group's regulation problems (H1b) and self-reported knowledge acquisition (H1c). Consequently, educators should develop ways to support groups in how to reach a homogeneous problem perception. However, instructors should consider that awareness of the homogeneity of the problem perception did not correlate with regulation success (H2a-2d). This finding indicates that even when learners are aware of their heterogenous problems perception, they might not try or be unable to regulate discrepancies and develop a homogeneous perception. The interview data supports this assumption. Here, even though a group member knew that the problem perception within the group was heterogeneous, he or she was still unsure on how to deal with this situation. Consequently, group members should not only be made aware of their different perceptions, but also be supported to achieve homogeneity. Potential support options might combine group awareness tools with prompts (e.g., Schnaubert & Bodemer, 2018).

Limitations and outlook

Analysis of video recordings might uncover the extent to which learners engaged in knowledge generating activities (e.g., Chi & Wylie, 2014) and consequently might explain why homogeneous problem perceptions did not significantly predict knowledge acquisition (H1d). Video analysis might also investigate if homogeneous problem perception indeed leads to a more coordinated selection and use of suitable strategies. Despite these limitations, our study helps to understand problem regulation and how it should be supported.

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Middle School Learners’ Uncertainties and Their Triggers During Collaborative Engineering Design Tasks

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Abstract: Uncertainty experiences are crucial for solving collaborative engineering design problems. They shape the teams’ design trajectories and affect their uncertainty management approaches. In this paper, we investigate the types of uncertainties that learners at the middle school level experience while they collaboratively solve an engineering design problem and examine how these uncertainties are triggered. We analyzed learner interactions of five teams of sixth and seventh graders from two different studies and identified seven types of learner uncertainties. We also found that the process of *Noticing* is central to learners’ uncertainty experiences and is triggered by various external cues or situations.

Introduction

Research has shown that when learners are exposed to uncertain situations, it provides them opportunities to develop problem-solving skills and acquire new knowledge (Manz, 2018). However, in the case of open-ended problem-solving situations that are collaborative in nature, such as engineering design, knowledge is often unclear, ambiguous, and constantly changing. Making decisions in such cases and dealing with the complexities of collaborative contexts can become challenging, especially for young learners (Dym et al., 2005). Previous work also shows that learners are not always driven to ‘learn’ when they face uncertainty and usually fail to acknowledge the need to address them (Kaur & Dasgupta, 2022). Therefore, it is crucial to comprehend learners’ uncertainties since they reflect the most significant issues they encounter and also shape their interactions.

Even with a growing emphasis on engaging young learners in ill-structured problem-solving, we have little understanding of what kind of uncertainties learners experience and what processes lead to those experiences (M. E. Jordan & McDaniel, 2014). Developing scaffolds to engage learners in uncertainty management productively requires a deeper understanding of what questions or issues matter to learners and how different factors influence them. We can leverage learners’ uncertainty experiences and orient them in productive directions only when we understand their inherent nature and how they emerge during learner interactions naturally. Therefore, in this paper, we tap into these issues and investigate the following research questions: What type of uncertainties do learners experience? And how these uncertainties are triggered during a collaborative engineering design activity.

Method

To answer our RQs, we analyzed learner interactions of five groups of middle school learners. The data came from two studies where groups solved an engineering design problem given to them. In the first study, two groups of seventh-grade learners (Group A (2 participants) and Group B (3 participants)) designed a cleaning robot while optimizing the design cost using the LEGO Mindstorms^{TM} kit during a one-day study conducted in a workshop mode. The second study was conducted with three groups of sixth-grade learners (Groups C (4 participants), Group D (3 participants), and Group E (4 participants)) who designed a balloon-powered toy vehicle with the objective of maximizing the distance. This was an in-class study spread over four days (1 to 1.5 hours each day) conducted in a large public school in India. Along with two primary observers (who are also the authors of the paper), teaching assistants from the same department were also present in both studies to handle the logistics and also mentor teams from time to time.

The data analysis started by identifying the uncertainty instances where learners externalize their uncertainties. These expressions were captured using a coding scheme by Jordan et al. (2014), which uses markers like hedges, probabilistic statements, and non-verbal indicators. A total of ninety-four instances were identified and analyzed from the two studies combined. The data analysis process was inductive, and we used interaction analysis methods (Jordan & Henderson, 1995). To interpret types of uncertainties, we asked ourselves: What aspects/issues concerning the content-related or interpersonal uncertainties do learners experience? Following the inductive coding method, we started labeling the identified uncertainty instance with short text segments explaining what the uncertainty is about. We then combined the overlapping and redundant themes into categories, finally refining them into broad themes describing the types of uncertainties expressed by learners.

To understand how uncertainties are triggered, we asked the following questions: What situations or cues lead to learners expressing uncertainty? And What factors influence learners’ uncertainty experiences? We prepared detailed descriptions of related learner interactions for each uncertainty instance to trace critical moments and situations connected to how uncertainties are triggered. Along with the uncertainty episodes, we also analyzed the neighboring events to make sense of processes that led to learners experiencing different types of uncertainty.

Initially, three researchers independently analyzed Team A episodes, followed by extensive discussions to resolve discrepancies in the initial findings. The codes and descriptions were then iteratively refined through elaborate discussion sessions among the three researchers while simultaneously analyzing data from the remaining teams.

Findings and discussion

In this section, we will first discuss the types of learner uncertainties identified in our data. Next, we describe how these uncertainties emerge while learners collaboratively resolve the design problem.

Types of learner uncertainties during collaborative engineering design activities

We found that learner uncertainties during a collaborative engineering design activity can be categorized into broadly seven themes (T1 to T7) as described below:

Uncertainty pertaining to problem definition (T1)

Learners experience uncertainty related to understanding and redefining the problem parameters. For example, this may include clarifying the objectives that they need to fulfill, identifying constraints that must be met, and defining functions that their design should be able to perform. For example, in the excerpt below, we see that a participant from Team C expresses her uncertainty about whether the *"looks"* of the vehicle matter (line 1) and whether it should be included as an objective to fulfill (line 3). The other participant also related it to the client's expectations (kids as end users) and acknowledged it as an essential design aspect (line 2).

1 Pooja: Does looks matter?
2 Krish: It is a toy for kids. Looks will matter.
3 Pooja: We have to decide if it is one of our goals to make it beautiful. Will we get extra credit for that?

Uncertainty pertaining to the conceptualization of solution (T2)

Most learner uncertainties are about conceptualizing the solution-related aspects. For example, this includes understanding the required domain concepts, coming up with alternatives, selecting appropriate materials, deciding the shape and structure of their designs, and choosing optimal options.

For example, in the case of Team B, while exploring the materials kit, a participant, Shilpa, expressed uncertainty about using different cleaning materials provided to them. She suggested an idea about how to use a cleaning mop. This was followed by a discussion about different possible alternatives for placing the materials, where another participant, Karan, added to her idea and suggested an alternative placement option. Finally, Shilpa suggested finding and using a *"broom"* like material to swipe away the dry waste.

Uncertainty during troubleshooting an issue (T3)

Many uncertainties are experienced when learners troubleshoot issues during the prototyping phase. These uncertainties are usually triggered when learners struggle to determine the causes of failed trials or make sense of unexpected or contradictory outcomes.

For example, in an episode from Team A, the team faced uncertainty regarding why their robot was not moving as expected. A participant, Sneh, expressed his uncertainty by writing it on a post-it note, saying, "*Why is it acting like a horse?*" as their robot moved with breaks and jerks. They had made earlier attempts to resolve this issue by making several changes to the program code; however, they were unsuccessful in correcting it.

Process-related uncertainty (T4)

Learners also express uncertainties when they do not know how to proceed further. These are uncertainties about what steps they should take next, both with respect to resolving the uncertainty and making progress in the overall design process. For example, in the example discussed in T3, when the participants could not resolve the issue they were facing, Sneh felt uncertain about what they should do next. Additionally, the repeated unsuccessful attempts, and another participant, Aditi's action of abruptly dismantling their current design made him feel confused and panicked. This further added to his uncertainty about what steps to take next to resolve their uncertainty.

Anticipatory uncertainty (T5)

Learners also anticipate future events, especially feeling uncertain about the expected outcome of their actions, decisions, and uncertainty management approaches. They specifically wonder whether they will be able to complete on time, if they will perform better than other teams, and whether their plans will work out as expected. For example, the following expressions from different participants indicate learners' uncertainties about the future: *"What if we do not complete on time?"; "Do you think our car will be the fastest?"*; *"It isn't easy. Will we be able to make it?"*; "*I am not sure if this will work out."*

Reflective uncertainty (T6)

Learner uncertainties can be reflective in nature, where they contemplate their present or prior actions to resolve their doubts and confusions. In these cases, learners may express uncertainties related to the propriety of their decisions, whether they are on the right track, and if and how they should regulate their actions.

For example, in the case of Team C, the team reflected on the previous experiments they performed to test which nozzle straw to use and expressed their uncertainty about changing their strategy. This initiated a discussion where participants reflected on why their earlier experiment failed. For example, Krish said, "*We were testing it without attaching everything. That is why it did not work. How did you decide then?*" Then they discussed how they should regulate their approach to deciding which nozzle straw to use. For example, Pooja suggested, "*Let's ask sir which one to use.*" And Krish recommended completing the construction of the vehicle first and then testing each straw one by one.

Relational uncertainty (T7)

Learners sometimes express uncertainties regarding their own and peers' roles in uncertainty management. For example, learners can experience uncertainties about what actions or behaviors are expected from them (by their peers or teacher/mentor) in a situation of uncertainty, how other team members perceive them, or uncertainty about their own or their team members' roles and positioning in the team.

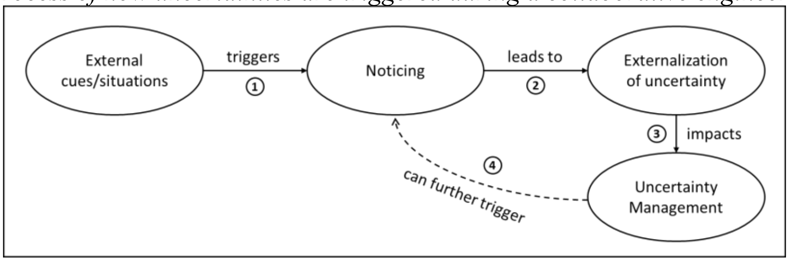
For example, in the case of Team E, one of the participants, Shreya, kept expressing her uncertainty about why her teammates were doing everything alone and how she should participate in the problem-solving tasks. For example, she repeatedly asked them why they were not *"turning around"* and doing things *"together."* When they did not listen to her, she finally asked them if they would ever include her in the decision-making process.

How are learner uncertainties triggered while they solve an engineering design problem?

While analyzing data to understand uncertainty triggers, we found that the *Noticing* process mediates uncertainty experiences. Particularly, we observed the following relationship trail*: The external cues/situations trigger the Noticing of critical information leading to the experience and hence externalization of uncertainty.* This process often impacts what type of uncertainties learners experience and how they respond to them. We show these connections through a schematic representation in Figure 1 and elaborate on its components below:

Figure 1

Process of how uncertainties are triggered during a collaborative engineering design activity



Noticing means actively selecting and interpreting relevant information in a situation (Lobato et al., 2012). Our analysis shows that *specific external cues or situations often trigger Noticing* while learners collaboratively solve a problem *(connection 1 in figure 1),* leading learners to externalize the uncertainties they experience *(connection 2 in figure 1)*. In our data, these cues majorly included – (a) Materials and artifacts, b) Peers' actions, (c) Mentor's intervention, and (d) Unexpected or contradictory outcomes.

In both studies, the teams spent a large chunk of their time dealing with uncertainties that concerned the *materials provided to them*. These were – *How to select and use the cleaning materials for building the robot?*

(Study 1) and *Which one of the three different-sized straws to use as a nozzle for building the balloon-powered toy?* (Study 2). Materials provide a good starting point for teams to begin thinking about how to solve the problem. Therefore, in all the teams, we saw that the moment teams are given the materials kit, they divert all their attention to it.

The relational uncertainties are usually triggered when learners notice oddities in their *peer's actions and behaviors.* For example, in Team E, Shreya noticed that her teammembers Kartik and Sehaj are not including her in any discussions or decision making and even ignoring her suggestions and inputs. This led her to express her uncertainties regarding her role in the team and her doubts regarding how her teammates position her.

Learners' uncertainties are also influenced by *how a mentor intervenes* during learner interactions. For example, in the case of Team C, we found that the questions posed by the mentor, where he asked a team member about the justification for a decision he made on behalf of the team and then doing careful counter questioning on his responses, acted as reflective prompts for the team. It enabled them to notice the gaps in their knowledge and realize the need to gather more information. However, there were also cases where the mentor's intervention was not fruitful. For example, in the case of Team B, even when the mentor asked learners to "*discuss," "think about,"* and *"pay more attention to"* how to optimize cost and simultaneously build a sturdy robot, team members ignored these suggestions. They kept thinking about how their robot should look better than the other team.

The other prominent factors that triggered most uncertainties were *unexpected or contradictory outcomes* or *failure during the prototyping and troubleshooting phases.* Such situations initiate conversations among team members where learners reflect on their actions or decisions (T6), identify knowledge elements needed to troubleshoot issues (T3), or even wonder about process-related uncertainties (T4).

There were also situations where *Noticing* was not directly triggered due to any external cue but rather resulted from the uncertainty management processes where learners strived to maintain uncertainty. This happens when learners engage in deep discussions to resolve uncertainty. This is because expanding on different aspects of uncertainty makes the interconnected issues more visible. In such cases, managing uncertainty triggers noticing and hence results in the externalization of connected important uncertainties *(Connection 4 in figure 1).*

We found that different situations trigger different learner responses to uncertainties. For example, situations of failure can cause learners to notice important variables they need to test to resolve the issue (uncertainty related to troubleshooting). In the same case, learners may notice that they may not be able to resolve the issue due to a shortage of time, causing them to experience anticipatory or process uncertainties. These different situations impact how learners respond to uncertainty, i.e., the strategies they use to deal with it, as represented by *connection 3 in figure 1.*

Conclusion

The findings give us insights into different learner uncertainties and factors triggering *Noticing* when middle school learners engage in a collaborative design activity. The analysis showed that learners could perceive the same information differently and do not naturally notice relevant details by themselves. Therefore, learners should be scaffolded in a way that they not only notice what is critical for their problem but also find it meaningful.

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“It Was… Frustration That I Inflicted on Myself Because I Wanted to Know”: An Elementary Preservice Teacher’s Vexation About Responsive Teaching

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Abstract: There is a growing consensus on the significance of tailoring instruction mindful of students’ resources, which is known as responsive teaching. When encountering such student-centered pedagogies, teachers often express vexations - feelings of concern and discomfort. This case study surfaces one elementary preservice teacher’s (PST) vexations as she was sensemaking about responsive science teaching during a science methods class when her vexations became the *disciplinary substance* of the instruction. We described an iterative cycle of vexations, starting when this PST was positioned to wrestle with figuring out phenomena for herself. As she worked through these vexations, she began recognizing her resources and reflecting on her past experiences and realized how “*powerful*” her learning experience was, which resulted in additional vexations yet a shift in her perspective towards science.

Introduction

The recent reform in science education presents a vision for science learning in which students develop science proficiency by figuring out phenomena from the physical world. This requires them to draw on their resources (meaning their prior knowledge and experiences) to connect with scientific concepts through discursive practices and to negotiate their ideas with peers. While students are expected to wrestle with why and how questions when they are situated as sense makers, teachers need to attend to and pursue students' ideas and experiences and tailor their instruction accordingly. This is called “responsive teaching” (Hammer et al., 2012; Robertson et al., 2016). A growing body of research suggests that novice teachers often express concern and discomfort – which may signify the presence of *vexations* in this study -- when encountering this unfamiliar approach (Jaber, 2021; Radoff, 2017; Robertson & Atkins Elliot, 2020). The term *vexations* refers to feelings of discomfort, bother, or unease as learners engage in the learning process when something does not make sense or the learner identifies an inconsistency in their knowledge (Jaber, 2021; Odden & Russ, 2019). When the notion of vexations is applied to understanding teacher learning, we begin to see that teachers often face ambiguities and uncertainties when engaging in a new pedagogical approach. These vexations emerge when teachers try to reconcile the norms of traditional instruction with their attempts to be responsive (Robertson & Atkins Elliot, 2020; Robertson & Richards, 2017). While much of this work has emerged in secondary and post-secondary science classrooms, less is known about the vexations experienced by elementary preservice teachers (PSTs) as they make sense of responsive teaching.

The role of vexations

Scholars argue that vexations can be critical sensemaking moments when learners experience and then work through conflicts in their learning (e.g., Jaber, 2021; Jaber et al., 2022; Radoff et al., 2019). From the asset-based perspective, when teachers are engaged in *responsively facilitated scientific inquiry* and provided spaces to articulate their vexations and share and interact with peers, vexations are found to function to trigger or sustain sensemaking and evolve into productive resources to gain perspective and sensemaking about responsive practices (Gray et al., 2021; Jaber, 2021; Radoff, 2017; Robertson & Richards, 2017; Smith & Southerland 2007). In this study, we examine a PST’s sensemaking process about responsive science teaching, which surfaced her vexations. Moments of vexation are identified as instances when PSTs articulate uncertainty and ambiguity, problematize knowledge or experience, raise a question, and construct meaning, often accompanied by a display of affect (Jaber, 2021; Robertson & Richards, 2017).

Methods

The data for this study are drawn from a science methods course in an elementary education degree program in which elementary PSTs engaged in a series of scientific investigations, video case study analyses, and discussions centered on responsive teaching pedagogies. During the investigations, PSTs were presented with a phenomenon and encouraged to make observations, create models, and ask questions to surface their ideas and experiences. PSTs were left with their lingering ideas between classes (~2 days) to provide them with time and space to wrestle with their ideas about the phenomenon. In tandem, the PSTs explored a series of video case studies in which elementary students work to explain scientific phenomena. The PSTs answered questions focused on their ideas about the substance of students' sensemaking and the instruction that allowed for the elicitation of that sensemaking.

Participant: Harper

Using a case study approach, we focused on the experiences of one Black woman, Harper (a pseudonym). At the outset of the class, she expressed to the teacher "I hate science. No disrespect, ma'am". Her openness in sharing her views, questions, and feelings made her a particularly informative participant, as it was evident that she consistently tried to work through her vexations by actively participating in discussions. In addition, she often provided cues to her thinking by using her gestures (e.g., facial and body) animatedly. For instance, when offering her ideas to the class, she often used her hands to express frustration and her face (e.g., smiling or frowning) to indicate when she was satisfied or dissatisfied with an idea. The shift in Harper's expressions toward science and science teaching was distinct as the weeks progressed.

Data and analysis

Data were drawn from classroom recordings, class artifacts (e.g., discussion board posts and exit tickets), and interviews. After collecting the participant's consent to the study, we focused on observation and in-depth data collection to understand the focal participant's vexations in a targeted way. The first round of data analysis was to examine available data sources for Harper to tag data that suggested possible movements of vexation. For this, we searched for when she problematized any experience or practice which did not make sense to her (i.e., raised a question or expressed uncertainty and ambiguity) and/or displayed an affect, such as confusion, frustration, discomfort, or excitement (Allen & Penuel, 2015; Jaber, 2021; Radoff et al., 2019; Robertson & Atkins Elliott, 2020; Robertson & Richards, 2017). Harper's vexations were then tracked, to see whether they were surfaced during her learning process again or how these vexations shifted over time and across activities. This led us to identify whether there is a pattern in the vexations of Harper. For example, in one of the initial reflections, Harper noted '*Thinking back over the week, my thinking about science was challenged because I realized that science is way more than just book work and worksheets'*. Here, Harper was expressing a '*challenge*' about science learning from textbooks and worksheets which we tagged, then sought related moments in different data sources following weeks to see whether Harper mentioned about the challenge again or made a connection with a past experience or if this idea caused a vexation for Harper during sensemaking about responsive teaching. So, all data were tagged for any evidence about questions or affective displays that included confusion, excitement, anxiety, or uncertainty.

Findings

Reflecting on her initial experiences in the class, Harper described the way she engaged in scientific investigations in the science methods class (e.g., figuring out a scientific phenomenon) as different from her past science experiences. She noted that she had not been situated as a "*science thinker*" in her prior science learning experiences. As she was reflecting on these different ways of engaging in science, she described how the early activities in the methods class had been frustrating as she was asked to sit with her scientific uncertainties, she said:

> So I felt like I was giving too much time on [these ideas]. So I was just like, 'Okay, I'm done. The answer is what it is.' ...It was really like self-frustration that I inflicted on myself because I wanted to know. Why? Like, why is this answer wrong? What? What? ...It was like a self-inflicted quit. I had to quit [thinking about these things] because I was overthinking it way too much like more than what it was.

Harper's vexation was evident that she was "*frustrated*" and "*challenged"* during her wrestling with lingering uncertainties about scientific phenomena, which transformed into a "*wanting to know"* perspective that sustained Harper in sensemaking she found herself *working on something far way too long* and *analyzing the wrong answer even though she knew the right answer*.

As Harper continued to work through these vexations, she regularly drew upon her everyday knowledge to connect with the science content. She shared her experience of leaving a container in a microwave and the heat impact on the change of shape, or she described physical change by drawing on her observations of "*steam filling up the bathroom*" and "*floors feel wet*" another time. In another lesson, Harper and her cohort were figuring out the melting time of an ice cube suspended in tap water versus salt water. As the instructor was pressing for students' explanations using their own words rather than striving to use scientific vocabulary, PSTs were animated in this exploration talking over one another and indicating confusion about the ideas being explored. In Harper's reflection the following day, she noted:

> The most challenging part to me was understanding density! This was a struggle for me because the only instances I could think of density were in the aspect of a thickness (a cake and hair extensions). This frustration!... I didn't fault my learning. Rather, it made me want to keep going. It felt like I was almost there, but there was something that I was missing…

In this excerpt, Harper discovered that she had everyday resources she could use in sensemaking. While she came into the class thinking that science was not her "*strong suit*", later in the semester she noted, "*I know more about science than I thought*!" There was evidence that Harper worked through these science vexations outside the class. Instead of *"quit(ting)"* as she said before, she wrote, "*I have been talking about the ice phenomena since Thursday to both my family and coworkers."*

By engaging in the class and the realization of her own resources, Harper started to problematize her past learning experiences and distinguished affordances of responsive teaching based on her past experiences. She described just "*learning different concepts*" in the past and saw her past experiences as a "*waste of her time*" because she engaged in learning material to *"just pass the course".* She added "*You read passages and answer questions...nothing that requires thinking."* This resulted in her distaste for science, "*I hated science because I was never taught properly"*. She expressed, *"If I would have had a more interactive and thought-provoking science experience, I would be able to further expand on my ideas about things a lot more…That's something that this class has helped me do--explain my reasoning, …. Now I'm able to do like more explanation and put more thought into it".* Through reflecting on her past and current experiences in the class, she realized that "*Science is way more than just bookwork and worksheets*" instead recognizing and embracing some responsive moves such as giving students the "*floor*" for sensemaking. *"[Responsive teaching] gets students thinking. But it doesn't give any answers"* and appreciating students' different ideas "*..all answers are good answers. That's a that's a really, really big thing that I learned…. [that] as a teacher we need to accept all students' answers, even if they're maybe not right".* Toward the end of the semester, she continued *"I feel like being a responsive teacher is the only option like. That's the only way that you're going to be an effective teacher".* In her last exit ticket submitted before her teaching in the field placement she wrote: "*…I came to the realization that maybe I don't hate science after all…. I was just hating the manner it was being presented before".*

Discussion

This work illustrates a preservice teacher's vexations as she experienced responsive science teaching as a learner and as she considered it as a teacher. Harper was vexed by authentic experience- being presented with a scientific phenomenon and figuring it out herself- and then she started to recognize her resources and how "*powerful*" her learning experience was, which made her reflect on the past science learning experiences and caused some vexation relatedly. When Harper was given the floor to speak up through different spaces, her vexations surfaced which positioned her to realize that her past experiences conflicted with her current experiences, that this realization led her to sense make the affordances of responsive teaching practices.

PSTs can feel vexed when encountering student-centered pedagogies (Jaber, 2021) because these pedagogies are counter to the ways that they have been taught (Cohen & Ball, 1990). These vexations may be precursors to PSTs considering student-centered pedagogies in their future teaching when they are positioned to explore the power of these ways of learning (Jaber, 2021; Jaber et al., 2018, 2022).

Conclusion

This research speaks to a gap in our understanding of PST's sensemaking about responsive teaching and the role that vexations play in that sensemaking. Being mindful about presenting a case study, Harper's sensemaking process and emerging vexations shed light on how these vexations influenced the beliefs of oneself, science, and science teaching, which allowed her to juxtapose traditional and student-oriented pedagogies and also on that possible ways to support PSTs' engagement in the teacher education programs by recognizing their vexations and providing spaces to articulate and sit with these vexations (Robertson & Atkins Elliot, 2020; Robertson & Richards, 2017).

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Quickstart Spaceship Programming for Developing Physical Intuition and Connecting it to Propositional Physics Knowledge

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Abstract: Decades of research reveals that students enter physics classrooms with non-Newtonian intuitions that are difficult to change. We present a "quickstart" blocks-based programming environment in which students program the engines of a spaceship to navigate it to a new location. We then present a theoretical framework and analysis methodology combining student-produced computational artifacts with interaction analysis to investigate student learning in the environment. Preliminary results from a case study analysis of two students shows that through the programming task they align their intuitive mental models with Newtonian physics, and then by answering questions about the computational model afterwards, they were able to connect these intuitions to propositional physics knowledge.

Background

Decades of research shows that students enter the physics classroom with non-Newtonian intuitions and that changing these intuitions is difficult (e.g., Clement, 1982; diSessa, 1982; Halloun & Hestenes, 1985). To help students develop Newtonian intuitions we designed a spaceship programming microworld. A microworld embodies some domain of mathematics or science in a computational environment which students explore (Papert, 1980). A very early class of physics microworlds used the "Dynaturtle", a computational Newtonian object that students interact with by applying virtual "kicks" (diSessa, 1982; Papert, 1980). This early work showed that naive non-Newtonian physics intuitions are difficult to change but that playing Dynaturtle games can help. We build on this work by constructing a spaceship programming microworld in which students program the engines of a spaceship to turn on and off using programming blocks in a "quickstart programming environment" (Wagh & Wilensky, 2018). The programming blocks in a quickstart environment represent important concepts or mechanisms in a science domain rather than low-level computational primitives, enabling students to learn about scientific phenomena through programming without needing any prior programming experience. Two broad Constructionist learning principles embodied in the design are that (1) constructing an external "public entity" facilitates constructing mental knowledge structures (Papert, 1991) and (2) thinking and talking about one's activity aids learning (Harel & Papert, 1990). The microworld and domain-specific programming blocks are implemented with NetTango Web (Horn et al., 2020), a block-based interface to the agent-based programming environment NetLogo (Wilensky, 1999) that makes it easy for students to construct a public artifact, in this case, the program for the spaceship. The design also encouraged students to work in groups and discuss their problem solving.

In analyzing student learning we build on research focusing on the convergence of two collaborators' understanding (Roschelle, 1992). We combine this with the frameworks of mental models (Gentner & Stevens, 1983; Johnson-Laird, 2010) and representational redescription (Karmiloff-Smith, 1992; Taber, 2010) to analyze the convergence and divergence of two students' understanding. In our usage, a mental model (MM) is a dynamically constructed mental representation of a situation which can be "run" to make predictions. According to the representational redescription hypothesis (Karmiloff-Smith, 1992), children (and perhaps adults) develop increasingly explicit representations throughout development that enable increasingly flexible behavior. On this view, the representation a person initially develops to enable "behavioral mastery" in a domain is not replaced. Rather, representations are *redescribed* at more explicit levels. We assume that student MMs can contain multiple types of representations at different levels of explicitness.

Following the Constructionist stance that a person's mental models are intimately linked with the external artifacts they construct, we analyze the alignments and misalignments between students' MMs and the computational model (CM) underlying the spaceship programming task. Using these frameworks, we aim to answer the following research question in future work: *How did students' MMs diverge and converge with each other and ultimately come to align with canonical physics knowledge embedded in the spaceship programming microworld?* The goal of our analysis method is to understand both what learning happened and how.

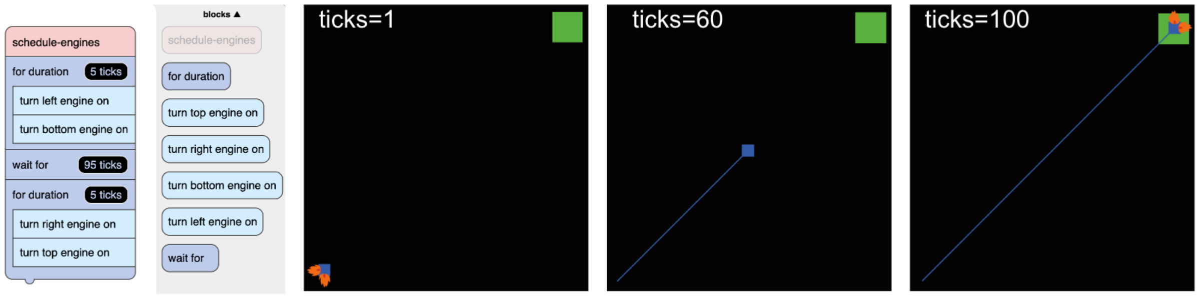
Methods

Software and task design

Students are given the task of programming the engines of a spaceship to reach a target square. They are encouraged to work in pairs to facilitate learning through discussion. In the microworld, the spaceship is visualized as a square with an engine on each side. Figure 1 shows the visualization along with a potential solution to get the spaceship to stop on the green square. The pane to the left shows the block-based programming environment. Learners drag blocks from the gray "blocks" area to program the pink "schedule-engines" procedure. In this case, the spaceship's bottom and left engine are scheduled to turn on for five "ticks" (the standard unit of time in NetLogo). Then the spaceship "waits" for 95 ticks without any engines on. Finally, the opposite engines are turned on for an equal amount of time to bring the spaceship to a stop. The blue line traces the path of the spaceship. This "diagonal" solution requires the fewest number of blocks, but many other solutions are possible. The next three panes in Figure 1 show the spaceship at the beginning, middle, and end of its journey with this block configuration.

Figure 1

A solution to the spaceship programming task.



```
schedule-engines
for duration 5 ticks
  turn left engine on
  turn bottom engine on
wait for 95 ticks
for duration 5 ticks
  turn right engine on
  turn top engine on
```

Data collection

Data was collected in an AP physics A course in large public high school in the midwestern United States. Every block configuration (schedule-engines procedure) that each student tried was logged. Additionally, we recorded audiovisual data for the focal pair of students in this study, Kate and Jay, as they worked through the problem. Each student had their own laptop but they worked together.

Analysis methodology

We began qualitative analysis by transcribing seven minutes of audiovisual data of two students from a larger corpus. Next, a team of three researchers analyzed the video and transcript. We iteratively watched and segmented the video into 24 episodes of coherent joint and individual activity, each roughly 15-20 seconds in length. We summarized the result of each episode in terms of the students' problem-solving approaches and their understanding of the computational model and its latent physics concepts. Next, we deductively coded each episode for *convergence* or *divergence*. During this process we recognized and inductively coded emergent moments of *alignment* and *misalignment* between the two students' mental models (MM) and the computational model (CM). We present these deductive and inductive codes in Table 1. After coding the episodes, the first author wrote a narrative description of the episodes interleaving parts of the transcript (including students' computational blocks) with analysis. Other authors read this narrative description and any disagreements were discussed until agreement was reached. The combination of audiovisual data and a record of the students' computational blocks provides a rich combination for characterizing students' learning processes and trajectories.

Table 1

Deductive (convergence) and inductive (divergence/alignment) coding scheme

Code	Description
MM convergence	The two students' MMs converge
MM divergence	The two students have different MMs
Blocks convergence	The two students set up the same programming blocks and parameters
Blocks divergence	The two students set up different programming blocks and/or parameters
Alignment	When a student's MM agrees with the CM
Misalignment	When a student's MM does not align with the CM

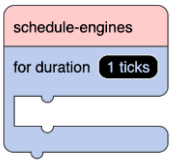
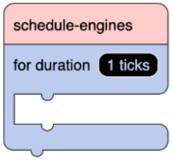
Example analysis

Thirty seconds after starting the activity, with the blocks in their default starting position, Kate realized they could move the ship diagonally. They *converged* on this with a brief exchange:

Figure 2

Initial convergence excerpt

Kate (0:30): We only have to use certain engines (makes a triangle gesture with both hands together)
Jay (0:35): Wait what do you mean?
Kate (0:36): Go diagonally
Jay (0:37): Ooh yes. Okay, I want to see how far
Kate (0:42): How much does a tick go?
Jay (0:43): Yeah. Okay, I'm gonna do just "bottom" (engine) for one tick.

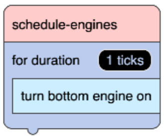
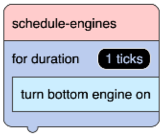
Kate's blocks	**Kate's MM**	**Jay's blocks**	**Jay's MM**
 schedule-engines for duration 1 ticks	Go diagonally❼ only certain engines	 schedule-engines for duration 1 ticks	Go diagonally❼ only certain engines

It is important to note that Kate initially uses a triangular hand gesture and only then uses the words "go diagonally" to clarify. This indicates she first developed an explicit but non-verbal MM and only afterwards redescribed it in words. At this point Kate and Jay's MMs have *converged* on the idea to "go diagonally". Despite this, Jay decided to start by turning on just the bottom engine for one tick. After setting up the blocks and running the model, Jay saw that the ship did not slow down or stop after the engine turned off and concluded, "So, it looks like there's no friction. That's useful," and then they both laughed. Their shared laughter might suggest that Kate and Jay had converged on an understanding of "no friction," but when Kate ran the model herself for 30 seconds, it is clear there was actually a *divergence* between their mental models and a *misalignment* between Kate's MM and the CM:

Figure 3

Divergence and misalignment excerpt

Kate (1:52): Why does it keep going? Oh it's "for duration" // wait // Or, you have to stop it? It will just keep going?
Jay (2:05): Yeah, yeah

Kate's blocks	**Kate's M**	**Jay's blocks**	**Jay's MM**
 schedule-engines for duration 1 ticks turn bottom engine on	Ship will keep going❼ unclear why	 schedule-engines for duration 1 ticks turn bottom engine on	Ship will keep going❼ no friction

After running the model herself Kate got confused as to why the spaceship did not stop on its own, revealing the *misalignment* between her MM and the CM. She quickly realized that it will "just keep going" but phrased it as a question to Jay for confirmation. After his confirmation, we can infer that her MM was *aligned* with the CM in that the spaceship will not stop on its own, but it is not clear if she had connected this to the physical concept of "no friction" as Jay had. Based on her later reactions, she probably had not.

Preliminary results

Due to space restrictions, we are unable to present a full case study here. However, preliminary analysis shows Kate and Jay progressively *aligned* their mental models (MMs) with the computational model (CM) embedded in a physics microworld. At times their MMs and programming blocks *diverged* from one another, but ultimately, they *converged* on both a shared solution to the spaceship programming task and a shared MM of why the solution works. In answering subsequent questions in the assignment, they linked the behavior of the model to canonical physics concepts such as force, acceleration, and inertia, helping them connect the non-verbal understanding they gained from interacting with the microworld to more formal physics concepts, including previously disconnected propositional knowledge.

Discussion and future work

The spaceship programming activity helps students develop physics understanding, because there is immediate feedback if the spaceship does not move or stop as they expect given the sequence of programming blocks. This creates a feedback loop which allows the student to iteratively refine their MM of the situation to align with the physics embedded in the microworld. Working in pairs, students discuss their activity and can learn from each other both through spoken interactions and through sharing their computational artifacts. The block-based programming activity additionally gives students experience with a simple form of programming and computational thinking (CT), aligning with current science standards. Incorporating CT into physics also expands participation and advances equity in CT, because a much more diverse set of students take physics courses compared to dedicated courses on computer science (Wilensky et al., 2014).

The block-based programming activity advances a methodological contribution of relating students' MMs to their programming blocks. The full record of a student's block-based program gives insight into the student's learning trajectory, because the state of their program often reflects their MM. When paired with video data, we have shown it is possible to construct a narrative that accounts for the dynamic *alignments* and *misalignments* between students' MMs and the CM as well as *convergences* and *divergences* between the two collaborating students' MMs. These theoretical constructs and methods can be used to understand students' learning trajectories and patterns of collaboration. Future work will present full case studies of student learning using the theoretical frameworks and methods presented here.

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Understanding of a Law of Science and Its Relation to Science Writing With Automated Feedback

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Abstract: Building causal knowledge is critical to science learning and scientific explanations that require one to understand the how and why of a phenomenon. In the present study, we focused on writing about the how and why of a phenomenon. We used natural language processing (NLP) to provide automated feedback on middle school students' writing about an underlying principle (the law of conservation of energy) and its related concepts. We report the role of understanding the underlying principle in writing based on NLP-generated feedback.

Introduction

Understanding cause-and-effect relationships is an essential part of reasoning about scientific phenomena and writing scientific explanations. At the core of this process is learning underlying principles that explain observed/identified relationships (Russ et al., 2008; Vieira et al., 2019). This contributes to "a clear conceptual understanding of the principles and theories, plus the knowledge of how to apply these principles to a different context" (Vieira et al., 2019, p. 203). For example, when experimenting with a roller coaster simulation, students may be able to identify that a car's motion will be sustained through the remainder of the ride when the initial drop height is higher than a subsequent hill. However, they may not be able to explain why this is so, particularly when they do not understand the underlying principle.

In this study, middle school students learned about the law of conservation of energy (LCE) and its associated concepts and relationships (e.g., potential energy, kinetic energy, total energy), and received automated feedback through natural language processing (NLP) on their writing about the principle and related concepts. Our research questions were:

1. How does students' early understanding of an underlying principle (law of conservation of energy) relate to their writing about the principle and related concepts?
2. How does students' understanding of the underlying principle relate to feedback effectiveness (evidenced in the quality of the revised essay)?

Conceptual framework

We constructed the conceptual framework of the present study based on literature recognizing intuitive knowledge (diSessa, 1988, 2018), intuitive theories (Gopnik, 2012), and intuitive explanations (Keil & Wilson, 2000) as part of a pathway toward scientific theory and scientific explanations. We acknowledge the importance of mechanistic reasoning (Carmichael et al., 2010; Russ et al., 2008; Vieira et al., 2019) in scientific explanations in that it enables one to understand underlying principles. Given that scientific explanations describe the how and why of a phenomenon based on scientific facts (Osborne & Patterson, 2011), covariational reasoning, which identifies cause-and-effect relationships without the why, is not sufficient. At the same time, we value the learning process that includes covariational reasoning and even perceptual explanations, especially considering that causal knowledge involves both scientific and intuitive theories (Gopnik, 2012). The conceptual framework guides us to attend more to the process of "reconciling theory with experience of the natural world" (Furtak et al., 2010, p. 177). We conceptualize automated feedback from NLP in the present study as a scaffold for students to translate between underlying principles and experience during the reconciliation process.

Method

Two eighth-grade science teachers and their 138 students from a mid-sized, US Midwestern city participated in this study. The study was conducted during a three-week, design-based physics unit focused on energy conservation and transformation, where students were invited to design a roller coaster using what they learned about physics. During the unit, students participated in five virtual labs using a roller coaster simulation, answered questions after each lab, and wrote and revised two design essays. The initial design essay (Essay 1) was to explain how height and mass affected the amount of energy there was in their roller coaster system, as well as how the LCE could be used to explain transformations. This initial essay was sent to our NLP technology, called PyrEval, to automatically assess students' essays for feedback, which students could later use to revise their ideas. Students then learned about how height and mass affected speed. Students then wrote their second design essay (Essay 2), building on the ideas in their initial essay, using the feedback from PyrEval. Automated feedback was generated through the NLP technology that detected four main content units in students' essays: one was about LCE and the other three were about related concepts (i.e., height and energy; mass and energy; initial drop in relation to hill height). Based on the presence or absence of each content unit, the feedback was given to either acknowledge their inclusion of the content unit or prompt them to explain the missing content unit. For example, students who did not explain LCE but explained other related concepts in their Essay 1 were asked to elaborate on their current explanation in connection with LCE.

Data for this study consisted of students' written responses from short answer questions about LCE after labs and for their design essays. Two researchers independently coded 15% of all students' responses and achieved an Intra Class Correlation value of .947, which is considered excellent (Cicchetti, 1994). All discrepancies between raters were resolved through discussion.

Findings and discussion

RQ1: How does students' early understanding of the underlying principle (LCE) relate to their writing about the principle and the related concepts?

We sorted students into four groups depending on which of the early short answer questions about LCE they answered correctly. We also categorized Essay 1 into four explanation patterns depending on which of LCE and related concepts were explained. We then ran a Fisher's exact test. Table 1 lists all groups and patterns.

Table 1
Early Understanding Groups and Essay 1 Explanation Patterns

Early Understanding of the Underlying Principle: Answers to the first and second lab questions about LCE		**Essay 1 Explanation Patterns:** Explanations of LCE and related concepts	
Group A (n=29)	Correctly answered the first and second lab questions	**Pattern 1** (n= 70)	Wrote about LCE and at least one of the related concepts
Group B (n=23)	Correctly answered only the first lab question	**Pattern 2** (n= 4)	Wrote about LCE
Group C (n=32)	Correctly answered only the second lab question	**Pattern 3** (n=51)	Wrote about at least one of the related concepts
Group D (n=54)	Did not answer either question correctly	**Pattern 4** (n=13)	Wrote neither

Fisher's exact test results showed that there was a statistically significant association between students' early understanding of LCE and their Essay 1 writing quality (two-tailed, $p<.001$). Observed frequency table (Table 2) shows that among students who answered both lab questions about LCE correctly (Group A), 65.5% explained LCE and at least one related concept correctly in Essay 1. Among students who answered one of the lab questions about LCE correctly (Groups B and C), 65.6%-73.9% explained LCE and at least one of the related concepts correctly in their Essay 1. Among students who were not able to answer any of the lab questions about LCE correctly (Group D), only 24.1% explained LCE and at least one of the related concepts correctly in Essay 1, but 64.8% explained at least one of the related concepts correctly in their Essay 1. The results also show that it was possible to write about related concepts without understanding the underlying principle. For example, one of the related concepts that students were expected to write about in their essays was the initial drop height of the roller coaster being higher than the subsequential hill that they designed to get the car to travel to the end of the roller coaster. That is, without understanding of LCE, cause-and-effect relationships were discoverable on the simulation and the data summary table without knowledge of underlying principles. Such phenomenological explanations (Furtak et al., 2010) written by students in Group D are not deficits within our conceptual framework. They are the opportunity for the process of reconciling underlying principles with data to begin. These students received automated feedback on their Essay 1 asking them to write about LCE.

Table 2

Observed Frequencies of Essay 1 Explanation Patterns per Early Understanding Group

	Pattern 1 LCE and related concepts	**Pattern 2** LCE only	**Pattern 3** Related concepts only	**Pattern 4** No LCE and no related concepts
Group A	65.5% (n=19)	0.0% (n=0)	24.1% (n=7)	10.3% (n=3)
Group B	73.9% (n=17)	4.3% (n=1)	8.7% (n=2)	13.0% (n=3)
Group C	65.6% (n=21)	9.4% (n=3)	21.9% (n=7)	3.1% (n=1)
Group D	24.1% (n=13)	0.0% (n=0)	64.8% (n=35)	11.1% (n=6)

Note. Output in each cell indicates percentage within each early understanding group.

RQ2: How does students' understanding of the underlying principle (LCE) relate to feedback effectiveness (evidenced in the quality of the revised essay)?

We categorized Essay 2 into the four explanation patterns as in the first Fisher's exact test and used the same early understanding group data. We then ran another Fisher's exact test and found a statistically significant association between students' early understanding of LCE and their Essay 2 writing quality (two tailed, p<.001) (Table 3).

Table 3

Observed Frequencies of Essay 2 Explanation Patterns per Early Understanding Group

	Pattern 1 LCE and related concepts	**Pattern 2** LCE only	**Pattern 3** Related concepts only	**Pattern 4** No LCE and no related concepts
Group A	72.4% (n=21)	0.0% (n=0)	20.7% (n=6)	6.9% (n=2)
Group B	65.2% (n=15)	0.0% (n=0)	21.7% (n=5)	13.0% (n=3)
Group C	81.3% (n=26)	6.3% (n=2)	12.5% (n=4)	0.0% (n=0)
Group D	37.0% (n=20)	0.0% (n=0)	57.4% (n=31)	5.6% (n=3)

Note. Output in each cell indicates percentage within each early understanding group.

Overall improvements in writing quality were visible in that more essays included correct explanations of both LCE and related concepts (Pattern 1), and less essays included no correct explanation of LCE and/or related concepts (Pattern 4) in Essay 2 than Essay 1. Automated feedback that prompted students to write about LCE when other related concepts were explained without explaining the why, beyond referring to their simulation data as reasons, may have helped students connect concrete experiences (from the simulation) to LCE. These findings also suggest that early understanding of LCE could be impactful, but based on Group C who showed the largest increase in Pattern 1, a longer process of reconciling theory with data may have been even better.

The overall improvement in explanation patterns hinted that the feedback given between Essay 1 and Essay 2 may have played a positive role. We ran a repeated measures ANOVA to see if there was a statistically significant difference in writing quality scores between Essay 1 and Essay 2. The results showed that Essay 2 was significantly better than Essay 1, F(1, 134) = 22.96, p<.001. The effect size was medium (Cohen's d = .42). Furthermore, the improvement from Essay 1 to Essay 2 differed depending on the explanation patterns that the students included in Essay 1, F(3, 134) = 101.77, p<.001, Cohen's d = 1.5. That is, the improvement from Essay 1 to Essay 2 shown among students who included explanations of only LCE (Pattern 2) in Essay 1 was significantly larger than the improvement shown among the students who included explanations of only related concepts (Pattern 3) in Essay 1. Feedback worked better among those who understood and wrote about the underlying principle (LCE) than those who were able to write about one or more of related concepts but without the underlying principle. The effect size was large (Cohen's d = 1.5).

We also ran linear mixed effect models using the lme4 R package (Bates et al., 2014) to see further about the relations between students' understanding of the underlying principle and their revised essay, with other possible predicting variables for the revised essay quality. Table 4 lists the output of mixed effect model analysis with Essay 2 writing quality as a dependent variable. We included fixed effects of early understanding group, Essay 1 explanation pattern, Essay 1 writing quality, NLP accuracy, Essay 1 revision, and engagement. We also included in the model teacher and class clustering factors as random effects to control for the potential impact of the teacher and class variance. The model specification was as follows: Essay 2 writing quality ~ early understanding group + Essay 1 explanation pattern + Essay 1 writing quality + Essay 1 revision + engagement + (1|Teacher) + (1|Class). There were two significant predicting variables at .05 significance level: Essay 1 writing quality (ß=0.87, p<0.0001) and Essay 1 revision (ß=1.12, p<0.0001). While there were still indirect effects of early understanding and Essay 1 explanation pattern reported above, only these two variables were direct predictors for Essay 2 writing quality. This means that students' revised essay quality was better when they revised their Essay 1 as per automated feedback. It seems intuitive that their revised essay quality was better when their first essay quality was already better, but this finding also suggests that the automated feedback did not ask students to revise their essay when unneeded. Also, the finding that their revised essay quality was better when revisions were made according to the automated feedback suggests that the positive impact of automated feedback on improving writing quality. Especially considering the improvements reported above including more Explanation Pattern 1 in Essay 2, the findings demonstrate a unique potential contribution of PyrEval to science learning and writing as a scaffold for students' translating, connecting, and reconciling between theory with experience (diSessa, 2018; Furtak et al., 2010; Puntambekar & Goldstein, 2007). This will in turn contribute to knowledge building that recognizes possible interplay between intuitive explanations and scientific explanations and value the role of intuitive explanations that can be leveraged through automated feedback scaffolding toward scientific explanations.

Table 4

Linear Mixed Effects Model Analysis results for Essay 2 Writing Quality Scores

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.2564	0.37739	0.679	0.498	
Early understanding group	-0.06933	0.0457	-1.517	0.132	
Essay 1 explanation pattern	0.01206	0.08241	0.146	0.884	
Essay 1 writing quality	0.87115	0.07475	11.655	0.00002	***
NLP accuracy	0.01633	0.05768	0.283	0.778	
Essay 1 revision	1.12133	0.11685	9.597	0.00002	***
Engagement	0.10284	0.13072	0.787	0.433	
Marginal R^2/Conditional R^2	0.691/0.803				

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

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"Are You a Match?": Coordinated Embodied Activity Using Multiple Perspectives to Support Algorithmic Solutions

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Abstract: Algorithmic thinking is the process involved in formulating a problem which can be represented by computational steps. We investigate the impact of students' perspective-taking during a mixed reality embodied activity and how the emergence of a blended perspective mixing agent and global perspectives has the potential to improve learners' algorithmic thinking by concretizing the computational steps.

Introduction

Algorithmic thinking is a cornerstone of programming and computational thinking (CT), that allows one to solve problems effectively across contexts (Shute et al., 2017; Grover & Pea, 2013). Algorithms are sets of precise steps commonly used in computational settings. Developing expertise in creating algorithms require planning, writing, and debugging processes. Algorithmic thinking can be challenging for novice programmers due to its abstract nature (Yadav et al., 2017). The use of embodiment to concretize abstract principles in computing education, shows promising results both for CT and STEM and deepens the understanding of the purpose of computing (Sung et al., 2017). In this paper, we investigate the impact of embodied activities in GEM-STEP (Generalized Embodied Modeling - Science through Technology Enhanced Play), a mixed reality environment, designed to encourage learners to take a first-person perspective while modeling. Specifically, we ask: How does perspective taking mediate the creation of algorithmic solutions in embodied modeling?

Background

Algorithmic thinking and embodiment

Computing education, particularly CT, is becoming increasingly important as technology is becoming more integrated in everyday lives and most fields. CT is broadly understood as a "universal attitude and skill set" that "involves solving problems, designing systems, and understanding human behavior" (Grover & Pea, 2013). Shute's et al. (2017) definition emphasizes that CT can be expressed through thinking and acting, and is exhibited using specific skills, including decomposition, abstraction, debugging, iteration, generalization, and algorithm design. Other researchers claim algorithmic thinking is a particularly hard task (Yadav et al., 2017).

A growing body of CT research highlights activities that involve the use of gestures to represent the abstract concepts associated with CT (Wang et al., 2021; Danish et al., 2020). Agent-based modeling also focuses on the benefits of body syntonicity: the connection learners make when imagining themselves as agents in a programming environment leveraging embodied roles or movement (Papert, 1980).

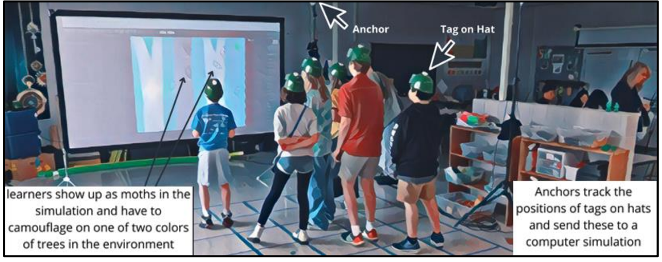
Perspective taking within modeling

The embodied or syntonic connection that learners make with computational agents can support them in leveraging new perspectives to explore ideas. Scholars use viewpoints to delineate learners' perspectives: agent perspective (i.e., ground-level, or first-person agent) focus on individual contribution to the system; global perspective (i.e., top-level, or aggregated observer, with a third person or bird's eye viewpoint) focus on how the broader system-view affects the individual. Although it is a hard process to move between agent and global perspectives, moving between perspectives supports deeper and more complex reasoning (Lindgren & DeLiema, 2022).These benefits are further extended in embodied contexts. When the physical and symbolic worlds blend, it creates an in-between space where learners can reason about ideas and experiences, described as liminal blend. Such liminal blends help to concretize abstract concepts through perspective taking (Enyedy et al., 2015).

Methods

This study focuses on a group of 6 learners (1 Female & 5 Males), in a fifth-grade classroom in a southern middle school during 3 days (90 minutes) of a 9 day intervention. The curriculum leveraged the anchoring phenomenon of peppered moths to explore camouflage and adaptation. We focus on an activity that aimed to enhance students' CT, and specifically algorithmic design. This GEM-STEP model allows learners to control virtual moths by moving around the room, using tracking tags. The color of each moth was unknown to the group. The goal was to camouflage by matching their moth's color to one-of-two tree colors within 30 seconds (see figure 1). A match-meter goes up if a learner stands on the right color of a tree, and down if the learner moves elsewhere. The CT goal of the model was to develop a strategy for a Binary Matching problem through an embodied solution. Finally, as a group activity, this activity required students to collaborate to successfully design and enact the algorithm in the model. After the group participated in the embodied activity, we asked them to develop a strategy for a new group to be successful. The goal was to help learners shift from being agents in the model to taking a global perspective to make sense of and explicate the mechanism of the algorithm. To support learners, we asked series of questions: 1) ‘What are the different situations you could be in? What is your position? What are the different actions that you can take?’, 2) ‘When you played, how did you decide what to do?’ and 3) ’How would you explain to another group how they should act in this activity?’ (Zipitría, 2018). The learners created a paper-based artifact to represent their strategy. After completing their own artifact, the group tried another group’s strategy.

Figure 1
Group activity in the GEM-STEP mixed-reality system



In prior work (Ayalon et al., 2023), we identified the development of algorithmic solutions by comparing the learners’ movement in the environment before and after a discourse on their strategy. Here, we focus on the hands-on activity designed to support the development of algorithmic thinking. Specifically, we examine the ways that students extend their embodied experiences through perspective taking as they negotiate and create an algorithm. Using Interaction Analysis (Jordan & Henderson, 1995), we developed a coding scheme (see table 1) to identify the perspective taken: Agent, Global and a novel perspective which we called *blended perspective*. The coding scheme considers ways in which learners may be taking perspectives both verbally and through gestures. When learners used the pronounce “I” to describe individual strategy or “you” to describe a single other, we coded it as an agent perspective. When learners used the pronounce “it” or “YOU” to describe a plural other or a generic moth, we codded it as a global perspective. We coded for a blended perspective when learners expressed ideas that leveraged both agent and global perspectives together. Specifically, when the following three events occurred: (1) talking about individual and group strategy in the same sentence, (2) talking about one moth while using hand gestures to refer to the entire system and, (3) switching the use of the word “You” & “YOU”.

Table 1
Framework of discourse analysis about perspectives’ indications (color coding for table 2)

Agent Perspective	Global Perspective	Blended Perspective
Individual strategy	Group strategy	Both individual and group strategy
One particular moth	All moths	Agent perspective dialog combined with Global perspective hand gestures
Limited, first-person view	Top down, bird's eye view	
"I" & "You"	A generic moth ("It" & "YOU")	"You" & “YOU”

While pronouns alone are not inconclusive evidence for perspective taking, triangulated with additional verbal and interactional cues they provide reliable indicators of a given perspective. Nevertheless, we acknowledge the limitations of this approach that integrates these observations with learner gesture, content of speech, and patterns of engagement.

Findings

The perspectives are expressed in three phases: the first round of the model, during the hands-on activity, and last round of the model. Below, we provide an overview of the learning trajectory while uncovering the perspective taking that occurred during the hands-on activity, focusing on blended perspectives in algorithmic design. During the hands-on activity, the facilitator prompted a discussion, asking learners to consider the different positions they may take in the model. The learners had a gradual shift in perspective taking, as learners first shared perspectives across agent and global perspective then began to blend these as the strategy was concretized. Ahead (see transcript in table 2), we explore how this blended perspective emerged in three ways.

Table 2

Transcript of group discussion between learners guided by the facilitator.

	All pseudonyms were selected by the learners, see color coding in table 1		
1	**Swaggy Muffin (SM):** Yes it's the way you can successfully do this, look at it, right?	12	**SM:** Two on each tree
2	**Crazy Wolf Love Pizza (CWLP):** Look at the match-meter is it right? Are you a match? Yes.	13	**PX:** Yeah, you're just two on each tree
3	**Facilitator:** But you have six moths that you need to look at, [at] the same time as the match-	14	**SM:** You're just look and see if you//
4	meter, how can you do it?	15	**PX:** //Faster in a//
5	**Luke (L):** You can do it like- you can do it like one or like two at a time maybe and go on a tree	16	**L:** //If you think about it, if all going on a tree//
6	and see if two matches go up.	17	**SM:** //It might be a bit faster, it's all
7	**Facilitator:** Okay, so you go, [by what] you suggest. Before PX suggested one by one	18	**L:** //Going on a tree it would be confusing. //
8	and you suggest[ed] let's do it two by two.	19	**PX:** If we go on one tree//
9	**L:** Like the whole group	20	**SM:** //How about//
10	**ProfessorX (PX):** Or three	21	**L:** //And then it would be confusing on what's not the match. Yeah.
11	**L:** Like the whole group? Like two on each tree		

First, as learners began to discuss their strategy efficiency, they would shift between expressing ideas on the individual and group strategy. For example, in line 2 of the transcript, CWLP says "Look at the match-meter is it right?" expressing a blended perspective when he refers both to another learner's ("Look") while talking about a generic moth in a global perspective ("it"). Another example are lines 16-18. In line 16, L is explaining what will happen "if all [group] going on a tree" (global perspective). He expresses a group level strategy when SM adds to it (line 17), expressing that "it might be a bit faster" to send multiple moths to trees than their strategy so far. L shifts back into the agent perspective when in line 18 he suggests that going all at once might be a bit confusing, reflecting that he is embodying the individual moth in the strategy. In both examples, the learners shifted between agent and global perspectives to balance goals of efficiency with simplicity in agent rules.

Figure 2

On left, hand gestures used during the group discussion expressed in lines 3-4 of Table 2. On right, hand gestures used during the group discussion expressed in lines 13-14 of Table 2.

Second, we observed that both learners and the facilitator expressed first person perspective in their speech while expressing global perspective in their gestures (i.e. motioning with their hands to create the borders of trees). In one example, PX and SM explore together the idea that learners could walk in pairs to discover matches more efficiently (lines 12-15). In the brief interaction, SM first repeats a suggestion made by another student "two on each tree", without use of pronouns which suggests a more global perspective. PX contributes by agreeing and repeating the idea but adding "you're", which centers the learner using an agent perspective (line 13). Adding to PX's statement, SM then begins to describe, from an agent perspective, what two moths at a time would physically do in the model (looking at the match-meter), "you're just look and see if you". As they both use the agent perspective to explain the strategy, they gesture with their hands, indicating trees in the model and the match-meter (see figure 2). From this shared communication and set of gestures, PX determines that this strategy is "faster" than if they go one by one (line 15, 19). In this example, learners used their embodied experiences and an agent perspective to make sense of a global strategy, which they expressed through gesture.

We observed a third expression of blended perspective, when the learners used the word "you" while discussing strategies (lines 1-5, 7-8, 13-14, 16). The conversation shifted frequently between you as one moth or a player to YOU as the group or a general moth, reflecting a potential comfort between the shifts in agent to global perspectives. Moreover, "you" (you & YOU) was often a bridging pronoun that was used by students to shift between perspectives. For example, CWLP refers to both agent and global perspectives of 'you' as a moth by asking "are you a match?". While asking another learner to identify their state, his word choice of "a match" indicates a bird's eye view of the model; rather than 'are you matching', he asks the learners to attend to the match-meter. Throughout the discussion, learners continued to center themselves within the strategy and the designed algorithms, even while attending to global perspectives or outcomes of the system.

Discussion & conclusion

In the study, we explore the impact of multi perspective-taking, using embodied activities, to enhance the development of algorithmic approach in the scientific context. The activity supported learners to switch from an agent perspective when they played in the mixed reality embodied simulation, into a global perspective, when we invited them to think of a strategy. The expected behavior could have been that the students will switch from agent to global perspective or maybe switch back and forth, However, analyzing their interaction revealed that the students were able to hold both agent and global perspectives **at the same time** and created a blended perspective. We argue that the embodied activity helped to concretize the abstract components of the activity and allowed a glimpse inside the algorithm. Moreover, a significant aspect of their learning was due to the invitation to think globally about the group's strategy, and the creation of *blended perspective*.

We suggest that this coordinated embodied activity while changing between agent and global perspectives has the potential to improve the efficiency of learners' algorithms and support abstract concept-learning by concretizing them. The use of the body improves performance by taking a blended perspective, a space where learners can act simultaneously as a group and as individuals. We suggest that further research is needed on methods to design activities that encourage the blended perspective. In addition, another aspect of future work should test learners' algorithmic thinking assimilation over time.

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Explaining Thermodynamics: Impact of an Adaptive Dialog Based on a Natural Language Processing Idea Detection Model

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Abstract: We explored how Natural Language Processing (NLP) adaptive dialogs that are designed following Knowledge Integration (KI) pedagogy elicit rich student ideas about thermodynamics and contribute to productive revision. We analyzed how 619 6-8th graders interacted with two rounds of adaptive dialog on an end-of-year inventory. The adaptive dialog significantly improved students' KI levels. Their revised explanations are more integrated across all grades, genders, and prior thermodynamics experiences. The dialog elicited many additional ideas, including normative ideas and vague reasoning. In the first round, students refined their explanation to focus on their normative ideas. In the second round they began to elaborate their reasoning and add new normative ideas. Students added more mechanistic ideas about conductivity, equilibrium, and the distinction between how an object feels and its temperature after the dialog. Thus, adaptive dialogs are a promising tool for scaffolding science sense-making.

Introduction

Students develop everyday ideas about heat and temperature. Instruction can help them connect their normative and mechanistic ideas to gain coherent understanding (diSessa, 1988). During instruction, students distinguish between heat and temperature; explain when and why materials feel hot or cold; connect how materials feel to their measured temperature; sort out heat flow from cold flow, and grapple with the process of thermal equilibrium (Donnelly et al., 2015; Lewis & Linn, 1994). They can form powerful explanations while distinguishing among everyday ideas (Sandoval & Millwood, 2005). We draw on Knowledge Integration (KI) pedagogy to support the process of eliciting student explanations, encouraging students to discover additional ideas, guiding students to use evidence to distinguish among their ideas, and asking students to reformulate links among their ideas (Linn & Eylon, 2011). We studied how an adaptive dialog (Fig. 1) based on an idea detection model informed by Natural Language Processing (NLP) facilitated student ability to make productive revisions of their explanations of thermodynamics. We build on prior research demonstrating ways to promote productive revision with NLP tools (Gerard & Linn, 2022). In this paper, we investigate: How do two rounds of adaptive guidance support students' science learning? How do students from different grades, gender, and prior thermodynamic experiences respond to the adaptive dialog?

Methods

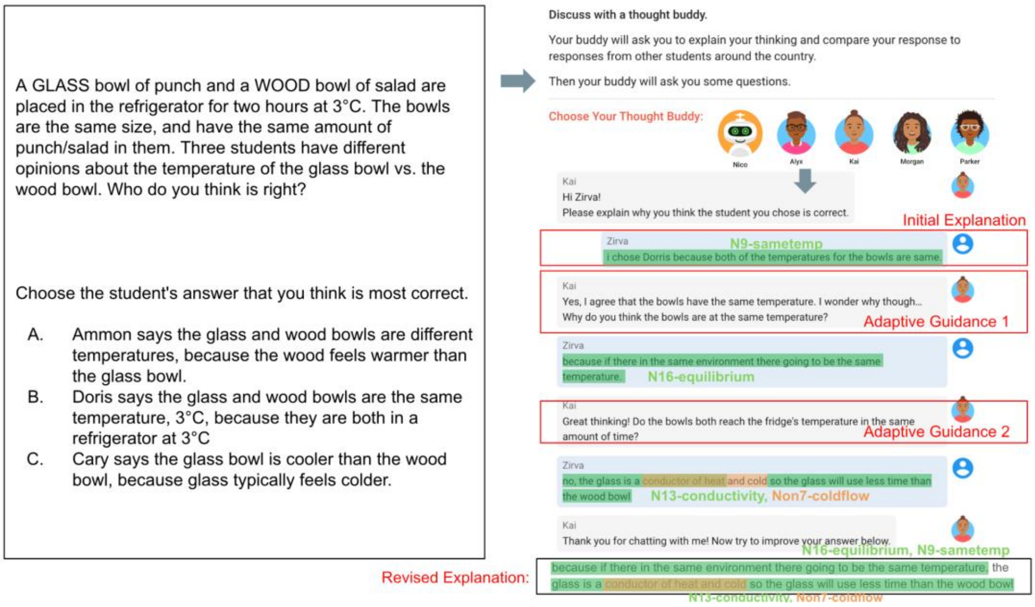
Participants

The 619 middle school students (72 6th graders, 323 7th graders, 224 8th graders) were taught by 11 teachers from 4 public schools. Among the students, 42.97% were female-identifying, 48.95% were male-identifying, 2.10% were non-binary, 5.98% preferred not to answer. Overall, 55.6% were monolingual English speakers and 49.1% had parents who speak another language at home. The idea detection NLP models were trained on student written explanations in English from a sample with similar demographics.

Adaptive guidance design

We embedded the NLP adaptive dialog in an end-of-year inventory using an open-source Web-based Inquiry Science Environment (WISE). The inventory elicits explanations for topics students studied during the year. We designed the dialog to promote productive revision of the initial responses. We report on the revisions students made to the *Bowls In A Fridge* item about thermodynamics (Figure 1). Students first select the answer they think is most correct, then engage in a dialog with a virtual *thought buddy*.

Figure 1
Example adaptive dialog with idea detection NLP model (detected ideas shown: e.g. N9-sametemp =normative idea 9-two bowls at same temperature, Non7-coldflow=non-normative idea 7-absorb coldness.)



A GLASS bowl of punch and a WOOD bowl of salad are placed in the refrigerator for two hours at 3°C. The bowls are the same size, and have the same amount of punch/salad in them. Three students have different opinions about the temperature of the glass bowl vs. the wood bowl. Who do you think is right?

Choose the student's answer that you think is most correct.

A. Ammon says the glass and wood bowls are different temperatures, because the wood feels warmer than the glass bowl.
B. Doris says the glass and wood bowls are the same temperature, 3°C, because they are both in a refrigerator at 3°C
C. Cary says the glass bowl is cooler than the wood bowl, because glass typically feels colder.

Discuss with a thought buddy.

Your buddy will ask you to explain your thinking and compare your response to responses from other students around the country.

Then your buddy will ask you some questions.

Choose Your Thought Buddy:

Kai
Hi Zirva!
Please explain why you think the student you chose is correct.

Initial Explanation

Zirva
i chose Dorris because both of the temperatures for the bowls are same.

N9-sametemp

Kai
Yes, I agree that the bowls have the same temperature. I wonder why though...
Why do you think the bowls are at the same temperature?

Adaptive Guidance 1

Zirva
because if there in the same environment there going to be the same temperature.

N16-equilibrium

Kai
Great thinking! Do the bowls both reach the fridge's temperature in the same amount of time?

Adaptive Guidance 2

Zirva
no, the glass is a conductor of heat and cold so the glass will use less time than the wood bowl

N13-conductivity, Non7-coldflow

Kai
Thank you for chatting with me! Now try to improve your answer below.

N16-equilibrium, N9-sametemp

Revised Explanation: because if there in the same environment there going to be the same temperature. the glass is a conductor of heat and cold so the glass will use less time than the wood bowl

N13-conductivity, Non7-coldflow

NLP Idea detection model and KI scoring model

For idea detection, we developed and applied an NLP model using a *token classification* approach (Riordan et al., 2020). For KI scores, we updated a validated NLP model for the initial and final explanations (Liu et al., 2016). KI scores reward students for linking ideas and evidence, in this case, linking their science knowledge about thermodynamics in explanations of complex situations. There are 5 levels of KI scores, the higher the KI score is, the better that students can integrate and link their science knowledge. To develop both of the NLP models we collected over 1000 student responses to the target question, in prior research, from five schools. To update the KI model, two researchers reached inter-rater reliability above Cohen's Kappa 0.85, and then scored the remaining items. To build the idea detection model, researchers collaboratively scored and labeled ideas until they achieved inter-rater reliability above Cohen's Kappa 0.85. The researchers identified 14 distinct ideas expressed by students in their explanations, including normative, non-normative and vague claims and reasonings. The *multi-label* idea detection model achieved an overall micro-averaged F-score of 0.68. When the rule-based adaptive guidance detected multiple ideas in a student explanation, it was tailored to encourage the student to elaborate their reasoning for one of them. In order to honor the students' reasoning and evidence, we prioritized the ideas as the following sequences: 1) non-normative reasoning; 2) vague reasoning ideas; 3) normative reasoning; 4) normative claims; 5) non-normative claims. The resulting labeled dataset was used to train separate idea detection and KI scoring NLP models.

Data analysis

We chose Cumulative Link Mixed Models (CLMM) to analyze KI scores because students are measured repeatedly before and after the dialog and our KI scores are not normally distributed. We modeled four factors: Dialog effect (initial explanation before dialog, revised explanation after dialog), gender (Female, male, non-binary, prefer not to answer), grade (6, 7, 8), and prior experience with the thermodynamic WISE unit (Yes, No). We chose to include prior experience with the Thermo WISE unit because the unit features simulations aligned with our inventory item. We did not test the interaction between grade level and the WISE unit because only grade 6 and 7 students had the opportunity to study the Thermo WISE unit. We used Generalized Estimating Equations (GEE) with Poisson regression with repeated measures for the idea counts. We used GEE with binomial regression with repeated measures for each single idea.

Results

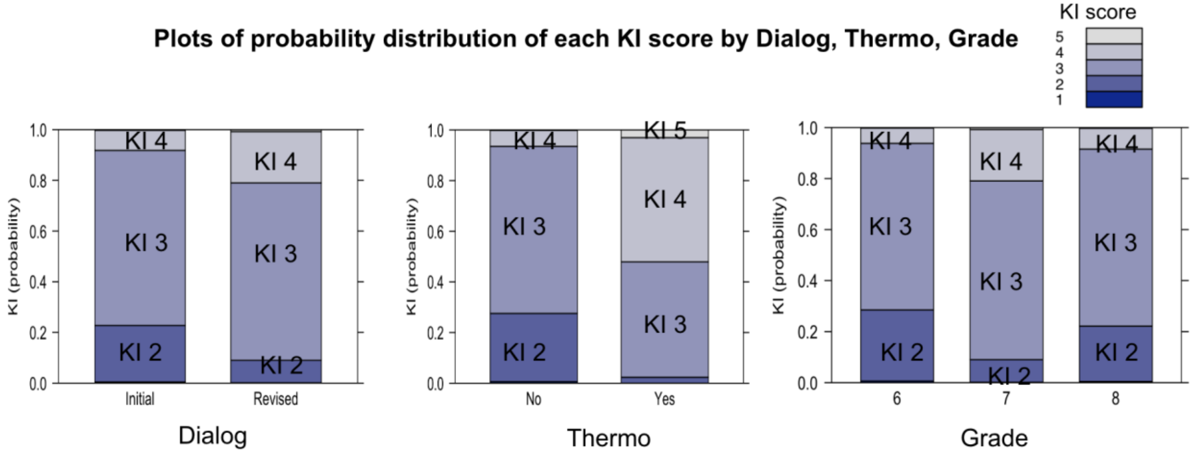
1. Do students integrate their ideas as measured by their KI scores?

Students' revised explanations (M=3.15, SD=0.97) were more integrated than their initial explanations (M=2.85, SD=0.98) across all grades, genders, and students' previous unit experiences. For 6th and 7th graders, students who had studied the unit (M_{6Y}=3.31, SD_{6Y}=1.02; M_{7Y}=3.64, SD_{7Y}=0.99) achieved higher KI scores than those who had not (M_{6N}=2.25, SD_{6}=0.46; M_{7N}=2.94, SD_{7N}=0.89). In a related study of this corpus, students from monolingual and multilingual backgrounds made similar KI gains (Holtmann et al., 2023).

Using CLMM, we found that NLP dialog, grade, and prior Thermo unit experience all have significant impacts on the model fit (AIC=2969, p<.001). After controlling other variables, for the dialog, students have higher predicted cumulative probability of revised KI scores compared to their initial scores (β=1.09, p<.0001, Fig. 2, Dialog). This means that students are more likely to link normative, relevant ideas after they received the NLP adaptive guidance. After controlling for other variables, students who studied the Thermo WISE unit before received higher cumulative KI scores than students who did not (β=2.76, p<.0001, Fig. 2, Thermo). After controlling for other variables, Grade 7 students had higher cumulative KI scores after the dialog compared to Grade 6 (β=1.39, p<.01, Fig. 2, Grade). The differences between grade 7 and 8, and 6 and 8 are not significant.

Figure 2

The probability distribution of each KI score by dialog, Thermo WISE unit experience, and grades



2. How does the NLP dialog elicit ideas?

2.1 Total number of ideas elicited

Using GEE, we found that students are 1.2 times more likely to express more ideas for their revised explanations than for their initial explanations (Wald=30.21, p<.001). Students expressed more normative ideas (Wald=19.22, p<.001), and more vague ideas (Wald=7.35, p<.01) at their revised explanation. Revised explanations had slightly and not significantly fewer non-normative ideas. Adding gender, prior thermo experience, and grade into our model, we found that students who studied the Thermo WISE unit expressed significantly more ideas (Wald=33.19, p<.001), more normative ideas (Wald=7.31, p<.01) and fewer non-normative ideas (Wald=5.85, p=0.016) than those who did not study the unit. 7th graders expressed more ideas (Wald=13.24, p<.001) and more normative ideas (Wald=6.15, p=0.013) than 6th and 8th graders. Since thermodynamics is often taught in 6th grade, our 7th graders have the most recent experience. Female students expressed more ideas (Wald=34.62, p<.001, Cohen's d = 0.1), especially more vague (Wald=20.67, p<.001, Cohen's d = 0.29) and non-normative ideas (Wald=15.59, p<.001, Cohen's d = 0.19) than male students. The effect sizes of these idea differences are small, and the KI score for gender is not significantly different. This aligns with the previous research showing that women compared to men, have slightly better performance on verbal tasks (Hyde & Linn, 1988) and that differences between genders in science are small and declining (Linn & Hyde, 1989).

2.2 Integrating individual ideas

The ideas that students integrated, after controlling other variables, include conductivity (92% more likely; Wald=26.63, p<.001), "feeling is not the actual temperature" (60% more likely; Wald=5.27, p=0.022), and equilibrium (37% more likely; Wald=4.52, p=0.034). The changes in other ideas were not significant. 7th and 8th graders were more likely to add conductivity compared to 6th graders ($Wald_7$=18.75, $Wald_8$=12.62, p<.001). Students who studied the Thermo WISE unit compared to those who did not, were more likely to add conductivity (Wald=24.06, p<.001) and equilibrium ideas (Wald=36.16, p<.001). Among the three significantly integrated ideas, based on the odds ratios in the GEE model, the conductivity idea is most likely to appear when students revise their ideas, followed by the "feeling is not the actual temperature" and equilibrium idea. The equilibrium idea is the least likely to emerge during the dialog and without instruction, consistent with its complexity for middle school students (Lewis & Linn, 1994).

3. How do two rounds of adaptive guidance work?

Two rounds of adaptive guidance helped students distinguish their ideas from everyday observations and to continue adding mechanistic ideas to explain thermodynamics. In the first round, 56.06% of the students dropped vague and non-normative ideas; 31.99% added new normative ideas and 38.77% of students added another normative idea to their previous response. For specific guidance, compared to prompts that ask broad and general questions, we found that prompts that ask students to explain specific mechanisms work well. For instance, students' explanations are 41.24% irrelevant vague ideas for the prompt to idea *Non3-onebowlcolder* ("*I see, you're saying the bowls have different temperatures. What affects the temperature of the bowls in the fridge?*"). They either have very broad associations like "Refrigerators cool the bowls through evaporation", or have a vague and general answer like "fridge/bowls/the stuff inside", or have responses like "idk what you're talking about". In contrast, 31.67% of students expressed N13-conductivity evidence after they received a prompt to idea *V6-bowlmaterial* ("*Yes, wood and glass are very different materials! Thinking about heat energy, what are glass and wood good or bad at doing with heat energy?*").

Conclusion

Consistent with the KI pedagogy, this study illustrates that students have more ideas than they initially express and that when they are supported to follow the KI process with adaptive dialogs, they form more coherent and sophisticated explanations. Specifically, this study shows that the NLP adaptive dialog can elicit a significant number of ideas including normative ideas without further instruction. Further, the NLP dialog can help students revise explanations to achieve a higher KI score. This holds across 6th, 7th, and 8th graders whether they have prior thermodynamics WISE experience or not. Using the KI pedagogy to design the adaptive dialog facilitated this progress (Gerard & Linn, 2022). Rather than correcting students, the adaptive dialog supported them to analyze their own reasoning and the evidence underlying their perspective. This spurred many students to sort out their ideas and engage in refining their explanations. Next steps include continuing to partner with teachers to refine the dialog so that it focuses students on identifying evidence they need to sort out their ideas in adaptive dialogs and with peers.

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“For the First Time in a Long Time, …”: Teachers’ Transformative Agency During the Creation of a Professional Community

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Abstract: The goal of this study is to support a group of mathematics teachers in creating their professional community under a non-profit organization in Turkey and to examine how teachers exercise collective transformative agency in this community-building process as they engage in mediating tools and activities. Analysis of the data collected during this ongoing project reveals that when teachers are provided with mediating tools, activity structures, and discursive practices that provide enough space, time, and support to face the contradictions in their activity system, they begin to see their power to transform their practices and the system in a positive way. This becomes the first step in designing a sustainable community by teachers.

Introduction and purpose

Teacher communities have long been recognized for their value as learning environments in which teachers can seek professional learning in agentic ways and develop collective solutions for their problems of practice (Palincsar et al., 1998). On the other hand, research on teacher communities has revealed that these communities are not effective by itself and that opportunities to learn in teacher communities vary according to the conceptual resources teachers draw on and a shared sense of what is possible (Horn & Kane, 2015). In this study, we argue that in order to support teacher communities to expand the opportunities to learn in them and also ensure their sustainability, different from the mainstream focus on the development of knowledge and skills in teacher education designs, teachers’ agency should be the ultimate learning goal (Haapasaari & Kerosuo, 2015).

This ongoing study follows the participatory design research (PDR) paradigm in Learning Sciences to support a group of mathematics teachers in designing their professional community under a non-profit organization in Turkey called Teachers’ Network, which promotes teacher empowerment by supporting teacher solidarity in communities. The method of formative interventions (Engeström, 2016) is put into practice, and how participants exercise agency while designing their community through this intervention is examined. As a specific form of PDR, formative interventions include mechanisms to support practitioners’ collective agency in both facing the paralyzing disturbances in their activity system and designing and implementing novel solutions (Engeström, 2016). In line with this, in this study, community building is interpreted as a problem-solving process in which the activity model of the community is designed as a solution to teachers’ common problems of practice.

Theoretical framework and research question

The method of formative interventions is organized based on the steps in the expansive learning cycle (Engeström, 2016) and the methodological tools that Vygotsky (1997) employed in his double-stimulation experiments. In formative interventions, it is expected that expansive learning would emerge in a cyclical manner through specific epistemic or learning actions (Engeström, 2016). The expansive learning process is mediated by two types of artifacts: the “first stimulus,” which helps practitioners face the contradictions in their activity, and the “second stimulus,” which is put into action to design a novel solution (Engeström, 2016). Transformative agency is considered the main learning outcome, which “goes beyond the individual as it seeks possibilities for collective change efforts” (Haapasaari et al., 2016, p. 33). Through analyzing conversational data, Haapasaari et al. (2016) came up with six types of discursive manifestations of transformative agency in a formative intervention. These are: *resisting* the change, new suggestions or initiatives; *criticizing* the current activity in a change-oriented way to identify the problems; *explicating* new possibilities or potentials in the activity relating to past-positive experiences; *envisioning* new patterns or models in the activity; *committing to taking actions* and *taking consequential actions* to change the activity.

Unlike conventional applications of formative interventions, in which practitioners from the same organization collectively transform their work practices, in this study, we used this method to support a group of experienced teachers working in different schools, levels, and cities in Turkey to design their community model under the Teachers’ Network. The activity system that these teachers share is the mathematics education system in Turkey, which is highly centralized with a Ministry of Education, a common curriculum, and high-stakes testing for high school and university enrollments. Within the boundaries of this project, the transformation in this activity system is interpreted as follows: the collective activity model that participants design will offer a local solution for the identified contradictions in the system, which prevent the country’s mathematics teachers from improving their practices and solving their crises in their classrooms. This local solution, produced by the participants and concretized as the community's activity model, will be generalizable in the sense that it will have the potential to spread among other teachers in or outside the network in similar or hybridized forms (Engeström, 2009).

The overarching research question of this study is "How does a group of teachers who teach at different schools design their professional community during a formative intervention?" This paper answers the following sub-research questions specific to the first phase of the study: 1. How did the mediating tools and activities support teachers in identifying the common contradictions in their activity system? 2. What types of expressions of transformative agency emerged as teachers exercised expansive learning actions?

Data sources and analysis

Because of this study's interest in discursive expressions of transformative agency expressed in practitioners' conversations and written artifacts, this paper primarily draws on video recordings of eight online or hybrid community meetings that lasted between 129 and 172 minutes, artifacts (reflection papers, the "our problems" map) produced by the participants, and post-first phase interviews that mainly aimed to understand teachers' experiences with the first phase of the intervention. For analysis of the meetings, we have focused on topical interaction episodes to identify the collective achievement of transformative agency during conversations and speaking turns within them. The data were analyzed against the above-mentioned theoretical framework following the abductive analysis approach (Timmermans & Tavory, 2012). The selected quotes were translated from Turkish to English by the authors. Pseudonyms for all participant names have been given.

Findings

Two transformative agency expressions —criticizing and envisioning— have been identified from the analysis of the data collected during the first phase of the study, which aimed to support teachers in identifying the contradictions in their activity system that gave rise to paralyzing disturbances in their activity system (Engeström, 2016).

Achieving change-oriented criticism: "As we researched the causes, causes of the causes, …"

In Turkey, the centralized exam system is mostly seen as the fundamental problem that keeps teachers from creating meaningful and engaging learning environments for their students. This is because, in this eliminative system, the common belief is that students should do a lot of math exercises instead of getting deeper into the mathematical ideas at a slower pace to be successful at the exams. Teachers mostly believe that it is their responsibility to "show and tell" how to solve a variety of problem types that may be asked in these exams. Even though teachers are eager to make their classrooms more engaging for their students by designing and implementing alternative activities, they cannot sustain such classroom environments. This dilemma makes them feel paralyzed since the examination system is a major systemic problem that they are not able to overcome. On the other hand, this dominant discourse hides other structural and cultural problems that are obstacles, but that teachers can produce solutions for if they face them. In this study, as teachers engaged with tools and activities to identify their common contradictions, they collectively achieved change-oriented criticism by seeing alternative explanations for their dilemmas, which paved the way for them to "break away from the given frame of action and take the initiative to transform it" (Virkunnen, 2006, p. 49).

In the first meeting of the community, we discussed teachers' problems through the question, *"What do you think about the problems of mathematics teachers in Turkey?" "What are the obstacles that prevent teachers from teaching in a way that they idealize?" "Under which conditions do you feel yourself in a double bind?"* This discussion has been analyzed and transformed into an interactive map by the first author, utilizing a dynamic collaborative working space that has been revised and worked on by community members at different stages of the phase. Participant teachers mentioned various problems that prevent them from performing their ideal practice; however, centralized exams dominated the discussion. For that reason, "centralized exam system" was located as a major title in this map, which was named "Our Problems Map." Throughout the following four sessions, to trigger teachers' questioning action, the book *The Teaching Gap* (Stigler & Hiebert, 1999), which compares mathematics teaching practices in three countries (Germany, Japan, and the USA), and the accompanying lesson videos provided the first stimuli. The community read the book part by part, wrote reflection papers, and discussed it along with various activities that helped them identify their common problems. In the eighth session of the first phase, which included the discussion on the short clips of previous sessions to clarify the problem situations, the community was invited to reconsider the "centralized exam system" title on the "Our Problems Map" based on a prominent finding of this analysis: neither their reflection papers nor their session discussions talked about centralized exam systems different from the first meeting of the community. The first author (YGA), who conducted the sessions, initiated the discussion by saying:

> YGA: When I watched six sessions… -the book may not have led us to discuss the exam- but while we were discussing the book, we continued to discuss our own problems and questions, and the exam was almost never pronounced. What do you think when you re-evaluate it - should it continue to be a main topic [on the map]?

Defne responded to this conversation, and other community members continued it. The following collective discussion represents how transformative agency was achieved in the community and how mediating tools and processes supported teachers in developing an alternative perspective for their problems of practice.

> Defne: During this process, I realized that, yes, this [centralized exam] is one of our problems; but that's not the problem we should have taken on in the first place. The problem we need to take first is the teaching method. How are we going to teach this [mathematics]? How should mathematics be taught? I think we have to move forward beginning here…

> Açelya: When we started this process, it was a period when the stress and pressure of LGS [High-school enrollment exam] were felt very intensely by teachers in every school, and naturally… we thought of this as the primary problem situation, but then we read, thought about, and discussed... As we researched the causes and causes of the causes and examined them, we concluded that the real problem is not the exam but the mathematics teaching or the curriculum/framework.

> Yonca: I think in a similar way as Defne and Açelya. At first, I thought that the exam system was a very big problem, but as time went on and our studies increased, I saw that there was actually a serious problem in mathematics teaching … and here the exam system turned into a very, very small building block of this big picture for me…

> Lale: I thought we could relate the exam system there as a sub-title as the [systemic] problems under the Ministry of Education... It is no longer a situation that directly affects our practice in the classroom, at least after understanding the book. It seemed to me that it could turn into something that we can solve by ensuring [students'] deeper learning. For example, as my colleague Yaprak said, everyone thought it was the exam system at the beginning; it seemed like a big problem, but as I read it, I had started thinking in the same way. You know, the exam system is a small part of it; actually, the thought has settled [in the community].

As a result, the community decided to include the "centralized exam system" as a sub-problem category on their map. Seeing centralized exams as the most prominent systemic problem was preventing teachers in the community from proposing any meaningful solutions to the crises they were experiencing in their practices and in the system, making them feel powerless. *The community identified many aspects of their cultural codes regarding "mathematics teaching and learning" and the lack of a robust curriculum to transform these codes as the fundamental problem, which changed their perception of what is possible, supported their transition to the possibility discourse, and expanded their collective zone of proximal development* (Engeström, 2007; Horn & Kane, 2015).

Envisioning: "For the first time in a long time, I can think of so-called extreme ideas."

As teachers broadened their perspectives about the problems of the current mathematics education activity system that prevent them from improving their practice and making mathematics classrooms more engaging, they started to see their power in controlling their teaching practice, and the community started to have a different function for them: a place that guides and informs their imagination (Cole, 2019), a place where they can realize their dreams. Another transformative agency indicator, envisioning, emerged in the community as the intervention opened a space for them to be the "designers of their own futures" (Gutiérrez et al., 2016, p. 276) and supported them during the process of expansive learning as the community and researchers were learning *what was not yet there* (Engeström, 2016, p. 9).

During the post-first phase individual interviews, the first author asked questions to help teachers reflect on their experiences throughout the first phase. Defne answered the question, "Do you think there was room for your opinions and contribution in this study?" by stating that this study accomplished more than that:

> Definitely… I keep coming up with ideas, ideas, ideas, and maybe, you know, extreme ideas... For the first time in a long time, I can think of ideas you can call crazy … I think it [the study] is a catalyst that reopens my imagination or my creativity. This made me extremely happy... I reproached the environment and society, "How, how did they kill my creativity?" But it's nice … to be able to say, "Yes, I can do those so-called crazy ideas here, and from here [the community], I can get support, we can feed each other, and we can do it together."… It feels safe to be able to think about it. (Defne, post-first phase individual interview)

She continued sharing her reasons that she started to dream again with the community: *the quality of the things we were doing in the process made her think this way, which was not the case at the beginning; some decisions that the community made nourished her dreams.* The decisions that Defne referred to were those the community made at the end of the first phase as actions that the community could take to understand the roots of teachers' common problems and to design local solutions. Some of the ideas that emerged during this meeting were these: they could contact people who were in charge of the mathematics curriculum development and ask their questions; design the community's principles and orienting framework for teaching by reading scientific resources; model, implement, and disseminate a collective instructional design activity that could support the development of a teaching culture among mathematics teachers in the country. These decisions could be made by the researcher as "design elements" of a professional development program as a response to the teachers' needs that researchers determined at the beginning of the process. However, this would not support the collaborative design of a sustainable community model that teachers own and in which they could pursue their professional learning in agentic ways.

Conclusion and significance

This study reveals that when teachers are provided with appropriate mediating tools that help them question their practices and with activities and discursive practices that provide enough space, time, and support to face and analyze the contradictions in their activity system, they develop alternative perspectives in understanding their transformative power in influencing their practices and the system. In this way, they develop their community together with its novel practices and its artifacts as a solution to these contradictions. We conclude that participatory design research is fundamental so that practitioners experience transformative agency and a door for a sustainable community is opened.

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Diaries and Digital Artifacts: Investigating Teens' Daily Experiences Through User-Shared Images

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Abstract: This study explores the effectiveness of collecting digital artifacts from teens, specifically photographs and screenshots of their daily lives, to help better understand their online and offline experiences. When debriefed in interviews, these user-shared images led to rich conversations about the teens' experiences. Participants alternately sought to document their activities or provide specific evidence they thought would interest researchers. This data collection approach holds promise for phenomenological and case study research, documenting learning events and experiences in settings and at times when a researcher's presence may not be feasible or welcome.

Introduction

As a researcher, it is not always possible to be present and directly observe a phenomenon, especially when that phenomenon occurs at unscheduled times or is naturalistically distributed across parts of life. For example, while much learning research is situated in formal class settings that researchers can access, many learning activities occur in other locations, including at home and in virtual spaces. It is not always feasible or even appropriate for researchers to be present and observe these activities directly. Experience sampling techniques are one way to capture moments *in situ*, documenting some aspect of a participant's life as it happens (Christensen et al., 2003) without the researcher needing to be present.

Teenagers are a population that can be challenging to research with authenticity. Social media and related online social spaces (e.g., networked gaming) provide teens with multi-purpose spaces for engaging in various activities. A recent Pew survey found that teenagers aged 13-17 most frequently listed connections/socialization and information/learning as their primary reasons for using social media (Anderson et al., 2022). Teenagers transition between online and offline life, and in and out of school settings in a fluid manner, with friendship and peer groups connected across contexts (Dennen et al., 2020; Rutledge et al., 2019). Adults may be present in these offline settings but are generally not welcome in or privy to activities in online environments.

Experience sampling has captured elements of the teenage experience in other studies. In particular, teens' experiences have been documented using brief surveys throughout the day, focusing on feelings and activities (Pouwels et al., 2021; Siebers et al., 2022). Other studies have used diaries to collect experience data, with video diaries preferred over text-based ones due to the relative ease of recording (Debbag & Fidan, 2020). Photographs are another option for documenting experiences, allowing researchers to see through the lens of a participant (Zirkel et al., 2015). In the era of smartphones and social media, screenshots also can capture an individual's experiences in the online world.

Purpose, research questions, and context

This exploratory study aims to investigate the effectiveness of user-shared images as a form of experience sampling, considering the value of this data collection approach for enhancing qualitative research methods such as phenomenology and case study. In both methods, interviews, and observations are expected forms of data collection, and together can be used for triangulation, strengthening a study's trustworthiness. Whereas interviews elicit stories, memories, and positions through the participant's lens, observations capture *in situ* events through the researcher's lens. However, in some research contexts, observations may not be practicable. For example, studying the online worlds of minor children can be fraught with practical and ethical issues (Dennen & Rutledge, 2018). Thus, we propose media diaries as a means of accessing direct glimpses of the participant's online (or offline) worlds, through their unique lens and with their full awareness. The research questions guiding this study are:

1. What was the volume and frequency of digital image sharing among participants?
2. How did the digital image diaries help answer the original study's research questions?
3. How did these digital image diaries enhance follow-up interviews?

Contextually, this study examines participant digital artifacts from a study about the intersection of teenagers' online, offline, and school lives (Dennen et al., 2021a, 2021b; Dennen et al., 2022). In this larger study, teenage participants were asked to document their experiences via photos and screenshots in a diary format. The study's research questions focused on digital school-based, informal, and incidental learning experiences during the first year of the COVID-19 pandemic when teenagers – a population already prone to heavy online activity levels – found themselves increasingly dependent on digital means of socialization and learning.

Method

Participants

The participants in this study are 29 teenagers who completed both years of a two-year study of their daily experiences and learning activities both on and offline. The researchers' Institutional Review Board approved the study. All participants provided consent if over 18 or assent along with parental consent if under 18. This paper focuses on data from Year 2 of the study, when the participants ranged in age from 13 to 19. There were 15 female and 14 male participants who completed the study in Year 2. Participants were offered an incentive in the form of a $100 gift card for each year they participated in the study.

Data collection and analysis

In the larger study, data collection during each year entailed participating in an initial interview of approximately 45-60 minutes, followed by a week of maintaining a video diary and a final semi-structured interview in which the diaries were debriefed. During Year 2, the focus of this study, a digital image component was added to the video diaries. Specifically, teens were asked to share up to three photos characterizing their day during each day of the video diary process. Participants were required to complete at least five diary entries during the week.

The daily diary procedure involved accessing a survey via a link. Participants were prompted via a daily text message. The diary survey began with a set of questions each day, including what social media tools they had used that day, what online activities they had engaged in, their happiness, and how much time they had spent on school activities, online, and with friends. These questions collected structured data across days and participants and helped cue participants' memories about relevant details of their days. After completing these questions, participants were prompted to upload photos and videos. Videos were shot selfie-style, with participants directly addressing the camera and recounting their day in 3-5 minutes.

Data analysis for the first research question involved inventorying and counting each participant's photo submissions. To address the second research question, we coded each image by type and content. Finally, to address the third research question, we explored four participants as brief cases. We selected the cases for the diversity of image type and content as well as the number of photos submitted.

Findings

Volume and frequency of photo sharing

All but one participant shared photos or other digital images as part of their diary submissions. That participant also did not record his own image on his video diaries, instead placing his phone on a table and simply recording audio. He was open and loquacious during interviews but reticent to share visuals. Across the other participants, contributions ranged from a low of 1 photo / 1 day (2 participants) to a high of 21 photos / 7 days (1 participant). The average number of photos per participant was 11, with female participants sharing more photos (mean=14) than male participants (mean=10).

Images as data source

Most participants shared a combination of original photographs and screenshots, each comprising close to 45% of the overall shared images. However, it is worth noting that although original photos and screenshots were shared with similar frequency, the proportion varied by participant. Additionally, 46% of the participants shared selfies, although – with one exception – selfies did not comprise the majority of a participant's photos. Topically, the photographs that participants shared were diverse in content. Many photos documented specific activities, such as submitting an assignment, working on homework, watching TV, or even getting a COVID vaccine. Screenshots similarly documented schoolwork, but also captured what the participants were searching for and seeing online. Screenshots documented hobby-related learning, current events (especially COVID and mask-related information), what the participants posted online, and things they found humorous. As a data source, the images gave the researchers an authentic look at what was otherwise merely described during interviews.

Shared images and follow-up interviews

During the second interview, participants were presented with a slide show of their images from the diaries and encouraged to discuss the content and the stories behind the images with the researcher. In many instances, the discussion of photos led to a deeper conversation about topics related to the photos, although this differed by interviewer. Some interviewers probed more than others, whereas others simply asked for a brief explanation of each image and then swiftly moved to the next. It also differed by participant. Unsurprisingly, participants who shared more images also had more to talk about across the images. Participants who shared fewer photos seemed less engaged overall and were more likely to report that they simply forgot to take photos. In this sense, however, taking more photos did not appear to be about actually having more going on in one's life, but rather having a stronger desire to engage in conversation about what was going on in one's life. Some participants were documentarians, photographing the places they visited and the things they ate during the week. During interviews the photos prompted stories, much like someone might share their vacation photos. Others appeared to seek out images to share with their interviewer specifically. For example, one participant mentioned to her interviewer in the first session that she felt bad when she spent too much time on TikTok and got the "TikTok stop guy" suggesting that she take a break. Her interviewer was unfamiliar, and she purposefully sought to capture a screenshot to share it during the second interview.

Case 1: Celine and a life lived offline

Celine, a 16-year-old girl, was not enamored of online life and indicated during interviews that she strongly preferred to just participate in activities in person and real time. Although she had a smartphone and social media accounts, she used them sparingly and mostly to support promoting her skills as an equestrian in the hopes of being noticed by a college scout. She spent substantial time riding and caring for her horse at the stables. As she documented her week, all 20 of the images she shared were photographs of locations she visited. In addition to photos of horses, she shared photos from her babysitting job and events she attended with her friends. Nowhere in her photos was anything that hinted at smartphones or social media.

Case 2: Charles, the aspiring filmmaker

Charles, a 16-year-old boy who wants to be a filmmaker, primarily shared Letterboxd screenshots. He spent substantial time on Letterboxd, writing film reviews and compiling lists of films. During the second interview, Charles indicated that he had purposefully created screenshots to show the interviewer specific examples of how he uses Letterboxd. He was eager to discuss these images during the interview.

Case 3: Cameron, a teen with a plan

Cameron, a 16-year-old boy, shared nine photos across multiple days. Collectively those photos told two stories. First were photos documenting a surprise birthday party he was throwing for his mother. He documented packages that arrived in the mail, tables being set up for the party, and getting his schoolwork done so he would have time to focus on the party. The latter photo, which included his computer screens, led to an in-depth discussion of how he has set up his school workspace for remote learning and what he does about school when there are Internet problems. Cameron's photos also documented his new hobby, creating t-shirts with heat-press designs. He had just received the heat press, which was shared in an unboxing photo, and shared screenshots documenting how he was using online videos to learn how to operate it.

Case 4: Briana and her online life

Briana, a 15-year-old girl, primarily shared screenshots from TikTok and Instagram. She was heavily interested in documenting things she saw online for later reference. For example, she captured Starbucks' secret menu, commenting that she is not allowed to have Starbucks during cheer season, but she saved it in her notes on her phone so she could remember it. She also shared a post of a giant knitting project, sharing that she was not actually doing it but would like to. She also shared memes and quotes because she found them funny and wanted the interview team to laugh as well. Each image that Briana shared led to a larger conversation that provided insights into her interests and her thoughts.

Discussion and conclusions

These findings show how experience sampling with digital images can effectively elicit data from participants, enhancing data collection for case study and phenomenological research approaches. Nestled between two interviews, a period of visual documentation encourages participants to share images that capture daily experiences and the phenomenon of interest to the researchers. In this study, participant-generated images allowed the researchers to see through the participants' eyes, prompting rich stories and conversation during an otherwise largely unstructured interview. In practical terms, the nearly ubiquitous nature of mobile phones makes experience sampling relatively easy to accomplish (Xie et al., 2019), and this study demonstrates how photos might be used to capture data instead of survey items. Although we did not prompt participants to take photos at specific times of day, mimicking the *BeReal* app, that is an alternate approach that could be taken.

This study shows how user-generated images help researchers see a phenomenon through the participants' eyes, which provides a valuable vantage point when studying all manner of learning. It was situated in the context of everyday life, with participants free to choose which activities they would (and would not) capture and share. Amid the mundane and special events that teens documented were images that captured moments of formal, informal, and incidental learning. This research approach could just as easily be used in a more structured context, encouraging learners to document learning processes during small group work or while doing homework.

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It's a Little Frustrating, but Fun: Supporting Novice Programmers' Learning Through Unscaffolded Problem-Based Designs

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Abstract: Past efforts to teach novices programming through pair programming and project-based learning utilizing different "low floors, high ceilings and wide walls" platforms have been successful. Building from related work, we propose that Productive Failure-based learning designs can also be an effective approach to supporting youth and novices when learning programming and fundamental computational concepts. We report on findings from an online synchronous remote workshop, which occurred during the COVID-19 pandemic, and was designed to support participants in federal programs for low-income families. Participants engaged in code debugging without scaffolding followed by a consolidation phase. Findings show the effectiveness of PF design in application accuracy of some computational concepts however persistent struggles with complex concepts such as conditionals and operators. We identify the need to design structured support structures in PF designs to manage failures, improve problem-solving approaches and generate optimal solutions.

Background

Programming is a useful and necessary skill for a technology focused workforce. However, learning to program is a difficult task for novices. Novices face difficulties in understanding and applying fundamental programming concepts. They are plagued by recurring bugs, syntax errors and code smells (Fraser, 2021). Novices also develop "bad" debugging practices by trying to solve buggy code through brute force, adding high frequency errors and fixating on first solutions without conducting detailed error location or hypothesis testing (Chmiel & Michael, 2004). Various efforts have been made to facilitate learning and address the difficulties faced by novice programmers in formal and informal education. Novice-friendly programming platforms with "low floors, high ceilings and wide walls" (Resnick, et al, 2009) such as Alice, Scratch and Blockly were developed. Additionally, instructional approaches such as pair programming (Umpathy & Ritzhaupt, 2017) and constructionist gaming (Kafai, 2006) have been shown to facilitate novice programming.

We argue that using "Productive Failure" (PF) pedagogical design can also be an effective approach to support novices learning and understanding of fundamental computational concepts (Kapur, 2008). The design and implementation of this study is also in line with this year's theme around building knowledge and sustaining community. We report on a DBR mixed methods study conducted with 10 high school students – all of whom participated in federally funded programs for low-income families - who engaged in a 3-week high school workshop, which was re-designed to occur remotely online due to Covid-19. Implementation of the curriculum followed the Productive Failure learning design where in Phase I, students generated multiple solutions to coding problems without scaffolding and direct instruction, and Phase II consisted of facilitator feedback and discussions of optimal solutions. Our guiding research question is: How do productive failure designs support learners' understanding of computational concepts when working with open-ended debugging problems?

Methods

Research design

A convergent parallel mixed methods research design was used to carry out this study (Creswell & Plano Clark, 2017). Qualitative and Quantitative data were collected concurrently, independently analyzed and results were interpreted together. A Design-Based Research framework (Sandoval & Bell, 2004) was selected to design and implement the debugging mini curriculum leveraging Productive Failure Design. Three iterative cycles have been completed, and the current study represents the second iterative cycle.

Setting and participants

The productive failure-based activity (herein termed "debugging mini curriculum") was implemented as a 3-week online synchronous "Coding, Game Design and Problem Solving" workshop in the fall of 2021 as part of a federal TRiO-supported after school program for high school students from low-income families from urban and rural communities in the Northeastern United States. The workshop was conducted twice a week for two hours via Zoom with one primary instructor (Author 1) and a TRiO assistant. Google Chromebooks were delivered to all so that they could participate. Ten students (7 girls, 3 boys; 6 Latinx, 2 Asian, 2 Black) between 15-18 years old (10-12th grade) consented, 9 of whom had no prior experience with programming and Scratch.

Curriculum design

The debugging mini curriculum was developed over two iterative cycles of the DBR project. Individual lessons were based on *Debugems* (Griffin, Kaplan, & Burke, 2012). Programming problems were presented as buggy games that participants had to troubleshoot to play. Faulty code was strategically placed within the problems and had a range of features including missing blocks (e.g., initialization, conditionals, and operators), containing incomplete object-oriented code on Sprites, or comprising erroneous sequences. A narrative was provided as a fun backstory for the challenges along with a task list. The curriculum consisted of 5 units with 14 debugging problems targeting fundamental computational concepts: U1= Sequences; U2= Events & Loops; U3= Conditionals & Parallelisms; U4= Operators & Data; U5= Combination (design game).

Implementation

Implementation of the curriculum followed Kapur's (2008) Productive Failure design. Phase I, which consisted of "Exploration and Solution Generation," involved exploring block-based programming through Scratch tutorials. Students then worked individually on generating multiple solutions to each debugging problem without scaffolding and direct instruction. Phase II consisted of guided "Consolidation and Knowledge Assembly" where Author 1 compared student generated solutions with an optimal solution and provided feedback on students' understanding as well as accurate examples of applications of computational concepts.

Data sources

We examined four primary types of student data. Students completed online pre-post surveys scored on a 6-point Likert scale (1=Strongly Disagree to 6=Strongly Agree), which consisted of items from previously validated instruments: (a) Problem Solving Inventory (PSI), a = > 0.80 (Heppner, 1988), (b) Attitude Scale of Computer Programing Learning (ASCOPL), r = 0.671, n= 476 p< 0.001 (Korkmaz, & Altun, 2014) and (c) Computer Programming Self Efficacy Scale (CPSES), α= 0.95; r = 0.966, n = 233, p<0.0 (Kukul et al. 2017). The survey assessed participants' problem-solving abilities, attitudes towards programming, programming self-efficacy and confidence. Think Alouds were administered during Phase I and II to examine conceptual and procedural understanding. Online semi-structured interviews were administered after each session to understand students' debugging processes, moments of failure and learning. Student generated solutions and their artifacts (games) were also analyzed to provide insights into the trajectory of students' applications of computational concepts.

Data analysis

The Wilcoxon signed-rank test was used to analyze pre-posttest changes in the discrete quantitative survey data, as it is suitable for non-normal distribution samples and accepted in peer-reviewed publications for small N samples. For the qualitative data, interaction analysis (Jordan & Henderson, 1995) was used to unpack discourse on failure mediated learning. We selected, coded, and analyzed prominent interactions during Phases I and II, focusing on participants' explanations. Initial codes and axial codes were informed by Litts et al's (2016) four stage coding process focused on identifying instances of debugging challenges, types of challenges and strategies used to resolve problems. Case studies were then created to understand the specific aspects of Productive Failure design that supported learning. Artifact analysis was conducted in conjunction to track students' iterative attempts and changes throughout the debugging curriculum.

Findings

Quantitative findings

A Wilcoxon Matched Pairs Signed-Ranks Test indicated that post-test scores were statistically significantly higher than pre-test scores z = -10.52, p < 0.001, r = 0.35 with medium effect size (r > 0.3). In particular, Computer Programming Self Efficacy (CPSES), z = -9.25, p < 0.001, r = 0.58, statistically significantly increased with a large effect size (r > 0.5), indicating improvements in students' confidence and perceived ability to program (Table 1). Similarly, participants' computer programing attitudes measured by ASCOPL, z = -4.83, p < 0.001, r = 0.28 (moderate effect), and participants' problem-solving confidence as measured by PSI, z = -2.12, p = 0.034, r = 0.11 (small effect) were statistically significantly higher. However, participants' "Approach Avoidance Style" (PSI subscale) was not statistically significant, z = -1.00, p = 0.317, r = 0.07 indicating that some participants may have shown a tendency to avoid as opposed to fully examine or troubleshoot problems at the end of the workshop.

Table 1
Wilcoxon signed-rank test results (α = 0.05)

	Pre(median)	Post(median)	*p* (2-tailed)	*z*	*r*
All Items	4	5	**< 0.001**	-10.52	**0.35**
ASCOPL	4	5	**< 0.001**	-4.83	0.28
CPSES	2	5	**< 0.001**	-9.25	***0.58***
PSI	4	5	**0.034**	-2.12	0.11
PSI--Emotion	3	4.5	**0.004**	-2.90	**0.37**
PSI--Avoidance	4	4	0.317	-1.00	0.07
PSI--Confidence	5	5	**0.001**	-3.20	0.28

Qualitative findings

Two case studies were created and analyzed to understand aspects of Productive Failure design that supported improvements in programming self-efficacy and application of computational concepts.

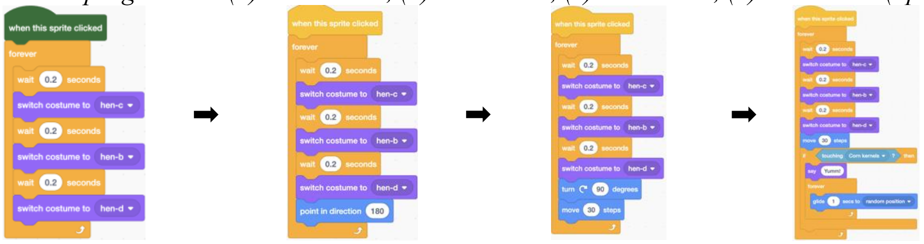
Case I: Learning through trial and error

During the Solution Generation phase on Day 2-5, students were encouraged to apply prior knowledge, informal heuristics, and any debugging strategies at their disposal to generate solutions. In the absence of direct instruction and prior programming experience, trial and error became the prominent informal heuristics applied. In one of the think aloud exchanges during the activities, Jamarcus (Latinx, 16 yrs., 11th grade), explained that he used trial and error to debug a problem where they had to get the chicken sprite from its coop to the corn kernels and around the farm (See Figure 1). By trying out different codes, he "knew what it did, where to put it and how [to use the] code block later" indicating that trial and error could be effective for exploratory learning. Later, during the interview, he expanded on this further.

> **Author 1:** So, how did you get to the right solution? How did you think about it?
> **Jamarcus:** Well, basically, I did trial and error. Basically, I found out the things [codes] that didn't work, so that when I found the glide button it solved my problem, because then I could have him move around...
> **Author 1:** Right! Talk to me about trial and error. How did that help you?
> **Jamarcus:** It's a little frustrating, but it's also fun, you know? Sometimes it's kind of disappointing, but I just have to keep trying cause every time I tried a code, I learn something. I knew what it did, where to put it and how I can use that [code block] later.

When working through the problem, Jamarcus generated 3 solutions first adding "Point in direction 180" which changed the sprite direction without moving it (Figure 1, b), then adding "Turn 90 degrees clockwise" and "Move 10 steps" which rotated the sprite on the same spot due to the "Forever" loop (Figure 1, c). In his third attempt, he got the sprite to the corn and around the farm by combining motion, conditionals, and loops (Figure 1, d).

Figure 1
Jamarcus's progression: (a) Given code, (b) Iteration 1, (c) Iteration 2, (d) Iteration 3 (optimal)



(a)

```
when this sprite clicked
forever
  wait 0.2 seconds
  switch costume to hen-c
  wait 0.2 seconds
  switch costume to hen-b
  wait 0.2 seconds
  switch costume to hen-d
```

(b)

```
when this sprite clicked
forever
  wait 0.2 seconds
  switch costume to hen-c
  wait 0.2 seconds
  switch costume to hen-b
  wait 0.2 seconds
  switch costume to hen-d
  point in direction 180
```

(c)

```
when this sprite clicked
forever
  wait 0.2 seconds
  switch costume to hen-c
  wait 0.2 seconds
  switch costume to hen-b
  wait 0.2 seconds
  switch costume to hen-d
  turn ↻ 90 degrees
  move 30 steps
```

(d)

```
when this sprite clicked
forever
  wait 0.2 seconds
  switch costume to hen-c
  wait 0.2 seconds
  switch costume to hen-b
  wait 0.2 seconds
  switch costume to hen-d
  move 30 steps
  if touching Corn kernels ? then
    say Yumm!
    forever
      glide 1 secs to random position
```

While Jamarcus found trial and error "frustrating" and "disappointing" at times, he also described it as "fun" and useful for his learning. However, he was especially persistent and resilient as a learner, so trial and error may have presented him with perceived benefits in ways it did not for others.

Case II: Changes in debugging strategies through facilitation

Facilitator feedback during the Consolidation phase was designed to support code optimization and accuracy by encouraging student reflections on their solutions and changes in their debugging strategies. One of the participants, Safiya (Latinx, 15 yrs., 10th Grade), explained in her interview how facilitators' feedback contributed to changing her debugging strategy from trial and error, "trying different blocks" to forward reasoning (or, in her words, "looking at the code and the problem and figuring out what blocks were missing"). When debugging this problem, she was trying to get a dog sprite to say "Come back" on through a loop sequence if the dog touched the butterfly sprite. However, she placed a Sensing Boolean block "touching Butterfly1" inside the "Forever" loop without the "If-then" conditional and was "confused" as to "why certain blocks didn't go together." After Author 1's feedback, that only container blocks (such as "If-then") can house sensing blocks, Safiya examined her entire code. She debugged the problem by adding in the missing "If-Then" container and placing the "touching Butterfly1" inside it along with the say "Come back" block. In a later interview, she expanded on her process.

> **Author 1:** How did you go about solving these problems? …
> **Safiya:** I got confused on what the task was and why certain blocks didn't go together. I tried different blocks, but it didn't work to just add the blocks while ignoring the hints and goals. But I got help with it and understood how to do it. Some solutions that worked were looking at the code and the problem and figuring out what blocks were missing instead of just trying different blocks.

Discussion

Findings show that well-designed and reinforced PF learning designs can enhance learners' comprehension and future troubleshooting efforts, despite introducing frustration and complexity. Students showed improvement in their interest, willingness to program, and self-efficacy in applying computational concepts. However, while some students mitigated their difficulty when confronting challenges, others lacked confidence in their programming and debugging abilities and tended to avoid challenges. The case studies shed light how different strategies or scaffolds can benefit different students. Ongoing work aims to find optimal ways to support novice learners in their understanding, awareness of their learning, and confidence over time.

Moreover, the workshop also provided initial insights into the effects of the pandemic and remote learning on vulnerable learners. However, future work is needed to explore how different designs can facilitate meaningful learning and community building for marginalized learners. Furthermore, the small sample size calls for larger studies, and additional research is needed to examine the effects of online and face-to-face learning interventions.

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Community-Driven Design: A Reorientation to Designing Tools for Learning With Communities

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Abstract: Design is not neutral. Making explicit the design assumptions that drive our work is essential toward designing for culturally sustaining/revitalizing futures. In this short paper, we share our development of a community-driven design process that supports our collaborative work of inviting Tribal families to share and preserve cultural knowledge through building relationships with the land. Specifically, we present a case study to illustrate the design process and reciprocal relationship that we cultivated between Tribal Elders and University designers. As a team, we collaboratively designed a series of learning guides to share the Tribe's culture with families. We characterize the community-driven design process with four design waves: sharing, interpreting, learning, and reflecting. This design process invites a slow, rhythmic, and intentional knowledge exchange. Our work contributes theoretical and practical understandings of community-driven design as a process to sustain/revitalize culture.

Objective

Designers hold exceptional power to invite or disinvite certain knowledge and values. Thus, *who* designs matters, *what* is designed matters, *how* it is designed matters, *why* it is designed matters, and *when* it is designed matters, especially in the context of designing for culturally sustaining/revitalizing goals (McCarty & Lee, 2014). Scholar, who labor in this area, highlight the importance of making explicit the assumptions driving our design work; for example, Bang and colleagues explicate the reality that "what is good, right, true, and beautiful" (Bang et al., 2016, p. 29) is rooted in cultural, historical, and political knowledge and values. Therefore, it is necessary to disrupt who designs learning environments and technologies by redistributing power from education researchers and designers to local communities.

As designers, Indigenous peoples have been actively reclaiming *who* designs by centering the uses of digital and original technologies on "meaningful community-driven goals" (Bang et al., 2013, p. 707). These goals disrupt colonizing purposes of technologies and repurpose them to assert self-determination through language revitalization and cultural preservation. By pursuing meaningful community-driven goals, communities become designers and redefine what it means to create with technology through rich innovations at the intersection of learning and culture (Bang et al., 2013).

In this paper, our team explores our development of a collaborative design process that supports the goal of sharing and preserving knowledge between and within Indigenous communities and families. As Indigenous and non-Indigenous researchers, designers, and educators, we specifically investigate: *how do we employ a community-driven design process to create learning guides for Indigenous families to build relationships with the land?* Specifically, we share our collective analysis and reflection on our design process, which led to the identification of four design waves: sharing, learning, interpreting, and reflecting. Our work contributes practical and theoretical understandings of community-driven design led by a Tribal Nation.

Background

In our work, we take a culturally sustaining/revitalizing approach (McCarty & Lee, 2014) to support and develop our relationship with the land. Culturally sustaining/revitalizing approaches emphasize understanding and conceptualizing educational practices specific to Indigenous learners. Culturally sustaining/revitalizing pedagogies are deeply rooted in recognition of Tribal sovereignty by pushing for the decolonization of learning (e.g., McCarty & Lee, 2014). These stances inform our work to center *relationship with the land* as a way to sustain and revitalize cultural identities. Thus, we understand our relationship with the land as fundamentally cultural. How people relate to land and nature is socially constructed and varies across cultures (e.g., Medin & Bang, 2014). Relating with the land is highly integrated and, in some cases, synonymous with culture. Thus, we need to restore our relationship with the land to sustain and revitalize culture.

Community-based approaches to design

As a field, the learning sciences is rich with seminal work around collaborative design processes that include designing *with* rather than *for* communities. In our work, we are heavily shaped by a community-based design research (CBDR; Bang et al., 2016) approach. Specifically, CBDR involves "design efforts that work from within the "ongoingness" of communities" (p. 11) and is characterized by axiological innovations that occur as a result of three interrelated design commitments: critical historicity, intergenerational learning, and transforming institutional relations (Bang et al., 2016). This orientation to design recognizes the historical, cultural, and political nature of partnering with Indigenous communities and embraces the need to invite community-wide and intergenerational participation. Since community-based efforts are often characterized by various levels and forms of community participation, we use *community-driven* in our work to clarify the Tribal Nation's sovereign role across our research and design efforts. As a team that includes non-Indigenous researchers, our stance on CBDR is characterized by a TribalCrit (Brayboy, 2005) orientation toward partnering with tribal communities: respect and reciprocity in relationships, self-determination, and sovereignty.

Methods

As part of a multiyear critical ethnographic study, we present in this paper an intrinsic case study (Stake, 2008). Through developing the case, we seek to better understand the design process and reciprocal relationship that developed between Tribal Elders and University design researchers, who collaboratively designed a series of learning guides to engage families in building relationships with the land. Given the iterative and multiyear nature of our approach, participants varied over the course of the design process. The bulk of the design work happened between Joaquin (pseudonym to maintain anonymity), a Tribal Elder and designer, and Author 1 (Kenden Quayle) & Author 3 (Breanne Litts), two University design researchers. The process also included other Tribal Elders and University-affiliated Indigenous and non-Indigenous design team members.

Data collection and analysis

To construct the case presented in this paper, we draw on *personal communication* between Tribal Elders and University design researchers, *design artifacts* developed throughout the process, *fieldnotes* that were collaboratively written every week, and *analytic discussions* across the entire project team. We employed a collaborative and reflexive meaning-making analytic approach to construct cases by triangulating (Creswell, 1998) interpretations and claims across partners, perspectives, and documentation. Joaquin's analytic insights are integrated into this work as transcriptions of data analysis meetings. In addition, University design researchers drafted a re-telling of our collective insights, and Joaquin reviewed these re-tellings before submission.

Findings

While analyses are ongoing, we present four waves of a community-driven design process: sharing, interpreting, learning, and reflecting. Here we share one moment between Joaquin and Kenden to illustrate how our design team employed community-driven design.

Sharing

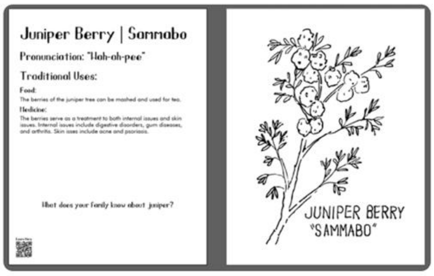
Building a relationship based on trust and reciprocity with community partners prompts the possibility of sharing. Thus, a community that shares ideas, designs, and knowledge is a key marker of a community-driven design process. In our case, the trust cultivated within the multiyear partnership made space for Joaquin to openly share a vision and plan for a Tribal Plant Guide, which included Shoshone words and his knowledge of plants. Part of the trust-building process includes only capturing what is explicitly permitted for research. Due to the confidential nature of this initial exchange, we do not have details of it captured as data. This level of confidentiality was maintained throughout the design process: nothing was shared with additional team members or beyond until Joaquin said it was the appropriate time to do so.

Interpreting

Interpreting often followed sharing because the design process allowed space for each designer to assess individual understandings of the knowledge that was shared. Interpreting occurred any time there was a meaning-making opportunity to understand cultural knowledge. Joaquin guided this wave with what he called "hints." By this, we mean that questions and unknowns were not answered hastily or entirely; instead, the team was invited to interpret their own meaning. In one example of interpreting through hints, after reviewing the first iteration of the Tribal Plant Guide, Kenden suggested to Joaquin that we include pronunciations for the Shoshone words in the guide. Though Joaquin agreed this would be helpful, rather than offer the pronunciations himself, he encouraged Kenden to sound out each word by herself first and then share the results with him. This prompted an active exchange of interpretation. Here is an exchange from 01/07/2022 that serves as an illustrative example:

> Kenden: "Does sammabo mean berries? For the berry side should it say sammabo instead of waapi?"
> Joaquin: "Ok lets put Juniper Berry under Sammabo like [where] Juniper under Waapi take out ok"
> Kenden: "Alright! Like this?" [see Figure 1]
> Joaquin: "Yes Kenden that's grt8 but pronunciation is Sammabo not Wah-ah-pee that's the tree itself other than that grt8 good work Kenden THANK YOU much"
> Kenden: "thank you for catching that! I will fix it! I think that is all I have for you today! Thank you!!"
> Joaquin: "Kenden grt8 this plant book will help the youth know more about how we used the things in nature and what we named them in Shoshone language thanks again Kenden"

Figure 1
Juniper Berry "Sammbo"



Juniper Berry | Sammabo

Pronunciation: "Wah-ah-pee"

Traditional Uses:

Food:
The berries of the juniper tree can be mashed and used for tea.

Medicine:
The berries serve as a treatment to both internal issues and skin issues. Internal issues include digestive disorders, gum diseases, and arthritis. Skin isses include acne and psoriasis.

What does your family know about juniper?

Learning

Learning served as a rhythmic knowledge exchange between Joaquin and Kenden to check in with their interpretation results. When developing the Shoshone pronunciations, Joaquin learned how to think about designing for learning in this written format and Kenden learned the Shoshone language and pronunciations. As time went on, many of the knowledge exchanges over Slack started to include knowledge beyond the Tribal Plant Guide, such as greetings and sign-offs. As an example, consider this Slack exchange from 01/23/2022:

> Joaquin: "Kenden Aishen AI has line under like Daigwade for thank you"
> Kenden: "Hi [Joaquin], sure thing, which book can this be found in?"
> Joaquin: "No book just letting you know how to say Thank you – Aishen"
> Kenden: "That's great, Aishen! (with a line under the ai) 😊"

Another important aspect in designing the learning guides involved relating with the land by learning directly from the plants and nature. Joaquin explains this process: "you know when you're doing this, you have to go out and find some of those plants. But then when you've found them you can put a lot more detail in them... When you have that, I guess I call it hands on contact with the things that you are interested in, you have a better way of being able to learn" (Reflective Conversation, 07/14/2022). In this iterative rhythm, we gain knowledge slowly.

Reflecting

Because this was an iterative process marked by the careful sharing, interpreting, and learning, there were moments between exchanges that allowed space for reflection. These spaces for reflection characterize the reflecting wave of community-driven design. For example, in one exchange, Joaquin continued researching the plants and shared via email on 12/10/2021 that he found a Shoshone name for a plant that was not currently included in the guide:

> Joaquin: "Good day (tsaaN da bai) Kenden one change a better name for horse tail Sebu so scratch out Isayugip thank you Kenden... Kenden one more change mountain mahogany name Tonambe I didn't have name before now I do"

Allowing this time is a critical characteristic of community-driven design, as Joaquin explains, "And then what was good was being able to edit, editing. Going back to refine everything. Having the ability to do that and not say, 'well, we're just gonna give you this much time, we need to have it out.' Because when you're ready and you say okay let's do it now, then all of a sudden something pops up." (Reflective Conversation 07/14/2022). The wave of reflecting remained unconstrained to allow everyone however much time and space needed to consider and (re)consider the guides and generate more sharing.

The process enacted with the learning guides

The waves of the community-driven design process that shaped the creation of the learning guides are reflected in the product of the guides themselves. Joaquin explains the goal of the Tribal Plant Guides: "so doing that coloring book, that was the whole idea was to get the youth and others interested in wanting to know more and to use them." (Reflective Conversation 07/14/2022). Everything included in and left out of the guides was intentional, as the guide serves as a starting point for the facilitation of Tribal members' relationship with the land. Joaquin takes the same "hint"-based approach in his design of the guides: "so, when people look at that book, they can also go further because we don't want to give them all the stuff when you're trying to use a guidebook, to give them all the information. They still need to find out a lot on their own, and it makes it better for them." (Reflective Conversation 07/14/2022). These goals of sharing, interpreting, learning, and reflecting manifested in the guide with a space for people to add their own knowledge by asking: "what does your family know about [particular plant]?". It is important to acknowledge how the waves of community-driven design are embedded in the product (i.e., the learning guides) of the process, because it further demonstrates the importance of *who* designs and *how* design happens.

Significance

The cadence embodied by the community-driven design process is unique, as it invites a slow, rhythmic, and intentional exchange of knowledge through four waves: sharing, interpreting, learning, and reflecting. Of special importance is how Joaquin and his vision led the entire process. Unlike standard Western design processes, which are often characterized by discrete steps and strict deadlines, the community-driven process is centered on trust and relationships. Community-driven design is, instead, characterized by meaningful community-driven goals – or "what is good, right, true, and beautiful" (Bang et al., 2016, p. 29). If we take seriously goals toward culturally sustaining/revitalizing design, we must also consider what forms of process will support these designs and accept that these forms will invite new rhythms of knowledge exchange.

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Theoretical Approach for Providing Feedback for Instructors Through a Standardized Assessment for Undergraduate Physics

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Abstract: Assessments are an integral part of academic environments and provide key insights on students' learning and the efficacy of pedagogical practices. In this work, we introduce the development process of a novel research-based assessment - the Thermal and Statistical Physics Assessment (TaSPA), for undergraduate physics courses. We elucidate leveraging of existing theoretical and design frameworks in the development of TaSPA, and how the interplay of these frameworks addresses some of the shortcomings of contemporary assessments. Unlike most of its counterparts, TaSPA focuses on providing actionable feedback for instructors to modify their courses. The current work represents a paradigm shift in how assessments are envisioned and designed by the discipline-based education research community.

Introduction

Development and dissemination of research-based assessments (RBAs) in higher education – commonly referred to as "concept inventories" – has attracted substantial traction in the physics education research community. The development of an RBA typically involves creating assessment items on a target domain (often based on the insights obtained from student interviews), and validating the items in terms of their content and the intended measurement. The assessments are then administered (usually in pre- and post-format), and students' scores are interpreted to gauge their learning along with the efficacy of relevant teaching and learning environments. However, researchers and practitioners have noted the lack of clarity for instructors in interpreting students' sores to make effective course modifications (Madsen et al., 2016).

In the current work, we elucidate the process of an RBA under development - the Thermal and Statistical Physics Assessment (TaSPA), which provides actionable feedback for the instructors based on their students' responses. When available, instructors will be able to use the TaSPA portal by selecting a set of valued learning goals from a list. Through a web-link accessed by an email, students can take the TaSPA online. After a stipulated time, instructors will receive a report on their students' performance along with actionable feedback (if required) about how they can modify their courses to better support their students' learning.

In the rest of this manuscript, we address the research question: *How can we develop a research-based assessment that provides actionable feedback for instructors to support their students' learning?*

Theory-of-action for TaSPA

The process of assessment design typically involves articulating the measurement argument, i.e., what the assessment intends to measure, and the mechanism through which this measurement occurs (Kane, 2013). The measurement arguments assume significance as they communicate what the education research community considers important to assess, and can influence instructors on guiding the everyday activities in classrooms.

For the current work, we consider assessments also as "instruments of change" rather than solely as "instruments of measurement". This paradigm shift then requires us to replace the measurement argument with a "theory-of-action" - an explicit argument on how the assessment brings about the intended change in an individual or an institution (Bennett, 2010). A theory of action entails articulating the components of the assessment, the change the components intend to produce (intended effects), and the mechanism which facilitates this change. Our intended effects correspond to shifting the emphasis of our classrooms from pure conceptual understanding to application of students' existing knowledge in making sense of novel contexts. The assessment components include assessment tasks and feedback reports. Instructors taking up the generated feedback and making relevant course modifications correspond to the mechanism through which our assessment components lead to the intended effects.

Three-Dimensional Learning

Educators have emphasized the need to shift the focus of academic learning environments from “knowing” to “doing” science (Harris et al., 2019). Three-Dimensional Learning (3DL) is the design framework which promotes the spirit of “doing science” by characterizing students’ learning across three “dimensions”. These include (i) *Scientific Practices* - the activities through which scientists generate new knowledge (e.g., constructing explanations), (ii) *Core ideas*- the key disciplinary concepts which provide organizational structure for students’ existing knowledge (e.g., energy), (iii) *Cross-cutting concepts*- the concepts which have applications across multiple scientific disciplines (e.g., cause and effect). While this framework was initially proposed for the K-12 education system, researchers have argued for its relevance to the college level (Laverty et al., 2016). We adopt this framework in design of our assessment tasks.

Self-regulated learning

The notion of learning as it relates to assessment scores has traditionally been focused on students learning. Here, we also position instructors as learners, or, more specifically, as self-regulated learners who seek to modify their pedagogical practices to better support their students' learning. Self-regulated learning (Butler & Winne, 1995) is a meta-cognitive activity in which learners regulate aspects of their thought processes, motivation, and behavior during learning. This can include: actively monitoring progress towards goals; consistently analyzing strategies employed in pursuit of the set goals; managing emotions, etc.; and responding to external feedback. Effective feedback, particularly external, has been considered as a catalyst in accelerating and providing necessary impetus for self-regulated learners in making progress towards their goals. Sadler (Sadler, 1989) put forward three features of external feedback that are effective at assisting self-regulated learners in their progress towards the set goals. These include clarifying: (i) the desired performance, (ii) the current state of the performance, and (iii) opportunities to close the gap between current and desired performance. We adopt these features in the design of our external feedback to instructors.

Development of TaSPA’s assessment components

Below, we briefly articulate the development of our assessment components by leveraging the frameworks discussed above. The development of the components 1-4 are strongly influenced by Harris et al. (Harris et al., 2019) and a detailed discussion on the contextual adoption can be found in (Rainey, Jambuge, et al., 2020) and (Laverty et al., 2022).

1. Articulating learning performances.

Learning performances (LPs) are assessable statements formed by blending scientific practices, core ideas and cross-cutting concepts, and reflect what students should know and be able to do with that knowledge (Harris et al., 2019). The focal content areas of our LPs are drawn from Rainey *et al.’s* survey (Rainey, Vignal, et al., 2020) documenting the conceptual ideas valued by instructors who have taught thermal/statistical physics courses across the United States. Below is an example of a learning performance with the scientific practice **“Constructing Explanations”,** the core idea “Energy”, and the cross-cutting concept “*Cause and effect”*.

> **Generate an explanation** about *the mechanism by which the temperature does (or does not) change* with heat flow into or out of a system informed by the process undergone and ambient conditions (e.g., pressure, temperature).

2. Generating knowledge-in-use tables.

The next step involves articulating the (i) *knowledge, skills, and abilities* required to demonstrate proficiency in addressing the learning performance, (ii) the corresponding *evidence statements* (ESs) in students’ work, and (iii) the *task features* which can engage students in the targeted scientific practice, core idea, and cross-cutting concept. The organization of these elements in a tabular form is referred to as the “knowledge-in-use” table.

3. Developing assessment tasks.

The task development begins by identifying a context which addresses each of the elements in the Knowledge-in-Use table and developing an open-ended task. This task is then piloted to undergraduate physics students, and their responses are analyzed through the lens of the evidence statements. The student responses assist in the development of a coupled multiple-response (CMR) version of the task (Wilcox & Pollock, 2014).

4. Designing rubrics.

Rubrics translate students' responses to the tasks into scores which in turn are interpreted with respect to ideal outcomes. Our rubrics reflect the evidence provided in students' responses demonstrating the extent to which they have achieved the given learning performance. We characterize students' responses into "Met" (strong evidence), "Partially Met" (weak evidence), or "Not Met" (no evidence) reflecting their extent of meeting the learning performance. The task development and the rubric design often occur simultaneously to ensure coherence in capturing relevant evidence for students' proficiencies. Every response pattern to tasks is associated with a rating characterizing the aforementioned proficiency levels.

5. Generating feedback reports.

Our feedback embodies the effective principles as specified in the "Self-Regulated Learning" subsection. Accounting for the instructors' diverse classroom practices, the feedback refrains from providing specific, prescriptive approaches. Instead, we focus on the nature of opportunities that students can be provided with, to better support their students' learning. However, the ways of operationalizing these opportunities are left to the instructors.

The process of generating feedback involves interpreting individual students' responses with regard to evidence statements and making inferences about the class' performance. Every rating of the rubric accompanies a feedback statement which specifies the desired performance, students' current performance, and the opportunities which can bridge the gap between the desired and the current performance (if required). For our example, if we have weak evidence of students demonstrating proficiency in meeting the learning performance (proficiency "Partially Met"), our feedback will look like:

Students were asked to:

- Identify relevant processes and conditions that influence temperature changes.
- Describe the physical mechanism justifying why heat flow does or does not change the temperature.

The TaSPA:

- Provided evidence that your students identified relevant processes and conditions that influence temperature changes.
- Provided evidence that your students partially accounted for the mechanism justifying why heat does or does not change the temperature of the system.

Students could benefit from more opportunities:

- To explore the physical mechanisms through which the heat flow into or out of the system affects its temperature.

This feedback structure was designed with attention to both simplicity and actionability. However, as the feedback will be delivered online, we plan to build in options for instructors to get more fine-grained suggestions if they are interested.

Intended effects of the TaSPA's feedback

Assuming that instructors find our generated feedback clear and actionable, they would then initiate changes in classroom instruction that could result in improved student learning. Going back to TaSPA's theory-of-action, our first intended change would be on students' learning on the valued LPs. Since the generated feedback is rooted in evidence statements, which are in turn derived from the learning performances, any uptake of feedback is also expected to result in students' improved learning on the corresponding learning performance.

Conclusion

We present a broad overview of the development process of a novel research-based assessment - the Thermal and Statistical Physics Assessment and providing actionable feedback for instructors. Our work presents a paradigm shift in how RBAs are envisioned and designed by the discipline-based education research community. We have presented our "theory-of-action"- an explicit account of how our assessment can bring about an intended change by shifting the focus of our classrooms from "knowing" to "doing" science.

Furthermore, in order to get instructors' perspectives on our feedback statements, ten faculty members who were teaching or had recently taught thermal and statistical physics at various institutions across the United States were interviewed. The interviews mainly revealed an overall positive response on the learning performances reflecting the viability of scientific practices, core ideas, and cross-cutting concepts for undergraduate level. In addition, every faculty member considered a different learning performance as important, thereby reinforcing the need for a design feature allowing instructors to select valued assessment objectives.

As for the future work, theoretical underpinnings in translating and interpreting the individual responses to the class' results are being explored. We are also in the process of piloting the entire exercise of our assessment administration, starting from instructors choosing learning performances to getting actionable feedback based on their students' responses at numerous undergraduate institutions in the United States. The assessment will be available to the public in 2024.

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Culturally Centered Curriculum: Sixth Graders' Learning Paths of Developing Knowledge About Native American Cultures

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Abstract: Developing knowledge of others' cultures is essential to cultural competence. To join scholars and educators who have varied approaches to engaging students with culture in formal learning settings, as a team of Indigenous and non-Indigenous researchers, educators, and designers, we designed a series of interdisciplinary, land-based curricular units to bring Native cultural perspectives into sixth-grade classrooms. This short paper focuses on the research question: how does sixth graders' knowledge of Native cultures and Native Americans change through engaging with culturally centered curricular units throughout a school year? We share three learning paths that illustrate sixth graders' movements in understanding. The learning paths provide insights into how sixth graders develop a closer psychological distance to culture, particularly Native cultures, as they actively negotiated their prior understandings with their culturally centered classroom experiences. This work contributes new insights into how youth learn in a culturally centered context.

Introduction

In the face of persistent attacks on culturally based education in K-12 classrooms in the United States, we join scholars who advocate for the need to center culture in learning (e.g., Nasir et al., 2020). Among the myriad of rich and fruitful approaches to engage young learners in culture, we focus on the opportunity to develop youths' cultural competence in the classroom (Keengwe, 2010). The core components of cultural competence include developing an awareness of culture (one's own and others) and the use of knowledge and skills (such as perspective taking and ethnocultural empathy) for effective and respectful cross-cultural interactions (Tehee et al., 2020). Moreover, there is a critical need for accurate and culturally sustaining representations of Indigenous cultures in K-12 classrooms (e.g., Sabzalian et al., 2021). Thus, as a team of Indigenous and non-Indigenous researchers, educators, and designers, we collaboratively designed culturally centered curricular units, particularly focused on representing Indigenous perspectives in the classroom, throughout a multi-year research partnership. In this paper, we are guided by the research question: *how does sixth graders' knowledge of Native cultures and Native Americans change through engaging with culturally centered curricular units throughout a school year?* In prior years, we observed that students' relationship and distance with other cultures change as they developed more cultural knowledge. Thus, in this analysis, we empirically investigate this observation. Findings provide insights into how youth develop a closer psychological distance (Medin & Bang, 2014) to Native cultures through engaging with culturally centered learning activities.

Literature review/relevant works

Teaching culture in K-12

Teaching cultural knowledge in a formal learning setting can be challenging, especially in the current socio-political landscape. Formal learning environments are often assumed to be acultural spaces even though they operate on a set of norms rooted in the dominant culture (Bang et al., 2012). Moreover, some argue for a distinction between "cultural knowledge" and school or domain knowledge, despite the reality that all knowledge is cultural (Nasir et al., 2008). From this stance, our inquiry is informed by a culturally disruptive pedagogical approach alongside place- and land-based approaches to learning. Culturally disruptive pedagogy focuses on the disruption of privilege, especially Whiteness, by making the socializing of Whiteness visible and disrupting hegemonic cultural norms (San Pedro, 2018). Informed by the culturally disruptive approach, we intend to make Western culture visible in the sixth-grade curriculum by introducing Native American cultural knowledge. In our design and implementation of sixth graders' curricular units, we adopted place- and land-based approaches that attend to "constructions and storying of land and repatriation by Indigenous peoples, documenting and advancing

Indigenous agency and land rights" (Tuck et al., 2014, p.13). As part of the curricular activities, we designed place-and land-based experiences for sixth graders to engage with Native cultures.

Relating with others' cultures through developing cultural knowledge

In this study, we examine the different paths of how sixth graders develop knowledge of Native American cultures as the processes of how their psychological distance (Medin & Bang, 2014) to Native cultures change over time. Psychological distance refers to the degree of subjective relatedness to an event or person across different kinds of distance, such as time, space, and personal identity (Trope & Liberman, 2003). Furthermore, researchers have identified the home-field disadvantage (Medin et al., 2010) that shapes our interpretations of cultural groups other than our own. The home-field disadvantage describes two models that are particularly relevant to this paper. We, first, tend to take different cultures as marked while our own culture as normal or "unmarked." We also tend to assume substantial homogeneity of other cultures while viewing heterogeneity in our own culture group (Medin et al., 2010). We intend to identify sixth graders' learning paths from how their understandings of Native cultures change along the two threads Medin and colleagues (2010) introduce: (1) marked vs. unmarked culture; (2) homogeneous vs. heterogeneous culture. We trace these tensions in our analysis.

Methods

The work we share here is part of a broader multi-year study investigating how youth develop relationships with culture. In this paper, we draw on data collected during the 2019-2020 school year at an experiential learning school in a predominately White community in the Mountain West. Participant demographics are representative of the student demographics of the school are 86% White, 5% Multiracial, 6% Hispanic, 1% Black or African American, 2% Asian, 1% American Indian or Alaska Native, and 0% Native Hawaiian or Other Pacific Islander. We conducted interviews across three timepoints: beginning, middle, and end of the school year. Our analysis focused on 105 interviews with the 39 sixth graders, ages 10-12, with parent/guardian consent and who assented to research. Participants chose their pseudonyms. The interviews capture how students' understandings of Native cultures and Native Americans shifted over time, particularly with two foci: (1) whether students understand Native cultures as marked or unmarked and (2) whether they regard Native cultures as homogeneous or heterogeneous. In our analysis, two researchers coded interviews using descriptive and in vivo codes (Saldaña, 2009) to develop a codebook that captured shifts in students' descriptions of Native cultures. Researchers conducted thematic coding around two forms of representation (historical and modern) and students' levels of understanding (i.e., misunderstanding, no knowledge, basic understanding, high-level understanding, and advanced-level understanding). We then traced individual students' changes across the school year.

Findings

Findings provide insights into students' diverse learning paths toward developing cultural competence. We identified three learning paths in knowledge development that supported students' movement in understanding Native cultures over the year. We characterize these learning paths in terms of scope, depth, and perspective, which include: (1) deeper nuanced understanding, (2) growth in modern understanding, and (3) awareness of limitations of personal understanding.

Deeper nuanced understanding

Over the course of the school year, students developed more detailed and nuanced knowledge about Native cultures. At the beginning of the school year, students often described limited or overgeneralized knowledge about Native cultures. Take Mandy's reflection as an example: "I know they [Native Americans] were very resourceful with what they had, and they, like, they were very strong and with their tribe, and they traveled long distances with and, um, yeah, so" (Mandy, Interview, Time 1). In this response, Mandy shared how she felt like she didn't know much about Native people. In her attempt to describe Native Americans, Mandy used the past tense and described Native Americans as “resourceful”, “strong”, and “traveled long distance”. However, towards the end of the year, Mandy showed a development in the understanding of Native people. Mandy demonstrated this change by sharing how she had learned a lot about the Navajo tribe and their culture:

> "Um. We learned a lot about, like, the, like, the Navajo tribe, and, like, the, um, like, the-their culture and that was really cool. Um. We also learned a lot about, like, the, um, like, cave paintings and all the paintings that the Navajo tribe did. And, yeah, we also learned about, like, I think, different animals and plants that were there that was part of our science. And, like, looking at stars” (Mandy, Interview, Time 3).

Instead of talking about Native culture in general, Mandy specifically described what she learned about the Navajo tribe and their painting, which is part of the field trip experience where she also learned about animals, plants, and stars. Across the year, students demonstrated growth through nuanced understanding by recognizing the unique Tribal communities in their local context, sharing personal experiences with stories learned from local Tribal Knowledge Holders, and highlighting the range of values and cultural practices that exist across Tribal communities. This learning path toward deeper nuanced understanding also demonstrates the process of starting to acknowledge heterogeneity (Medin et al., 2010) in Native cultures.

Growth in modern understanding

Students' deeper and more nuanced understanding was paired, in part, with their growth in modern understanding. A persistent misconception among students was that Native Americans are historical and ancient people who do not live in the same modern world students live in today. Over the school year, though, students grew in their understanding of Native Americans as modern and contemporary people with rich historical and ancient roots. For example, at the beginning of the school year, Ted's knowledge of Native culture centered on the use of "flint." Ted shared that "like, the way that they did stuff, like, a lot of Native Americans, they, Native American tribes, they … they, uh, like, used flint a lot" (Ted, Interview, Time 1). Ted not only used the past tense when describing his knowledge of Native Americans, but also showed historical knowledge about the flint tool that he gained from a book. Toward the end of the school year, Ted shared a more contemporary perspective of Native Americans:

> "Oh, um, hmm…I think I…I think I understand the cultures that live around here in Utah and in the, in the states around Utah. I think I understand them a little bit better because we went down there, and we saw a bunch of their cultural…or a bunch of that culture's um…yeah. We learned about that specific culture. And I'm sure that the other cultures…or the other, uh, native tribes that live in Utah and around Utah, I bet that if I went to their to places that have cultural significance to them, I would learn a lot about them, and I would appreciate that more" (Ted, Interview, Time 3).

Here Ted describes Native Americans as modern people and recognizes that land and place have specific cultural significance in Native cultures due to both past and present connections. He particularly highlights how the cultural experience of visiting southern Utah contributed to his growth in modern understanding. Similar to Mandy in the previous example, Ted also demonstrated the awareness of Native culture as plural rather than homogenous (Medin et al., 2010), which reveals the interdependence of these forms of knowledge shift.

Awareness of limitations of personal understanding

Students' knowledge of Native cultures shifted as they became aware of the limitations of their personal understanding of Native Americans, which they demonstrated as a reflection of their learning. This awareness was largely prompted by contrasting their prior personal understandings with new knowledge and experiences they were exposed to over the school year.

In this process of deepening nuanced understanding and growing in modern understanding, students often shared their developing awareness of the limitations of their personal understanding of Native Americans and Native cultures. Quentin grappled with this shift in his reflection at the end of the school year:

> "Um. I, well, when before when I thought of Nat-Native Americans, I more thought of, like, um, tribes living in the woods or living in, um, like, not living in a normal house. I thought of them, like, building their own houses and doing a – hunting themselves and some of them still do, but, um, they-a lot of them also just live in a house and that's just their religion and their same, but they still do the same stuff as us. Well, like, live in the same, um, spaces as us and eat some of the same food as us but still eat, like, um, don't go - some of them don't go hunting, and, to get food, and, like, before I kind of thought of them, like, living in the woods and, um, stuff like that. But, now, I, um, realize that they can have that, um, uh, culture and religion, but still, like, live and-and have the same lifestyle as us" (Quentin, Interview, Time 3).

In this reflection, Quentin addressed limitations of his previous understanding of Native culture, especially regarding how Native people live today and how they might engage in cultural activities. This critical reflection led to Quentin's developing self-awareness of the limitations of his personal understanding of Native people. This process not only results in a more nuanced and modern understanding but also shares a "now I realize" moment as an acknowledgment that his previous personal understandings were inaccurate. In addition, Quentin developed a closer distance to Native cultures as he negotiated with his own culture as unmarked (Medin et al.,2010), particularly while thinking about place and food as cultural. This learning path shows Quentin's engagement with his own understanding reflectively as well as their awareness of the limitation of understanding other cultures from a distanced view.

Discussion and conclusion

In this short paper, we share three interdependent learning paths to illustrate how sixth graders develop knowledge of Native cultures throughout a school year. Along these three learning pathways, we identified an overarching trend toward developing more cultural awareness and understanding. Initially, many students began the year with stereotypical and historical perspectives of Native Americans and Native cultures, which revealed as marked and homogeneous understandings. Over the school year, students demonstrated growth in more accurate historical understandings and deepening of contemporary understandings of Native cultures and Native Americans, which manifested as more unmarked or relatable and heterogeneous understandings. The three learning paths we highlight demonstrate sixth graders' processes of developing understandings of cultural others as they build relationships with Native cultures and Native Americans through being on their land and hearing from Native people. Students developed a closer distance to Native cultures as they moved away from seeing Native cultures as marked and homogenous toward unmarked and heterogenous (Medin et al., 2010). These insights contribute new understandings of how youth develop cultural competence and what and how students learn through culturally centered learning experiences.

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International Society of the Learning Sciences

Developing Medical Educators' Adaptive Practices Through Training in Learning Sciences and Design

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Abstract: Effective educators are adaptive, but adapting is challenging. We designed and implemented an intervention to train medical educators in teaching strategies from the learning sciences plus design processes to support them in adapting their instruction. In follow-up interviews, educators reported high rates of transfer and adaptation one and a half years later. Our work contributes new measures of transfer and adaptation, and a successful intervention model for disseminating learning science practices beyond K-12 contexts. Design process training may have enabled educators to adapt learning science content for their personal teaching contexts while encouraging them to be open to change and growth.

Introduction

An effective educator is *adaptive* (Darling-Hammond & Bransford, 2005), meaning they can transfer teaching practices learned in one situation to another, and they can change their teaching practices in response to new student needs or situational demands. Moreover, an adaptive educator is willing to try new practices when old practices fail. Research suggests that adaptive teaching can boost learner achievement (Hattie, 2009).

However, adapting is difficult in many contexts and domains. Years of research have demonstrated that transfer is challenging for most learners, and some have argued that meaningful transfer rarely occurs (Schwartz et al., 2005). It is also difficult for learners to resist routine behaviors and try a new way of doing things, as research on "set" effects and "functional fixedness" has clearly demonstrated (Schwartz et al., 2005). Adaptivity is often a challenge for teachers as well. For example, Hoffman & Duffy (2016) observed elementary literacy teachers over a 9-year period and found they seldom changed their instruction, often sticking to preset scripts.

In this paper, we describe research on an intervention that was explicitly designed to promote the development of adaptivity in medical educators. We view educator adaptivity through the framework of adaptive expertise (Hatano & Inagaki, 1986). Adaptive experts can adapt to the demands of a novel situation by engaging in several *adaptive practices*. They can (1) transfer their knowledge across contexts, (2) let go of old ways that are suboptimal and change their practices, and (3) seek out opportunities to learn and grow (Schwartz, Bransford, & Sears, 2005). While we did not study experts per se, we use this framework to explore the development of adaptive practices in medical educators.

To promote medical educators' adaptive practices, we taught them teaching strategies culled from the learning sciences in concert with a creative design thinking process that focused on adapting instruction for learner needs and contexts. While professional development programs often train teachers on teaching strategies, they rarely pair it with this kind of process-based instruction.

Design thinking is a set of processes and practices, derived from traditional design fields, that yield creative solutions to complex problems (Cross 1982). The crux of design thinking is that it is human-centered, which means that its major goal is to design for a human need. Instead of starting with a technological solution, the designer begins by investigating users' needs through interviewing and observation. Subsequent prototype testing and user feedback allow the designer to iterate towards a meaningful solution (Buchenau & Suri 2000). In short, design thinking provides a process for adapting to learner needs and revising one's design based on learners' feedback. As such, we believe it is particularly well-suited to helping educators adapt.

The learning sciences & design training program for medical educators

In this study, oncologists with an interest in education participated in a series of four 1-2 day training workshops, interspersed throughout the year. During these workshops, we taught medical educators 15 evidence-based strategies culled from learning sciences research: self-explanation, elaboration, generation, worked examples, contrasting cases, observation, feedback, deliberate practice, reward, reducing cognitive load, learning-by-teaching, just-in-time telling, question-driven learning, and providing constructive and interactive activities (strategies were derived from Schwartz, Tsang, & Blair, 2016). While learning sciences research has infiltrated the K-12 educator space, it has not gained much traction in other circles where it could provide great value. In particular, medical instruction suffers from an over-dependence on passive forms of instruction and factual, rote learning (McCoy et al., 2018), which runs counter to learning science recommendations.

In addition to learning science strategies, we taught a creative design process with two stages: 1) identifying learners and their needs and 2) developing and iterating on prototypes that address the learners' needs. In stage one, designers gather information about how learners engage in a learning task through interviews, observations, surveys, and other research methods. The goal is to understand what currently works and does not work for most learners in a particular context (i.e., the learner's needs). Designers in stage two construct multiple prototypes based on learning science strategies that address the needs they identified. The combined steps of creative ideation and iterative prototyping are practices that encourage designers to build out novel solutions that are refined specifically in response to feedback from learners.

Participants learned both the design & learning sciences content by doing design (Darling-Hammond et al., 2015). Participants worked in small groups to complete several "mini" design challenges before completing a longer, final design challenge. Examples included such diverse activities from designing a math lesson for a first grader to redesigning the format of a conference workshop.

In this paper, we evaluate whether teaching this combination of learning sciences and design processes promoted the development of medical educators' adaptive teaching practices. We focus on measuring two key aspects of adaptivity: (1) transfer of learning science strategies and design processes to participants' personal teaching contexts, and (2) other adaptive practices such as changing instruction and engaging in new learning.

Methods

Participants

Oncology faculty applied to participate in the program and were selected based on merit. All 12 participants of the program were solicited for the interview study, but only 8 were able to participate.

Interview and coding

Interviews were conducted with program participants about 1.5 years after completion of the program. The 45-minute semi-structured interviews were conducted by the first author on Zoom. Interviewees were asked to share an instructional experience they had designed or modified after completing the training program. This paper focuses on their responses to 5 core interview questions: (1) Describe the instructional experience you created and the context for which it was designed or used. (2) Describe how you applied or adapted learning science concepts within this experience, if at all. (3) Describe how you used a design thinking process to create this instructional experience, if at all. (4) How does this instructional experience differ from the types of experiences you designed prior to participating in this program? (5) In what ways do you feel your teaching, instructional practices, or instructional design processes have changed because of your participation in this program, if at all?

Responses to questions were analyzed to examine our three categories of interest: transfer of instructional practices, changes to old instructional practices, and engaging in new learning. We then conducted open coding to create subcategories that exemplified the ways in which participants engaged in these adaptive practices. In addition, new unexpected categories emerged, such as broader changes to the teacher's sense of self and dissemination of the training program content to others. Two coders independently coded all participants' data for the categories in Table 1. After two rounds of coding, good reliability was achieved (kappa > .7). All disagreements were discussed and adjudicated.

Table 1

An Overview of the Coding Categories Used in Analyzing Participant Responses

Category	**Subcategory**
Transfer of Instructional Practices	*Application of a Learning Science Strategy in a specific activity/context*
	Application of a Design Process in a specific activity/context
Change to Instruction	*Less didactic* and more interactive instruction
	Simplify presentation of content (to reduce learners' cognitive load)
	New objectives/goals (for learners)
Changes to Individual	*Affective change* (growth in confidence, awareness)
	Growth as a teacher/learner (developing new perspectives, honing practices)
	Becoming part of a *community* of medical educators
New Learning	*Explicit learning* (reading education literature, taking a course in education)
	New educational work (educational committee work, editing an educational journal)
	Prospective learning (specific future learning goals and plans)
Dissemination	*Dissemination* of LSSs and DPs to other faculty, fellows, or residents

Results

Transfer of content

Participants engaged in a sizeable amount of substantive talk about the learning science strategies and design processes they were applying (see Table 2). On average, participants uttered 13 talk segments describing the application of learning science strategies (LSS) in their home teaching contexts and 12 talk segments on the application of design processes (DP). In addition, participants applied both of the DPs and an average of 7.5 different LSSs (out of the 15 they were taught) in their home teaching contexts. This is reasonable, given that we taught them a large set of LSSs with the intention of giving them a choice in adapting the strategies that are most appropriate for their contexts. Finally, participants described applying what they learned from our training in an average of 5 different contexts (e.g., teaching patients, designing medical school courses, presenting at conferences, mentoring residents, parenting, etc.). In fact, several participants reported transferring LSSs to quite distal contexts. For example, one participant applied LSSs to help her study for courses in her Masters program. Another critiqued the pedagogy in her child's school from a learning sciences perspective. All together, these data paint a picture of impressive transfer of both learning sciences and design content to a variety of contexts.

Table 2
Medical Educators' Transfer of Learning Science Strategies (LSS) and Design Processes (DP)

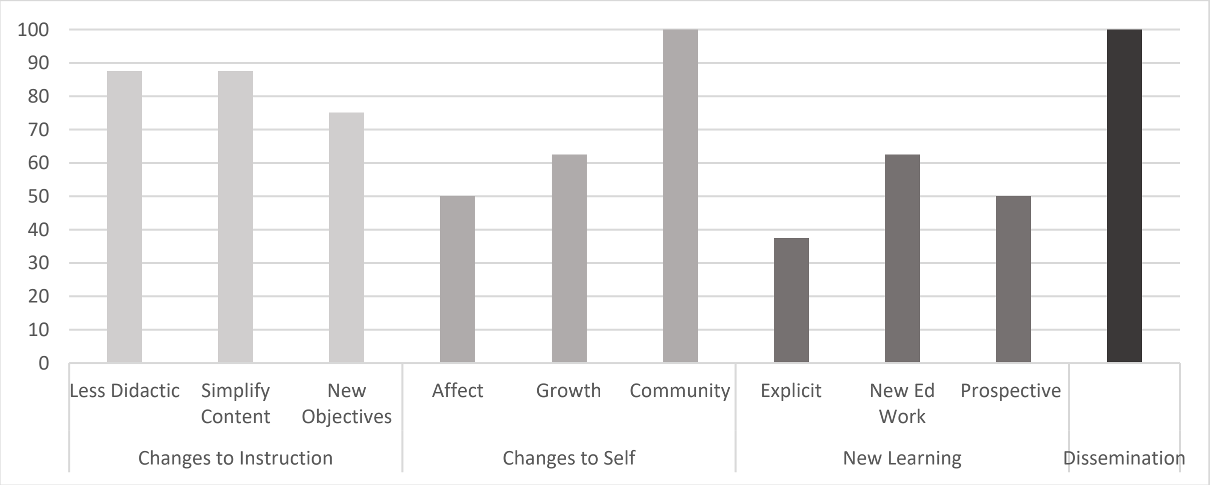
	# of LSS Application Talk Segments	# of LSSs Applied	# of DP Application Talk Segments	# of DPs Applied	# of Contexts Applied
Mean	13.1	7.5	12.3	2.0	5.1
Range	7-24	6-9	5-24	(no range)	3-7

Other adaptive practices

Participants also demonstrated significant engagement in other core adaptive practices, as shown in Figure 1. 100% of the interviewees described making changes to their instruction as a result of the program. Subcodes for types of instructional changes provide a window into the types of changes participants made to their instruction. 88% of participants made their instruction less didactic and more active and interactive. 88% streamlined the content they delivered to learners to avoid cognitive overload. Finally, 75% adopted new objectives for the learners they were teaching. For example, some participants reported a marked pedagogical shift from training students to remember facts and procedures to developing their critical thinking and transfer abilities.

In addition to changing their instruction, 100% of participants described changes to their broader sense of themselves as teachers. 50% reported affective changes, such as gaining awareness of and confidence in their teaching abilities. 63% described how they had grown as a teacher or learner. For example, some reported that their teaching had become more "organic and conversational," while others identified changes to the way they critiqued colleagues' lectures and presentations. 100% described how they became part of a larger community of medical educators and the myriad benefits this provided.

Figure 1
Percent of Medical Educators who Engaged in a Variety of Adaptive Practices



All but one participant (88% of the sample) described engaging in new learning in order to adapt. 38% of participants engaged in explicit learning, such as reading the medical education literature or attending professional development workshops. 63% took on new educational work that would continue to develop their expertise in education. For example, participants often took on educational leadership roles at their institutions (e.g., Associate Dean of Graduate Medical Education), joined education committees in oncology organizations, or volunteered to design new curricula. Finally, another 50% of participants had specific plans and goals around future learning they would undertake to improve their teaching.

It was surprising for us to learn that participants in our program were also helping others to adapt their teaching by disseminating the learning science content we had taught them. In fact, 100% of participants described disseminating learning science strategies to other medical educators. Several participants described teaching our learning science content to residents or fellows. Some participants designed instructional modules around the learning sciences strategies for an oncology website. One participant applied learning science strategies to redesign the whole feedback system for fellows at her hospital and trained 167 oncology faculty to use it.

Discussion

Effective educators are adaptive – they can flexibly adapt their practices for various learners and learning contexts and try new ways of teaching when old ways fail. However, being adaptive is challenging in any domain, and educators are no exception. Further, many professional development opportunities yield disappointing results, where educators fail to apply what they have learned in real-world settings.

In this paper, we describe an intervention that was explicitly designed to promote medical educators' abilities to adapt the learning science content we taught them. Medical educators reported fairly extensive transfer and adaptation one and a half years after the conclusion of our intervention. While our study was not designed to reveal which specific components of our intervention facilitated transfer and adaptation, we speculate that integrating design thinking was critical to the program's success. Design thinking may provide a process to supports educators in adapting their professional training for their personal contexts.

Another contribution is the development of new measures of transfer and adaptation. We used interview methods to uncover the unexpected and individualized ways and places where educators chose to apply their learnings, rather than assuming beforehand how and where they would adapt. In addition, our work provides an example of a successful intervention that promoted the dissemination of learning sciences research beyond K-12 education to medical education.

This research is not without limitations. Future research could gather causal evidence of the impact of our intervention, collect data on the interaction of learning science strategies and design processes, and create a design-focused training intervention for K-12 teachers.

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Online Arts and Design Studios and Experiential Learning: A Review of Literature

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Abstract: In traditional arts and design studio education, experiential learning plays a crucial role. COVID-19 quarantine orders forced studio education into online spaces, challenging instructors' capacity to provide experiential learning. This literature review uses the seven key features of experiential learning by Moon (2004) to explore how experiential learning is supported in virtual arts and design studios. This paper asks how virtual arts and design studios leverage learning and communication technologies in online instructional and learning experiences. Our findings from articles published in the last 10 years highlight that a variety of factors influence the virtual studio teaching and learning experience, including digital literacy, course design, instructional adaptations, and sociocultural interactions. Implications and practical recommendations for researchers and educators who design virtual arts and design studio experiences are also discussed.

Introduction

In arts and design studio education, experiential learning processes play a crucial role (Senbel, 2012; Sutherland & Jelinek, 2015; Köylü, 2019). Arts education requires "time, studio space, and a context for self-directed learning" (Mottram & Whale, 2001, p. 98), and close interactions and feedback on students' artwork (Fleischmann, 2019). During processes like sketching, collaborating, critiquing, and engaging with art-related objects, art studios allow students to gain aesthetic knowledge through sensory triggers and sense-making (Sutherland & Jelinek, 2015). Experiential learning in studio education emphasizes constructing knowledge based on practical, observational, and reflective experiences; its key characteristics are sense-making processes and continually modified interactions (perception, cognition, and behavior) between self and environment (Beard & Wilson, 2006; Kolb, 2014). Kolb's (2014) experiential learning theory identified a spiral process with four linked elements: "concrete experience, abstract conceptualization, reflective observation, and active experimentation" (Kolb, 2014, structural foundations of the learning process, para. 8). Drawing from Kolb's learning spiral and diverse literature on experiential learning, Moon (2004) posits seven key features of experiential learning: "1) is not "being taught"; 2) happens through direct experiences; 3) is an empowering way to gain knowledge; 4) involves reflections, 5) involves actions (making, doing, experimenting); 6) involves mechanisms of feedback, 7) includes a formal intention of learning" (p. 120) (see Table 1).

Table 1
Experiential learning features used for evaluation. (Wording modified by the authors for clarity).

	Features	Description
1	Experiential learning is not through "being taught"	It is about not merely the instructional process, but also guidance for what should be learned.
2	Learning happens through direct experiences	The material of learning is from experience.
3	Experiential learning is an empowering way to gain knowledge	Consider the overall functioning of an individual, including emotional, intellectual, and sensory aspects.
4	Experiential learning involves reflections	A deep approach to learning links new learning materials with previous experience and knowledge.
5	Experiential learning usually involves actions	Environment provides opportunities for teachers/students in active phases of learning (making, doing, experimenting).
6	Experiential learning involves mechanisms of feedback	Offer feedback that summarizes the learning outcomes.
7	Experiential learning includes a formal intention of learning	Deliver learning activities consciously and with specific intentions.

COVID-19 quarantine orders forced studio education into virtual spaces, posing challenges and affecting learning and instructional experiences. For instance, online studios differ from physical studios when it comes to sensory triggers and sense-making processes. While recent lifting of restrictive measures prompted many arts and design studios to return to on-site learning, online studios will remain a viable course delivery alternative because of recent acceptance and implementation of distance and hybrid learning strategies (Ceylan, Şahin, Seçmen, Somer & Süher, 2021). It is therefore necessary to review empirical studies of online studios to gain a deeper understanding of how experiential learning theories are supported and how pedagogic design strategies can be applied in online arts and design studios.

Research questions

To sustain the value and essence of studio education in virtual environments requires technology integration and experiential learning experiences in online studios. This literature review explores course delivery approaches and experiential learning theories reflected in online arts and design studios, and asks the following research questions: (1) What are the learning technologies and strategies used in online art and design studio classes? (2) How are experiential learning experiences supported in online arts and design studios?

Methods

In our literature review, we analyzed articles published over the past ten years (2011-2021); using a two-stage selection approach. We conducted the initial keyword search in 15 popular journals specifically associated with arts and design education, and the second keyword search within more comprehensive databases (JSTOR, ProQuest, ERIC) to identify existing research on online studios not covered by the specialized journals. The selection of these databases was based on wide use and inclusion of comprehensive art and education-related articles. Each of the selection stages involved two screening phases, conducted October 2021. Keywords included “Online Art Studio” OR “Distance Art Studios” OR “Online Education Art Studios” OR “Virtual Online Art Education” OR “Online Design Studios” OR “Distant Design Studio.” Disciplines were limited to Arts and Humanities, and Education. We limited our keywords search to title and abstract, and to peer-reviewed journal articles published in English. As a result, we identified 691 journal articles on the first screen phase through title and abstract review. In the second phase, we found 11 articles that met the inclusion criteria. We assessed experiential learning affordances in these articles to identify the presence of the seven experiential features (Moon, 2004) of online learning.

Results

The instructors of online arts and design studios integrated synchronous (e.g., Zoom, Microsoft team, and Blackboard), asynchronous (e.g., itslearning), social media (e.g., YouTube, Vimeo), geolocational (e.g., Google Earth), and communication tools (e.g., WhatsApp) in their teaching. Commonly reported benefits of online arts and design studios in these papers included flexibility (e.g., review of course materials at preferred time and location) (Marshalsey, 2020; Fleischmann, 2019), capacity to support in-depth learning (e.g., review recording) (Ceylan et al., 2021; Alawad, 2021), possibility to save travel time and reduce late arrival (Alnusairat et al., 2021; Alawad, 2021; Marshalsey, 2020; Fleischmann, 2020), reduction of energy consumption from campus utilities (Alnusairat et al., 2021), and opportunity for global collaboration (e.g., specialists located in geographically diverse locations) (Varma et al., 2021; Makemson, 2021).

The articles pointed to several challenges of online arts and design studios. Firstly, the online studio lacks a sense of belonging (e.g., distant feelings) (Marshalsey, 2020; Alawad, 2021). Secondly, working in an online studio may lead to cognition issues (e.g., difficulty focusing on video content) (Fleischmann, 2019; Fleischmann, 2020; Marshalsey, 2020). Thirdly, online studios may lack instructions and mediation tools. Makemson (2021) proposed that online studio learning requires less cognitive load and centers attention when learners have experience with a digital platform; a lack of prior knowledge may demotivate students, affecting their learning (Amro, 2021; Marshalsey, 2020). Further, because textures, materiality, and scale of art and design are difficult to display through digital formats (online images, videos), studio classes needing special resources and experimentations cannot be fully transferred into an online format.

Our study gathered student and instructor feedback from selected articles and investigated their match/mismatch with Moon’s (2004) seven experiential learning features. Two studies fulfilled the first criterion, *experiential learning is not through “being taught”* (Alnusairat et al., 2021; Makemson, 2021). Participating students stated online arts and design studios enabled them to conquer weaknesses and fears: “I bec[a]me more responsible about my design, as online learning gave us the opportunity to rely more on ourselves” (Alnusairat et al., 2021, p. 229). Makemson (2021) explained that technology-mediated tools and interactive digital platforms would facilitate students’ self-navigation of knowledge without teacher intervention. For the second criterion, *experiential learning happens through direct experiences*, one study thoroughly reflected the theory of experiential learning (Amro, 2021), finding that participating instructors encouraged students to connect their direct experiences and feelings of the pandemic to their design projects. In the end, the creativity in those projects exceeded teachers' expectations (Amro, 2021). Two articles fulfilled the third criterion, *experiential learning is an empowered way to gain knowledge* (Amro, 2021; Fleischmann, 2020). In Amro's (2021) study, teachers recognized students' emotional states within online contexts. To motivate and help students overcome negative emotions, teachers changed methods of teaching and communicating using digital tools. However, Fleischmann (2020) found students "need physical classes to motivate [themselves]" (p. 46). Those students emphasized that taking classes on-site enables them to stay focused and self-disciplined. For the fourth criterion, *experiential learning involves reflections*, some participants in the articles believed physical studio classes provide better interaction for students to become "reflective practitioners" (Fleischmann, 2020, p. 49); while others believed easy and flexible communication and collaboration in online studios would facilitate student reflections on peer feedback (Fleischmann, 2019). For the fifth criterion, *experiential learning usually involves actions (making, doing, experimenting)*, some studies noted that physical studios easily provide opportunities for unstructured activities, whereas this can be difficult for online arts and design studios (Ceylan et al., 2021); others found students' unwillingness to share their work with groups online may diminish learning outcomes in the long run since they have fewer opportunities to practice (Fleischmann, 2019). For the sixth criterion, *experiential learning involves mechanisms of feedback*, authors commented that some students preferred not to take design online because it was hard to keep up with content; however, physical studios allow iterative in-person interactions and fortuitous encounters (e.g., non-visual cues), two crucial elements for studio education (Varma et al., 2021). Other students appreciated the speed of communication and feedback received from the online studio (Fleischmann, 2019). For the seventh criterion, *experiential learning includes a formal intention of learning*, the articles revealed mixed results. Some studies revealed intentions of learning were missing: in on-site studios, these are usually presented at the beginning of the year (Alnusairat et al., 2021), while other studies stated their virtual studio posted a pre-planned assessment sheet online and presented it during a synchronous meeting (Fleischmann, 2019).

Discussion & conclusion

This literature review explored technologies adopted in online studio classes with student and teacher perspectives and reviewed how the seven experiential learning features (Moon, 2004) were supported in selected articles. Examining these articles through a lens of experiential learning theory, we found that a significant portion discussed student learning outcomes, student and teacher perspectives about key components of studios (iterative feedback, interactions and collaborations), and motivational aspects in online studios. Teachers and students offered mixed feedback about their online studio experiences. For example, Alawad's (2021) study found that freshmen in design majors prefer online over on-site learning compared to their senior peers. However, Amro's (2021) study found that freshmen experienced a higher level of anxiety due to inexperience with online creative and communication technologies, and that more fourth-year students preferred to continue their studio courses online. Studies also found that students who offered positive feedback about online learning usually already had previous online or blended learning experiences (Fleischmann, 2019).

Overall, online technology has permanently changed the way design and art education is taught through studio-based learning; and the advancement of digital technologies and networks has accelerated the transfer of knowledge from master to apprentice (Dreamson, 2020). However, the review of articles in this study indicated that the use of fully online studios is still in the testing phase and that digital literacy plays an important role in the experience of students and teachers in online studios. Online studio educators are exploring and experimenting with instructional technologies to replicate the sense-making, sensory trigger, and collaboration experiences that may occur naturally in on-site studios. To facilitate this process, teachers would benefit from implementation standards and guidelines based on experiential learning theory. Further, training for instructional technology prior to modification of the course would assist teachers in establishing online space that cultivates a collaborative culture and enhances sense-making experiences. Additionally, positive learning and teaching experiences are not based merely on the particular type of instructional technologies, because "technologies themselves do not determine social behaviors" and interactions (Smirnov, Easterday & Gerber, 2018, p. 593), one of the core characteristics of studio experiential learning. Studio experiences can be influenced by how course modules are designed (e.g., the length of an online video, the speed of feedback for students), how teachers manage classes (e.g., how teachers consider students' emotional factors, adaptations of teaching styles in virtual environments), and sociocultural interactions between teachers and students facilitated by educational technologies (e.g., the formation of a learning community and culture online). One study, for instance, included partial instruction through pre-recorded video lectures, and reported that students found it challenging to engage and learn without immediate feedback from instructors (Fleischmann, 2020). Another study revealed that one fifth of participating students found it difficult to express their ideas through digital tools without manual drawing or physical materials, while two thirds of students found online communication difficult and felt teachers disregarded their mental health

(Alnusairat et al., 2021). These students' reflections suggest that even though digital technology enabled virtual studios (e.g., pre-recorded video lectures, distance communication), its complexities present additional challenges to instructors, including how and when to use these technologies. Instructors should make informed decisions regarding which parts of the courses can be delivered via pre-recorded videos (e.g., where less feedback and interaction are required), which time is optimal for providing virtual support, and which types of web-based activities and platforms should be established to facilitate peer-support and virtual collaboration. When designing online studio pedagogy, instructors should consider technologies that facilitate self-exploratory learning, student motivation, and reflection during and after class. Future studies should further explore how the interaction of online communication technologies and instructional design can best support the social and cultural experiences of online studio learners.

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Identity Play: Nonlinear and Agentic Aspects of Middle School Youths' Self-Making

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Abstract: Identity development has been described as a process of *identity regulation*—structural arrangements that act to govern and shape people's identities—and *identity work*, which includes people's responses to identity regulation. While identity regulation emphasizes structural aspects of self-making, and identity work emphasizes a structure/agency dialectic, we consider a third construct called *identity play*, which emphasizes the agentic, nonlinear aspects of self-making. This is a grounded study of youths' identity play as they engaged in out-of-school, integrated STEM programs focused on environmental problem solving across three years. We outline features of identity play, illustrate what characterized it, and resources youth leveraged to do it with the cases of Mirabel and Josue.

Introduction

In schools, growth and learning are often considered with a measurement paradigm that assumes linearity. Educational research can also be guilty of this– from scores on standardized tests to measurements on Likert scale surveys, success is often defined with descriptors like *more*, *better*, *stronger*, and *higher*. Even a sociocultural lens implies that increased access, opportunities, and engagement will more likely lead to fuller participation and learning (Wenger, 1998). Qualitative and design-based studies of learning can also invoke a traditional growth paradigm, framing problems with scarcity or deficit lenses and positioning educational interventions as *fixing problems*. The assumption is that as participants experience a successful design or intervention, they develop "more"—e.g., more facility with a learning community's practices, have more knowledge, and/or are more affiliated with a learning community. We can apply this critique to our own work. This study takes a different approach. We studied middle school youths' identity development over two to three years as they participated in out-of-school learning focused on environmental problem solving. As we tracked their identity work over time, we noticed their identity work as playful, unpredictable, and nonlinear. This paper presents a grounded theory of STEM *identity play* to understand youths' self-making that occurs in nonlinear and less directional ways. The work builds on scholarship in organizational studies that introduced identity play (Ibarra & Petriglieri, 2010). Our research questions include: How do youth engage in identity play? What resources do they draw on to do so?

Conceptual framework

Wayfaring

Wayfaring informed our understanding of the nonlinear nature of identity play (Ingold, 2007). Wayfaring is the idea that experience is a journey that moves along paths of travel. A person travels these paths in starts and stops, "moving hither and thither" (p. 81), pausing here and there, before moving on with "no beginning or end" (p. 167). In this view, a journeyer travels lines that are "winding and irregular" (p. 81), revisiting old paths, looping into paths not yet traveled, all the while paying attention to their environment. While the middle school youth did not show such free-wheeling wayfaring, we were inspired to think of their engagement over time as experimental and less constricting than science that is more narrowly construed. Normative views of disciplinary identity development implicitly draw on milestone metaphors, which distort the adaptation, flexibility, and diversity of the ways youth grow, learn, try on and try out ways of being (Gallacher, 2017). Wayfaring is juxtaposed with the notion of transport, which is traveling from point A to point B. A wayfaring adolescent engages their environment and charts their own paths, emphasizing more agentic and playful imagery, and respects youths' individuality.

Self-making

We view the endeavor of identity development as "self-making" because it emphasizes the active processes of becoming somebody in and across settings as well as the multi-pronged nature of identity development. Self-making has also been used by Bruner (2001), but in a different way than we use it here. Identity studies have largely emphasized two primary elements of identity development– identity regulation and identity work. *Identity regulation* emphasizes structural and sociopolitical dimensions of self-making, or the parameters that shape meanings of legitimacy, competency, and belonging (Alvesson & Willmott, 2002). In other words, identity regulation is about the disciplining of subjects (Foucault, 1977). *Identity work* comes about when people navigate structural constraints of a setting, institution, or discipline (Varelas et al., 2015). The more tightly guarded the boundaries of the insider identity, the more challenging the identity work, especially for Black, Brown, and Indigenous youth (McGee, 2020). The focus on the structure/agency dialectic in identity studies emphasizes self-making as a negotiation between self-authoring and others' positioning. Identity work recognizes the struggle to become someone. We came to understand *identity play* as emphasizing the more agentic side of self-making, enacted for different reasons, prompted by different kinds of activity, and involving different kinds of negotiations (Table 1). In analytically separating identity work and identity play, we do not claim that identity play does not involve structural dimensions, nor do we claim that identity play happens without identity work. We argue that the identity play lens helps us see and understand the youths' self-making differently than if we considered identity play as a part of identity work. Identity play is a process involving: 1) playful self-discovery in trying on new performances and narrations of self; 2) imaginative engagements that deviate from expectations or self-understandings (Fachin & Davel, 2015); 3) exploration of possible selves (Markus & Nurius, 1986).

Table 1
Identity Work Versus Identity Play

	Identity Work	Identity Play
Purpose/ Telos	To be considered competent in a group; to belong; directed towards more central participation	To pursue individual curiosities; just for fun; nonlinear and wayfaring (Ingold, 2007); not always predictable or sticky
How	Engagement and proficiency in social practices deemed relevant for membership	Working in new spaces and/or outside of one's comfort zone; horizon-expanding
Negotiations	Negotiation of prior/desired selves with governed self; can be contentious, a struggle	Loosening up of pre-conceived notions of self; can be scary, joyful

Methods

BRIDGES focused on environmental problem solving for middle school youth in the southeastern United States. The program's framework highlighted the multifaceted nature of STEM and youths' identities. We considered multiple ways to engage environmental problems which included: altruism, conservationism, investigating, inventing, tinkering, and designing. We used these categories for curricular design and as a research heuristic. We introduced the terminology to youth as STEM profile categories; we gave them multiple opportunities throughout the program to name and discuss their affiliation using these categories. The categories were not used to stamp youth with labels. We used them fluidly to build a common vocabulary. As Wenger (1998) explained, some reification is necessary to narrate and reflect on one's own identity development. BRIDGES consisted of Saturday Academies, a Summer Institute, and after-school STEM clubs. Forty middle-schoolers participated in two or more BRIDGES programs. Twenty-one identified as female, 19 identified as male. Fourteen youth identified as Black, 10 as Latinx, five as multiracial, and 11 as white. We describe cases of Mirabel and Josue because their cases illustrate different ways of engaging identity play, and their social positioning differed.

We interviewed youth at the end of each BRIDGES program and then one or more years after their last participation. We took fieldnotes, video recordings, and audio recordings during all BRIDGES activities. Interviews included a card sort that asked youth to identify their affiliation STEM profile categories during BRIDGES activities. Following the creation of radial graphs (Figure 1), we analyzed video and interviews with Mirabel and Josue, coding for identity play using markers outlined in Table 1. These data allowed us to focus on youths' narrated identity play and identity play in practice. Informed by grounded theory (Charmaz, 2014), we created assertions which we tested out with additional empirical data through saturation.

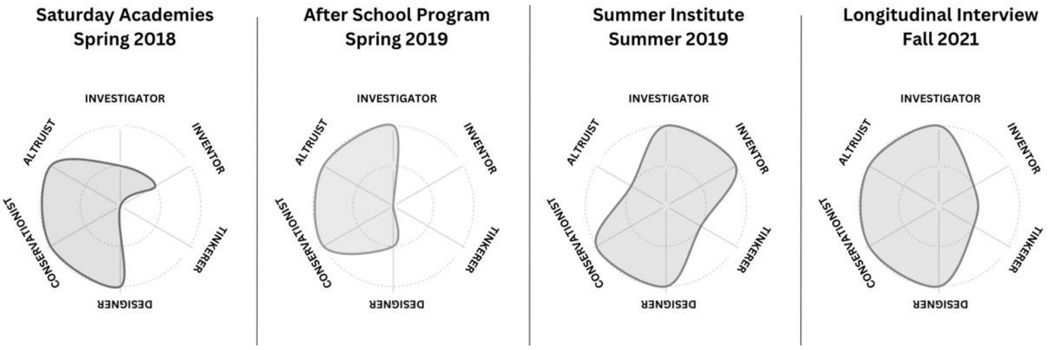
Findings

Mirabel

Mirabel had an easy, kind, joyful, confidence about her—she was outgoing, upbeat, and presented herself as comfortable in most social and academic settings, with peers and adults. Mirabel was academically successful; she skipped eighth grade so that she would have access to more academically challenging courses. Mirabel nearly always engaged fully in activities; she used opportunities she was given to perform herself in multifaceted ways. Socially, she could be silly, mature, serious, fun-loving, and kind. Using the STEM profile categories as markers, she consistently affiliated as a conservationist, usually an altruist and designer, only sometimes and somewhat an inventor and tinkerer, and affiliated as more of an investigator over time (Figure 1). The radial graph depiction is simply *beginning* evidence that there was some unpredictability happening with her self-making over time, which we explored further with analysis of interviews and video.

Figure 1

Mirabel's Identity Play Over Time



Note. The graphs depict how Mirabel narrated her affiliations with the STEM profile categories, in interviews, over time. Points on the outside of each graph indicate those she narrated as "very much like me," middle points are "somewhat like me," and the graph's center indicates "nothing like me."

When Mirabel discussed what she liked about BRIDGES, she described a version of wayfaring: "You never knew what you were going to do next….it was always just so exciting and so surprising… it was so diverse, so beautiful. It was so inspiring… a new way of looking at STEM every day." Her quote indicates going with the flow, with no immediate goal or purpose other than to enjoy. As indicated by wayfaring, she attends to and appreciates the journey. The unknown was not anxiety-producing, but exciting.

She enjoyed discovering new things about herself, demonstrating a typical purpose for identity play. For example, Figure 1 indicates a growing and shrinking affiliation with inventor. She viewed the makerspace in the Summer Institute a place to try out her inventor self. With friends, she developed an app to "help visitors in the park" by providing "information and presentation ideas about what to wear and even what to do if you find something dangerous" like poison ivy, ticks, and venomous snakes. Two years later, she reflected on how she "grew into" being more of an inventor in the makerspace. "I had a lot of fun with that, being an inventor. I did a lot of that that week...I had to create solutions and fix problems." It was perfectly fine with her that the inventor identity did not necessarily stick over time: "Even if [inventor] didn't become my big one, I got more into it." Unlike identity work, which can be higher stakes, she playfully tried out her inventor self.

Mirabel leveraged several resources to engage in identity play without visible constraint or struggle. She had a comfortable social position in BRIDGES; peers liked and respected her and often followed her lead in trying new things. This was an identity-affirming space. She leveraged comfortable identity performances when trying out new identity performances. For instance, her consistent affiliation with the altruist and conservationist categories ("I was already a person who cared about people and the environment") may have been a resource to persist with engaging with the invention and tinkering while developing the app. This activity also involved a lot of investigation. When working in the makerspace, she asked to go on nature walks with peers and a naturalist to explore the park so that she could recognize dangerous flora.

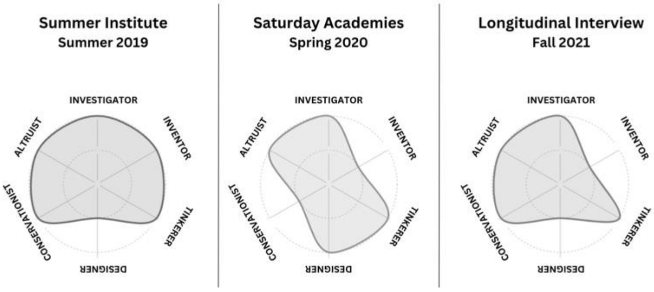
Josue

Josue was jolly, affable, and good-natured, describing BRIDGES as "a fun production." A self-identified Latino male, he described himself as "the volunteer guy" and "the social guy" who was open to anything new. "It was part of me that said, 'Try everything.'" Josue was not self-conscious— "It don't matter what people think." Figure 2 shows Josue consistently narrated himself as a tinkerer and altruist and sometimes as a strong conservationist, designer, and investigator, and inventor. All his interviews emphasized BRIDGES's influence on his love of and curiosity about animals in their natural habitats, helping peers, trying out new things, and having fun. He positioned Dr. M., a herpetologist, as his "best friend during that camp." He went with Dr. M. on optional field studies in afternoons and later arranged a visit to her property with his family during salamander mating season.

He explained BRIDGES as a good fit for "people who haven't done lots of things, people who need bonding with people" and "scared people who need to conquer their fears," which points to the horizon-expanding spaces we created for youth to try out new ways of being. In interviews, Josue talked at length about his learning, details about his experiences, and supplied multiple examples of each identity category and the ways he "got to be" an inventor, investigator, and so on. He appreciated an activity where youth chose "identi-beads" to represent their engagement because "the beads were a reminder of how you can be different things every day." Identifying his first frog call and catching a toad, he said, was "where my life really actually changed a little." His interviews and his uninhibited engagement were replete with examples of identity play. Resources that encouraged his identity play included: 1) embodied learning—like a frog peeing in his hand, the night hike, and holding a toad "turn into memories you…keep forever"; 2) his desire to try anything; 3) his affiliation with Dr. M.; and 4) his lack of self-consciousness—"A STEM-Y person doesn't care about getting dirty… just goes out there and tries."

Figure 2

Josue's Identity Play Over Time



Significance

First, identity play is an expansive construct. While our data show that we cannot expect identity play in spaces that are not also identity affirming, they also demonstrate the value and productivity of identity play. Second, the construct of STEM identity work has been dominant in science education, include our own scholarship. Identity work emphasizes the dialectic between structure and agency, often directed toward understanding the ways youth "become scientific." While our data clearly show the importance of context (structure) in prompting identity play, a focus on identity play allows us to pay attention to youths' multi-faceted, unpredictable, playful selves when they work beyond their comfort zones. Considering identity through a playful lens, one that highlights self-discovery rather than goals and endpoints, gives the field a nuanced and fluid account of self-making.

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A Community of Practice for Intangible Cultural Heritage: Phenomenographic Insights of Youth's Experience With Traditional Recital in Luang Prabang, Lao People's Democratic Republic

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Abstract: This paper presents preliminary findings of a phenomenographic study on a youth forum on intangible cultural heritage (ICH) in Luang Prabang (LPB), Lao People's Democratic Republic. Youth members participated in workshops for finding community-centred innovations for ICH. They formed a community of practice (CoP), collaborating closely with local cultural bearers. Preliminary phenomenographic findings of their collaborative learning experience presented in an outcome space reveal that youth members can be motivated to safeguard threatened cultural practices. Mapping the qualitatively different ways in which youth members experience learning about safeguarding ICH makes this study relevant for understanding a youth's participation in a CoP involving ICH.

Introduction

The inscription of Luang Prabang (LPB) as a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage site initiated a tourism boom that threatens its cultural heritage (Dearborn & Stallmeyer, 2009). Efforts to preserve tangible heritage sites at the expense of neglecting cultural practices or living heritage bear the risk of turning heritage sites into spaces devoid of their original social and cultural significance (Reeves & Long, 2011). Safeguarding intangible cultural heritage (ICH) has social benefits for communities, e.g., some cultural practices can enhance an individual's sense of belonging and identity (Shaharuddin et al., 2021). Maintaining and revitalising cultural expressions in LPB upholds the cultural identity of its inhabitants. This paper presents preliminary qualitative research findings on a 2.5-month-long youth forum in LPB, implemented by the United Nations University Institute for the Advanced Study of Sustainability in collaboration with UNESCO Bangkok and the Traditional Arts and Ethnology Centre (TAEC). The forum was designed to engage youth members on the human-centred design process in combination with ICT, offering sessions on ICH, design thinking, digital storytelling, and research ethics. This paper aims to 1) provide a phenomenographic analysis of the collaborative learning experience of one youth group and its selected culture bearer, and 2) present their experiences in an outcome space that illustrates the structure of the varied qualitative categories of description. It is guided by the research question: How can the empirical collaborative learning experience of youth members in a community of practice (CoP) on ICH be represented in a phenomenographic outcome space?

Literature review

Living cultural heritage can be defined as "the practices, representations, expressions, knowledge, skills … that communities, groups and … individuals recognise as part of their cultural heritage" (UNESCO, 2020). Thus, communities are integral in safeguarding local ICH. The theorisations offered by Wenger and Lave on CoPs will be applied as the general theoretical framework for the present study because it explains the structuring elements of social learning systems. Learning in a CoP is inherently social. Learners absorb and become absorbed in the culture of practice, which increasingly provides them with occasions to make the culture of practice their own (Lave & Wenger, 1991). Wenger and Snyder (2000) define CoPs as "groups of people informally bound together by shared expertise and passion for a joint enterprise" (p. 139). McKellar and colleagues (2020) argue that extra-organisational CoPs have not received much evaluation attention from scholars. Additionally, several studies point out that the participants of a CoP are instrumental in an assessment. For Mbassegue and Gardoni (2018), participants are core elements in terms of evaluating the outcomes of a CoP because it is the participants who generate knowledge. The benefits of a CoP can be described as an impact on participants, so frameworks to assess CoPs must favour the participants' points of view. However, the individual level as a unit of analysis presents a gap because methodological processes to assess CoPs have not taken individuals into account sufficiently. Jang and Ko (2014) stress that an individual member can significantly influence an organisation, e.g., when a member's unique knowledge enters the knowledge repository of a CoP. Moreover, the sense of identity of participating individuals is a critical factor for a CoP to reach maturity (Boughzala & Bououd, 2011).

For Wenger, learning takes place in the interplay between the ‘competence’ established in the community and the ‘experience’ of an individual. “Learning … is an interplay between social competence and *personal experience*” (Wenger, 2000, p. 227). Furthermore, CoPs “grow out of a convergent interplay of competence and *experience* that involves mutual engagement” (Wenger, 2000, p. 229) where practitioners of a CoP share an experience. Similarly, for Lave, learning is neither purely subjective nor purely within social interaction. Instead, “learning is recognised as a social phenomenon constituted in the experienced, lived-in world” (Lave, 1991, p. 64). Therefore, the individual experience of youth members participating in a CoP for ICH safeguarding is the entry point of the present study. We ask: What are the youth members’ experiences participating in a CoP and learning from a culture bearer in LPB? We hypothesise that examining these experiences will contribute to crucial knowledge about subjective concepts and understandings of youth members on learning ICH in their local community. A qualitative phenomenographic analysis is deemed an appropriate methodology for the present study because 1) it analyses the learning experience of the youth members with a culture bearer of their community, presenting their qualitatively varying experiences as categories of description, and 2) it allows said categories of description to be presented in an ‘outcome space’ that illustrates how individual categories are related to each other. Outcome space is a product of phenomenographic study. It is a “complex of categories of description comprising distinct groupings of aspects of the phenomenon and the relationships between them” (Marton & Booth, 1997, p. 125).

Methodology

Youth forum design

Twenty-five youth members between the ages of 14 to 31 took part in the youth forum, which consisted of hybrid workshops on weekends, and had a total of 41 hours. The youth members formed five groups, carrying out project group work, research, and fieldwork on weekdays. Each group selected a cultural practice and sought a 'culture bearer'. Here, ‘culture bearer’ refers to a person who is deeply knowledgeable about a particular living heritage, and has mastered its expression through many years of practice. The groups collaborated closely with their selected culture bearer(s) by researching their ICH; leading discussions on issues affecting its vitality; video recording interviews with the culture bearer; and designing an innovative solution to support or revitalise the ICH with the feedback and approval of the culture bearer. Final presentations included: 1) a documentary-style video to showcase their group’s working process; 2) introducing an innovative solution for their ICH.

Data collection and analysis

In total, twenty-four participants took part in a semi-structured post-interview. This is an analysis of the answers provided by five youth members of the “Elephant group” to a specific question of the post-interview protocol. The group was chosen because of the cultural practice they selected. Among the four living heritages of the forum, the oral practice of recital reading represented the most threatened one: Due to weakened practice and transmission, extremely few cultural bearers are left. Youth members remain anonymous, and all names are pseudonyms. Group members were: Mandis (F), Faani (F), Vandi (F), Sonbha (M), and Somchai (M). The analysed question of the interview protocol is: “What did you learn from your culture bearer, or what did they learn from you in the past two months in this forum?” Their responses were transcribed, translated from Lao into English, and subsequently analysed following the phenomenographic approach to find the qualitatively varied ways of experiencing a given phenomenon (Ornek, 2018). This approach draws on the assumption that “each phenomenon, concept, or principle can be understood in a limited number of qualitatively different ways” (Marton, 1986). The collected data was analysed iteratively to identify and describe ‘categories of description’ (Ornek, 2008). For presenting the results in an outcome space, the categories of description were set in relationship to one another to illustrate their structural relationship. Research shows that the outcome space can be structured, e.g., through diagrams, tables, or illustrations, depending on how the categories' relationships are mapped out (Han & Ellis, 2019). This study’s outcome space is represented below in Figure 1.

Findings

Members of the Elephant group did not know each other before joining the forum. They discovered that traditional LPB recitation was rare: “it was only in old videos, and not many people knew it, so we decided to choose it” (Somchai). They scouted for a recitation culture bearer, but most lived far away. Vandi asked her father, who suggested “Auntie Khamyai” from nearby Don Mai village. The youth members reported the threats to be the diminishing interest of younger generations and misunderstanding of its content and meaning, which consists of advice and instruction about the roles of husbands and wives. The group decided to use social media as a tool for awareness raising. Three categories of description emerged from the iterative coding of the interviewees’ answers.

Lack of interest of youth members

Faani reported that the culture bearer "was very happy that we were interested in recitation and interviewed her *because there were not many people interested in it, particularly young people,* who had less interest in this practice." Similarly, Somchai mentioned that many students were unaware of this cultural practice.

Self-awareness about new knowledge and reflection on the culture bearer's new knowledge gained

All group members talked about learning something from Auntie Khamyai, with variations about what new knowledge was acquired. For example, Mandis, Faani, Sonbha, and Somchai related their new learning to Lao culture, history, and recitation techniques. Sonbha gave a representative sample: "We learned background and history, skills and techniques of the recitation. Auntie Khamyai also told us that there are many cultures or songs … that are new knowledge for us." Vandi reported learning about the resilience of the culture bearer to keep practising recital readings, saying: "I learned from Auntie Khamyai that she always believed in and had a passion for this culture and that it could turn into a job. So, I learned that we shouldn't leave our passion and belief." Additionally, three youth members reflected on what they believed Auntie Khamyai learnt from them. Two mentioned her learning as being related to social media, whereas a third generally spoke about having conveyed to her the ways of thinking of young people.

Aims after the youth forum

Interestingly, three youth members revealed their plans to visit Auntie Khamyai after the conclusion of the youth forum. Two explained their plans to spread information to raise awareness. Sonbha specifically mentioned using social media platforms: "we plan to post it on social media sites like YouTube and Facebook so that not only Laotians but people around the world will see it."

Discussion and conclusion

In the outcome space, the relations between the categories of description can be interpreted as causal, where one category causes the existence of the other (see Figure 1). For example, reading the outcome space can begin with the category "Lack of interest of youth members". The disinterest of younger generations caused the Elephant group to select this ICH practice. Learning from the culture bearer made them realise their own lack of knowledge and identify what new knowledge they gained. Three of five group members perceived the culture bearer to have also learned from them. This collaborative learning motivated the youth members to continue advocating for raising awareness on recitations even after the forum, to counteract the lack of youth interest. This causal relation is illustrated as a circle arrow process (see Figure 1).

Figure 1

Circle Arrow Process Illustrating the Outcome Space

Phenomenographic data of the Elephant group has implications for understanding how youth members experienced collaborative learning of ICH in a CoP at an individual level. All group members reported having experienced a learning gain. The fact that the categories of description can be set in a structure of causality suggests that some youth members can be driven to learn about a cultural practice despite its low vitality. For example, the lack of interest among young generations challenged the Elephant group to learn more about a little-known cultural expression in their community. Rather than being put off by this cultural knowledge gap among their peers, they were compelled to know more about it and spread awareness. Their interviews revealed that: they learned more about recital readings during the youth forum; they realised that also they lacked knowledge about it; they set new knowledge in the context of their local community history, thereby identifying with it and appreciating it as new knowledge about their language and culture; they perceived their interactions as teaching the culture bearer as well. These experiences motivated them to pursue awareness-raising activities among others.

For the Elephant group, participating in a CoP involving ICH was a possibility to learn about a little-known living heritage of their community. The group's individual members are core elements of the CoP and are directly impacted by their participation. Phenomenographic insights into their qualitatively different experiences represent a unit of analysis of the CoP at an individual level. Summarised in an outcome space, these experiences imply that the low vitality of a cultural practice is not necessarily a barrier to youth members' attempts at safeguarding a cultural practice. It is empirical evidence that youth members can be driven to safeguard ICH among their peers if their experiences in the CoP: enhances their sense of local identity; leads them to recognise the value of cultural knowledge; results in collaborative learning between themselves and a culture bearer; challenge them to find innovative solutions. Methodologically, the present study shows that phenomenographic insights into an individual's experience in a CoP involving ICH contribute to understanding how CoPs can enhance collaborative learning for a cultural practice, especially those threatened by weakened practice and transmission.

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How Does an Adaptive Dialog Based on Natural Language Processing Impact Students From Distinct Language Backgrounds?

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Abstract: This study takes advantage of advances in Natural Language Processing (NLP) to build an idea detection model that can identify ideas grounded in students' linguistic experiences. We designed adaptive, interactive dialogs for four explanation items using the NLP idea detection model and investigated whether they similarly support students from distinct language backgrounds. The curriculum, assessments, and scoring rubrics were informed by the Knowledge Integration (KI) pedagogy. We analyzed responses of 1,036 students of different language backgrounds taught by 10 teachers in five schools in the western United States. The adaptive dialog engages students from both monolingual English and multilingual backgrounds in incorporating additional relevant ideas into their explanations, resulting in a significant improvement in student responses from initial to revised explanations. The guidance supports students in both language groups to progress in integrating their scientific ideas.

Introduction

Students develop heterogenous, valuable, evidence-based, and fragmented ideas from experiences in their family, culture, and daily routines (diSessa, 1988). Research shows that students are more likely to develop coherent understanding and appreciate the relevance of science to their lives when their ideas are respected (e.g., Basu & Calabrese-Barton, 2007; diSessa, 1998, Linn & Eylon, 2011). In particular, the rich ideas and arguments of students from non-dominant linguistic backgrounds are often overlooked or rejected (Bang & Medin, 2010). This research is a partnership with teachers and schools that serve students from varied linguistic groups. We take advantage of advances in Natural Language Processing (NLP) to build an idea detection model that can identify ideas expressed by students from distinct linguistic backgrounds (Lison et al., 2020).

Prior research shows that human guidance using dialog structures supports students to use strategies to discriminate between ideas and develop coherent and accurate scientific explanations (e.g., Chi et al., 2017). Research using web-based classroom instruction has demonstrated the benefits of adaptive knowledge integration guidance for strengthening students' science explanations (Gerard et al., 2015). Engaging students in explaining scientific phenomena in familiar contexts, encourages them to connect their ideas from prior experience with ideas from science instruction. Yet, ensuring that instruction responds to the varied ideas students develop about familiar contexts requires diligence. Using NLP idea-detection models embedded in a web-based inquiry environment, we identify the science ideas each student expresses and engage the student in an adaptive dialog. An avatar encourages each student to analyze the evidence underlying their detected idea, generate new ideas to deepen or refine their initial ideas, and integrate their ideas into a revised explanation (Linn & Eylon, 2011). The curriculum, dialog, assessments, and scoring rubrics in this study were informed by the Knowledge Integration (KI) pedagogy (Linn et al., 2014). We investigate whether adaptive, interactive dialogs similarly support monolingual English and multilingual students to revise and improve their science explanations. We examine the effectiveness of the idea detection rubrics for helping students' build on diverse everyday experiences. We study how the dialogs support each student to develop their understanding of scientific phenomena. Specifically, we ask, how does an adaptive dialog based on an NLP idea detection model, impact monolingual English and multilingual students?

Methods

Participants

We analyzed responses of 1,036 students taught by ten teachers in five schools in the western United States. Students were in 6th (20.3%), 7th (38.4%), and 8th (41.3%) grade. Students who reported that they speak mostly or only English at home were categorized as "monolingual English speakers" (58.1%). Students who reported never speaking English, mostly not speaking English, or speaking both English and another language at home were categorized as "multilingual speakers" (41.9%). The data do not include information about specific languages.

KI diagnostic inventory

Students explained scientific phenomena while responding to a diagnostic inventory featuring KI items: short essay explanation items that require students to connect multiple ideas, along with an adaptive dialog. The four items elicit student ideas about science concepts they will learn in the following months; items are situated within contexts familiar to the students. The KI scoring rubric rewards students for connecting their ideas with evidence and increasing the coherence of their explanation. The items and the KI scoring rubric for the explanations were validated in prior research and showed no bias for language status (Boda et al., 2021). This was the first test of the effectiveness of the NLP-based idea detection models and designs of the adaptive dialogs.

To build the idea guidance dialog, we identified the rich ideas students develop during their daily experiences and created a rubric with high human inter-rater reliability (Riordan et al., 2020). We designed dialog prompts aligned with each detected idea (see Bradford et al., 2022). The prompts were intended to encourage students to rethink their response and deepen their explanation. Specifically, (a) students write an initial explanation; (b) an NLP scoring model assigns a score based on a 5-point KI rubric; (c) the idea detection model identifies the ideas expressed in the response; (d) the students receive a prompt designed to encourage them to explain an observation or a mechanism based on the KI score and the idea(s) detected; (e) students revise their response; (f) steps *d* and *e* are repeated; (g) students write a final explanation for the initial prompt. We analyzed students' initial and final revised explanations.

NLP model validation

Prior to deployment in classrooms, we validated the human-machine agreement performance of the KI scoring and idea detection models on previously collected data from middle and high school classrooms. The KI scoring models were evaluated on quadratic weighted kappa (QWK), while the idea detection models were evaluated on word-level micro-averaged F-score (harmonic mean of precision and recall, weighted by frequency of idea category) (Table 1). All KI scoring models achieved greater than 0.8 QWK, showing high agreement with expert raters. The idea detection models' performance ranged from 0.59 to 0.82, indicating that the difficulty of modeling human-annotated ideas varied greatly by item (cf. Schulz et al., 2018).

Table 1
Human-Machine Agreement Results for the KI Scoring and Idea Detection Models across Items

Model	Metric	Thermodynamics	Photosynthesis	Climate Change	Sound Waves
KI Scoring	QWK	.809	.936	.889	.833
Idea Detection	F-score	.666	.819	.592	.763

Analysis

For all analyses, we use the software *R*. Missing data are handled by multiple imputation (Rubin, 1987) using the *R* package "mice" (van Buuren & Groothuis-Oudshoorn, 2011). In case of missing data, fifteen values are estimated. All results are pooled by Rubin's rules (c.f. 1987) using the *R* package "eatRep" (Weirich et al., 2022). To analyze differences between initial and revised ordinal scaled KI Score we conduct a non-parametric Wilcoxon signed rank test in both groups. We used a logistic regression to model students' increase in KI Score as a binary outcome indicating if they improved or not. We test whether language background is a predictor for the outcome controlling for school, grade, and parents' language at home.

Findings

Impact of dialog on KI score

The adaptive dialog leads students to add more relevant ideas resulting in a significant improvement in student responses from initial to revised explanations across all items. We confirmed the similarity of the response patterns for each item, before aggregating the analyses across all items. From initial to final explanation, the proportion of students at KI 1 and KI 2 level decreases, while the proportion of students on KI 3 and KI 4 level increases, in the total sample and among multilingual and monolingual English speakers. We observe similar KI score transitions from KI level 1 to KI level 2 or KI level 2 to KI level 3, for both multilingual and monolingual English speakers (Figure 1). Most of the students at KI level 1 move on to KI level 2 in both groups. Around one fourth of the students manage the transition from KI level 2 to KI level 3 or even KI level 4 at the end of the adaptive dialog; the majority of the remaining students at KI level 2 stay at that level. Likewise, the majority of students in both groups who started at KI level 3 remain at this level. Proportionally, slightly more students from the monolingual English-speaking group make the transition to KI level 4. A few differences in idea frequency emerged (Table 2).

For the multilingual group, the initial KI score mean is $M = 2.29$ ($SD = .75$) and the mean of the revised KI score is $M = 2.50$ ($SD = .77$). For the monolingual English speaking group, the mean of the initial KI score is $M = 2.36$ ($SD = .75$) and the mean of the revised KI score is $M = 2.57$ ($SD = .77$). The results of the non-parametric Wilcoxon signed-rank test indicate a significant difference in median between the initial and the revised measurement points for multilingual ($W = 101413.2$, $p < .01$) and monolingual English speakers ($W = 58747.73$, $p < .01$). This implies that both groups show a significant improvement in the median KI score. In a logistic regression, we test if the improvement in KI score is associated with students' language backgrounds controlling for school, grade, and parents' language at home. Students' language backgrounds do not predict the gain in KI score suggesting that they are independent of language background ($\beta = .09$, $p = .51$).

Figure 1

KI Level Transition (across all Items) – According to Students' Language at Home

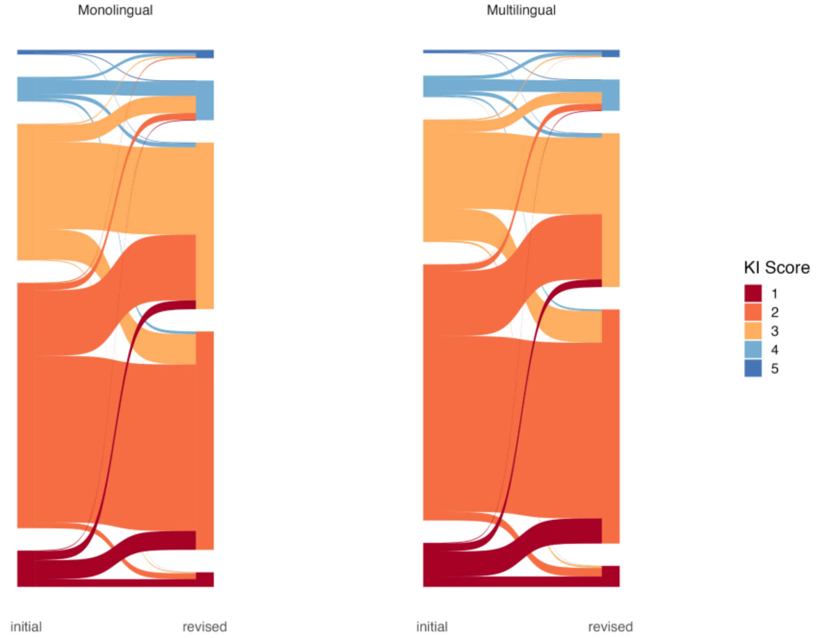

Table 2

For Each Item, the Idea with the Most Discrepancies between both Language Groups

Item: Idea	Initial Ideas	Added Ideas	Revised Ideas
Thermodynamics: cold flow	$W = 78267, p < 0.05^1$	$W = 60680, p = 0.14$	$W = 74097, p = 0.49$
Photosynthesis: animals use the sun's energy	$W = 99244, p = 0.11^1$	$W = 79444, p = 0.20$	$W = 93915, p = 0.73$
Climate Change: metal attracts heat	$W = 94721, p = 0.24$	$W = 81954, p = 0.07^2$	$W = 95976, p = 0.28$
Sound waves: sound travels same speed in water/air	$W = 98132, p = 0.52$	$W = 85744, p < 0.05^2$	$W = 96480, p = 0.17$

Note. ¹ more common for monolingual English speakers; ² added more often by multilingual English speakers.

Ideas detected

Additionally, we investigate differences between the ideas that are mentioned by students from both language backgrounds before, during, and after the adaptive dialog. Overall, the adaptive dialog elicits additional ideas and increases distinguishing of ideas in both groups. For four ideas (across the four items), we find trends or significant differences, using two sample Wilcoxon tests (Table 2). Two ideas were initially expressed more frequently by monolingual English speakers; two ideas were added more frequently by multilingual English speakers. Results for idea revision reveal convergence for language groups across the adaptive dialog, so that revised responses have similar idea frequencies.

Conclusion

The adaptive dialog supported both monolingual English and multilingual speaking students to progress in science sensemaking. We found no indication of possible language bias in the idea detection rubric and the adaptive dialog based on NLP. The adaptive dialog appears to help students of both language backgrounds use their own ideas as a starting point for generating additional ideas. It motivates each student to converge on a more integrated perspective. Thus, our results build on previous findings showing that eliciting ideas can result in greater learning gains than increased review (e.g., Karpicke & Roediger, 2008). Further, the study adds to prior research on student learning in science among multilingual speaking students (Lee & Buxton, 2010). Students of both language groups benefit from personalized scaffolding when engaging in sense-making around language rich (revising explanations, engaging in dialog), contextually familiar, and open-ended problems.

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Characterizing Stakeholder Change Agency During Expansive Learning Processes

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Abstract: Research on change efforts in higher education highlights the importance of change teams having sufficient authority to bring about the change they envision. This paper employs an activity-theoretical framework for organizational change known as expansive learning, along with theory on agency and intersectional power, to examine how faculty exhibited change agency in dialogue in observational data from an engineering department undergoing a major reform project. We analyzed discourse from audio-recorded faculty meetings and workshops within this six-year change project to characterize change agency in talk. Findings highlight the importance of meeting stakeholders where they are, acknowledging and legitimizing their concerns, sharing agency with them, articulating potential control, and inviting them into the effort in ways that suggest ownership. This study extends previous work on expansive learning by illuminating discursive practices that can further joint object-oriented activity in ways that foster stakeholder agency.

Background and purpose

Institutions of higher education face a variety of pressures for change, ranging from external accountability to increasing justice, equity, diversity, and inclusion. Over the past decade, much attention has focused on organizational change efforts in higher education, including those funded by the NSF Revolutionizing Engineering Departments (RED) program. Related research highlights the importance of change teams having sufficient authority to bring about the change they envision (Doten-Snitker et al., 2021; Kang et al., 2020), as well as the capacity to recognize and contend with ways that structural and normative power relations are reproduced (Collins & Bilge, 2020; Kellam et al., 2021).

We drew from a conception of organizational learning based in activity theory known as expansive learning (Engeström, 1987; Engeström et al., 2007; Engeström & Sannino, 2010) to examine how faculty involved in one RED project situated in a large, public, Hispanic-Serving Institution expressed agency in discourse during the change process, and how their expressions of agency were shaped by structural, cultural, normative, and interpersonal power relations. Findings highlight the importance of meeting faculty where they are and collaboratively moving the work forward by explicitly placing agency with stakeholders in the change process.

Theoretical framework

To explore faculty agency during organizational change, we bring together theory on framing agency, intersectional power, and expansive learning. An intersectional approach to understanding power relations suggests that power is distributed across structures, cultures, disciplinary norms, and interpersonal factors (Collins & Bilge, 2020). We intersect this complex, dynamic conception of power with theory about agency, including material agency. While classical conceptions of agency highlight dialectic tensions between human agency and structures that constrain such agency (Giddens, 1984; Sewell, 1992), more recent theory highlights the situated nature of agency, in which some decisions are consequential (Svihla et al., 2021). Rather than humans and structures in opposition, this conception of agency highlights how agency is distributed and negotiated across humans, structures, and materials (Eglash et al., 2020).

To consider how agency and power relate to organizational learning processes, we draw from expansive learning, based in cultural-historical activity theory (CHAT; Engeström, 1987, 2001; Engeström et al., 2007). Expansive learning is an iterative, evolving process of development in which interdependent elements of an activity system (e.g., rules, tools, community, division of labor) are re-mediated through collective activity in order to better serve the *object*, or collective motive, of activity (Engeström, 1987). CHAT highlights the role of historically-laden tensions within and between components of the activity system, known as contradictions, in driving change and learning (Engeström, 2001). These contradictions manifest through disturbances, conflicts, or double binds in the activity system (Engeström & Sannino, 2010). Development and learning occur as individuals and groups attempt to resolve contradictions through the development of new tools, practices, or social relations aimed at better aiding an evolving object. These developments and new practices lead to changes or expansions of the object through *expansive learning*.

In this paper, we attend to faculty's *change agency*, or agency aimed at shifting structures, norms, and practices towards the object of expansive learning. Boreham and Morgan (2004) identified dialogue, carried out within relational practices, as the fundamental process of expansive learning. We consider how faculty's change agency was exhibited in dialogue in observational data from an engineering department undergoing a major reform project, guided by the following research question: How do faculty exhibit change agency in dialogue during expansive learning processes?

Methods

The study takes place within the context of a RED project situated in an engineering department at a large, public, Hispanic-Serving Institution. Both authors were members of the change team, though neither are engineers. To examine faculty change agency, we selected data from a large corpus of qualitative data collected over six years, including more than 80 hours of transcribed audio recordings of interviews and faculty meetings and workshops, involving 20 faculty. We selected data with attention to contentiousness and disagreement, as contentiousness and disagreement seem to be markers of power differentials as experienced by the participants. We focused primarily on interactional data (e.g., faculty meetings and workshops) in order to characterize change agency in dialogue.

We analyzed transcribed data using the framing agency coding toolkit (Svihla et al., 2021), a discourse analytic approach adapted from past studies of how agency shows up in talk (Kanopasky & Sheridan, 2016). This approach focuses on how forms of speech, especially the subject and verb, express or mitigate agency. First person subjects show higher agency than third person. Verbs may suggest no, potential, or full control. As a sociocultural approach (Gee, 2014), we considered what and whom individuals expressed agency over or assigned agency to as they attempted to further particular organizational changes.

Results and discussion

To explore change agency within dialogue, we analyzed interactional data from transcribed faculty meetings and retreats to highlight what change agency might look like as it plays out. The vignette highlighted in Figure 1, which takes place during a faculty meeting near the beginning of the RED team's change effort, involves members of a change team who, at that point, did not share a common understanding of the object of expansive learning, including the change strategies they would employ to reach that object. Lin (names are pseudonyms), in the role of engineering education researcher, had developed the project's core curricular approach with Arun, the department leader. The change team planned to thread design challenges through core engineering courses, with teams of faculty, students, the engineering education researcher, and other partners collaborating across power differentials and employing an asset-based orientation to develop the design challenges. At this point in the project, while Arun was occupied during design challenge planning processes, Park stepped up to support the effort by meeting with students on the design challenge planning team.

In this vignette, Park raised concerns about the students' capacity to contribute to the development of the design challenge, taking a deficit-oriented approach to the students' contributions despite change goals emphasizing an asset orientation. In voicing this concern, Park displayed a lack of control ("what needs to be emphasized"), offloading agency onto the course content in ways that reinforced cultural norms about the role of students. Rather than forcefully countering Park, Lin and Arun met Park's concern with verbs showing potential control (e.g., might, going to, could). Lin, who held some power as an expert on learning, which was mitigated by their status as a non-tenured woman who was not an engineer, worked to recast the role of the student to align it with the planned change strategy. Next, Arun articulated what he thought was an assumption about the roles of students that Park held, which Park confirmed. This apparent openness seems counter to models of change that emphasize the importance of forming shared vision (Kotter, 1995). Arun made a discursive move to express sharing Park's concern (using "we,"), though Park's concern was counter to the specific strategy of engaging students for their perspectives and interests. Arun then took collective responsibility for the issues Park brought up ("We may not have been… successful in finding the right students in year one."), explicitly assigning Park agency in addressing this issue ("Well, you're going to develop the next one.").

Rather than directly confronting Park's concern as "wrong" or against the goals of the change project, Arun used his power as department leader to employ Park's concern in the service of moving the collective work forward. Arun employed a form of change agency by meeting Park where he was at that moment and encouraging development from that current place. By feigning shared ownership of Park's concern, Arun acknowledged the realness of the concern, then suggested that both the faculty collectively and Park specifically could address this challenge moving forward. By working with Park in a way that recognized Park's motives and aligning his responses with those of others involved in expansive learning processes, Arun demonstrated relational agency (Edwards, 2010). Arun capitalized on his power as department leader to discursively legitimize Park's concern, then worked to create an organizational narrative (Davis, 2022; Edwards, 2010) that attempted to move Park and other faculty in the room to expand the object of activity collaboratively by making specific suggestions of what "could" happen to address this concern moving forward (e.g., "This problem can be revisited with far more complexity in [junior classes] or later". Arun placed agency and autonomy with faculty in this process ("… We could build up or dispense with it and move on to something else. That's really up to each class."). Finally, Arun invited other faculty to engage in the joint work of expansive learning ("Now we really throw it open to everybody to say, how can your research be integrated into undergraduate education?").

Figure 1
A vignette from early in a change project. In the transcription, we used dashes to indicate pauses, all caps to indicate emphasis in the audio file, […] when part of the transcript was removed for clarity, brackets to help clarify statements, and // to indicate overlapping talk.

High agency marker. First person singular subject
Shared agency marker. First person plural subject
Framing agency marker. Verbs show potential control
Low agency marker. External person/object subject
Low agency marker. Verb indicates lack of control

Park: So, I express a couple of concerns about, so number one is the students that we are hiring to accomplish to develop these challenges. I- I- I—a particular student came into my office, [and] it seems he's essentially parroting what I told him to when it comes to the phase change and what needs to be emphasized, simply experiments that I suggested. And he had absolutely NO idea how to solve transient heat transport problems. um so not that we were expecting that from 101 students, uh, the student had no idea what their key problems were and if the students were actually helping them design, um, rather reducing the complexity of that problem to match the understanding of sophomores and freshman year students, I think there is, there's a lapse there's- I want to express that concern um.
Lin: I will say that the student point of view is also very important, having the students on the team, because they're able to tell us what kinds of things they know, what kinds of things were hard for them in the classes they've taken very much like the peer learning facilitators. They're also going to tell us if something seems interesting to them, it's the kind of thing that's come up in classes. What other classes they might've taken that this would have been beneficial for. Um, and so that point of view, that expertise they bring was actually a really //.
Arun: // I think what Park's concern is, I know what you're expecting is that the students who helped design this challenge should have a high level of understanding of the subject so that they know it fully. And then they'll simplify it down to//
Park: // Distill it
Arun: to freshmen level Right.
Park: yes
Arun: That's what we'd like to see now we may not have been done have been successful in finding the right students in year 1. Well, you're going to develop the next one. This is a good point.
Park: ALSO And then the second point that I was going to make is this will be much more appropriate for [a junior course] then perhaps even 101.
Arun: Yeah. So we're going to scratch the surface. […] This problem can be revisited with far more complexity in [junior courses] or later. So the idea is this is not the end of this challenge. This challenge could become far more sophisticated and we could build up or dispense with it and move on to something else. That's really up to each class. […] Now we really throw it open to everybody to say, how can your research be integrated into undergraduate education?

Significance and implications

Arun's response to Park's concern is characteristic of change agency. This single vignette of a contentious moment early in the project is not sufficient, on its own, to encapsulate how faculty exhibit change agency in expansive learning in what has become a very successful change effort. However, we argue that it does highlight key elements of change agency: as meeting others where they are, sharing agency with them ("we"), using potential control verbs (can, could, might, etc.), acknowledging and legitimizing their concerns, and inviting them into the effort in ways that suggest ownership.

In processes of expansive learning, contradictions unsettle existing practices and potentially motivate and guide re-mediation of the activity system in ways that further collective learning and development. However, contradictions do not necessarily lead to expansive learning; expansive learning cycles may be broken or abandoned (Engeström et al., 2007). Engeström and colleagues (2007) found that there were times when efforts to "bridge" the discontinuities leading to "breaks" in a cycle of expansive learning were successful in continuing organizational development towards an expanding object, while at other times these attempts were not successful. In these cases, expansive learning processes were abandoned and an alternative object was embraced. Research on organizational change from an activity theory perspective often ignores or underspecifies the important role and contribution of individual learning, identity, agency, and motivation (Billett, 2006; Edwards, 2010; Engeström & Sannino, 2010). This study expands on the important but undertheorized role of individuals and relational practices within processes of expansive learning (Boreham & Morgan, 2004; Engeström et al., 2007). In our data selection, we looked for contentious moments that illuminated contradictions between existing aspects of the activity system and the object of the change project. In this vignette, we saw such a contentious moment and the ways in which change team leaders addressed a concern counter to the goals of the project. Their discursive moves, which both legitimized the faculty member's concern and fostered stakeholder agency and ownership in moving the change project forward, offer a new glimpse into relational practices that help bridge discontinuities in expansive learning (Davis, 2022).

We recognize these discursive markers as potentially necessary but not sufficient ingredients for fostering agency within expansive learning. However, this analysis highlights possibility for both research and practice in attending closely to dialogue, the fundamental process of expansive learning (Boreham & Morgan, 2004), in considering faculty's change agency.

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Generative and Hindering Roles of Student-Material Intra-Actions in a University Makerspace

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Abstract: As design-based and construction-oriented maker activities are increasingly integrated into formal education, it has become important to better understand how materials and tools contribute to student learning. This study analyzed intra-actions between students and materials in a university makerspace during a graduate summer course. Incorporating constructionist and posthumanist perspectives, the study aims to understand how materials and tools 'co-contribute' to student engagement and learning. Conducting diffractive reading of student journals and reflections, we illustrate how materials in the makerspace intra-acted with students both constructively and counter-productively for their engagement and learning.

Introduction

The last decade has seen increasing recognition that design-based, construction-oriented creative activities, often referred to as 'making' or a maker approach, have numerous educational advantages for learners (Blikstein, 2013; Sheridan et al., 2014). This maker approach to learning is guided by constructionism, which considers learners most effectively construct knowledge by making sharable and personally meaningful artifacts (Harel & Papert, 1991). Constructionism posits that materials play a significant role in learning experiences by working as "objects-to-think-with," which Papert defines as objects representing ideas and understanding that learners physically manipulate, reconstruct, and refine through social interaction.

As maker approaches to learning are implemented broadly in both in- and out-of-school contexts in K-12, a number of higher education institutions have also started to adapt to hands-on, skill-oriented, project-based instruction and introduce university-wide makerspaces as part of their infrastructures (Wilczynski et al., 2017). Makerspaces are resource-rich environments that invite individuals to make, tinker with, and collaborate on projects and activities using a variety of materials and tools, including digital technologies and fabrication tools (Blikstein & Krannich, 2013). In higher education institutions, a makerspace is usually open to the entire community of the university and aims to allow students, faculty, and staff across disciplines to collaborate, tinker, teach, and learn in a shared environment. Previous research exploring maker learning in higher education has shown the impacts of makerspaces on learning and examined a variety of tools and technologies that could be incorporated into classes taking place in makerspaces (e.g., Tomko et al., 2021). Despite the growing literature in the field, few empirical studies show how tools and materials in university makerspaces contribute to learning opportunities. Investigating the workings of tools and materials in the educational process can highlight how makerspaces provide opportunities for students to engage in a creative construction process that contributes to their learning.

Theoretical background: Constructionism and posthuman perspectives

A growing number of educational research on making and construction has explored the application of the relational materialist perspective (Hultman & Taguchi, 2010) and posthumanist perspective (Barad, 2003) to gain further understanding of the role of materials and surrounding environments in educational environments (e.g., Keune & Peppler, 2019; Kumpulainen & Kajamaa, 2020). These perspectives look at "non-human forces" (Hultman & Taguchi, 2010, p.526) such as physical manipulatives or physical environments as equal participants in the process of learning. Keune (2022) claims that posthuman perspectives can expand the constructionist view of learning by (1) looking beyond the human and non-human binaries, (2) considering how material contributes to knowledge creation, and (3) explicitly focusing on ethics and multiplicity. Keune describes how "posthumanist perspectives make it possible to see how material directs bodies to produce the domain phenomena that a constructionist lens captures (p. 9)." Inspired by this premise, this exploratory study applied Keune's approach to incorporate constructionist views of learning and posthumanist perspectives to understand how university makerspaces co-generate or hinder learning for students. The research question guiding this study was: how do materials actively contribute to student engagement and learning in the summer graduate course? This paper contributes to the growing body of work exploring the role of materials in constructionist learning environments and also to an emerging understanding of how university makerspaces enhance student educational experiences.

Methods

We employed a diffractive analysis approach (Mazzei, 2014; Murris & Bozalek, 2019) using two theoretical orientations, constructionism and posthumanism, to gain an in-depth understanding of how materials 'co-contribute' to student engagement and learning in a graduate course hosted in a university makerspace.

Context, participants, data collection

This study was conducted during a 13-week graduate-level summer course in a faculty of education on maker pedagogy taught by the first two authors and assisted by the third author. Nine graduate students participated in this study. One student in the course participated entirely remotely. This course met three hours a week at a makerspace in a university library. The course covered both theoretical and practical aspects of maker education: the first half of each session focused on a discussion of reading assignments, and the second half was dedicated to hands-on mini projects using a variety of different materials each week: including cardboard and other traditional craft materials, sound, animation, coding, digital fabrication, biomaterials, and virtual materials.

The data collected for this study comprised an online web survey about students' making experiences, students' lab journals, and transcripts from the final reflection of the semester. Students were asked to keep a digital lab journal throughout the semester in a format they preferred (e.g., slide shows and blogs) to keep track of what they did, what they observed/learned, and what they reflected upon after each class. For the final class, students showcased their projects in a public exhibition. We then conducted a whole group reflection on the semester and takeaways from the activities, which we recorded and transcribed for further analysis.

Analysis

In this study, we engaged in diffractive reading of the research data (Mazzei, 2014; Murris & Bozalek, 2019) to understand how students and materials/environments around them intra-acted over the semester and the consequences of the intra-actions. Diffractive reading is a method to examine data from multiple perspectives "through, with, and in relation to each other to construct a process of thinking with the data and with the theories" (Mazzei, 2014, p.744). Like water waves diffract and go in different directions as they intra-act with each other, the approach aims for the expansion of thoughts and knowledge rather than drawing consolidated conclusions. To this end, the researchers of this study closely read the data with and through two theoretical perspectives, i.e., constructionism and posthumanism, to understand the multiplicity of the phenomena. Two of the authors repeatedly read the data, with two theories in mind, each created analytical memos as they discovered the moments of student-material intra-actions. The first author then diffractively read the two memos to combine and organize the findings in their entirety and all authors discussed to refine the findings for clarity.

Findings

Our diffractive reading of the data enabled us to capture the intra-action between students and materials in the makerspace contributing to student discovery and generation of creative ideas, spontaneous collaboration, engagement in deeper thinking, and learning beyond class sessions. On the other hand, the analysis revealed that the intra-actions also limited student engagement by discouraging them from continuing certain actions, assimilating their ideas with their peers' ideas, terminating deeper and critical thinking, and not attracting them enough to continue exploration beyond the class activities. Below, we showcase a few examples and summarize the major findings, to illustrate the ways in which material intra-actions contributed to student participation and learning in both constructive and counter-productive ways. All participant names are pseudonyms.

(1) Unexpected discovery ⇔ Discouragement over unexpectedness

One of the most interesting findings was how many students learned something new about the material characteristics and tool functions through intra-acting with materials. In particular, they gained sensitivity to materials around them when what they worked with reacted in ways contradictory to their expectations or plans. For instance, Cynthia participated in a scribbling machine activity where students created motored scribbling machines using recycled materials and toy motors and described, "[after some struggles] I ended up just connecting the marker directly to the motor and started to see some success." Her intra-action with the LEGO material made her realize that her original plan would not work, allowing her to discover a simpler structure to make the machine work. While such dissonance between material affordances and student expectations or plans contributed to discoveries and a deeper understanding of the characteristics of materials and tools for many students, the gap between what they anticipated and the feedback they received from the materials also led to frustration and the termination of activities. For instance, Janice described her experience with a video-sensing function in a visual coding platform Scratch, "Every time I tried to adjust my webcam transparency settings, the screen would go blank … eventually I just stayed away from that button," implying that contradictory material feedback can have a strong discouraging impact on student activities.

(2) Conditioned collaboration ⇔ Peer assimilation

Another major observation was that many students collaborated with one another out of necessity demanded by the materials at hand. For example, working on stop-motion animation, Polly pointed out that collaboration with her peers was inevitable because all physical materials needed to be constantly moved around to create an animation. Janice also noted that a chain reaction activity—where each group made sure their parts were physically connected and worked with other teams' parts—required careful coordination between the teams. These student-student interactions helped students like Janice to make meaning out of their experiences from the feedback they received from other students on the part that they created. However, several students noted that seeing and learning about other physical examples drew them to choose similar ideas or restricted their imagination in coming up with new ideas. While many of them described that they resisted the temptation, it is worth noting how the materials played a role in encouraging students to work together, yet may have contributed to the assimilation of ideas among them.

(3) Material-inspired thinking ⇔ Material-constrained thinking

Materials often inspired project ideas and deeper thinking for students, especially when they were contextualized in stories or particular conditions. For example, Skye described his experience in the stop-motion animation project, "the concept of personifying objects … made the project easy to imagine." The material he chose as the main subject in their animation inspired the animated story they eventually created. Janice also mentioned the experience during the stop-motion animation, "the yarn comes into frame [and] makes the whole storyline work." The cat character that they created—inspired by a spherical yarn ball—provoked much affection for the character and helped them come up with an interesting storyline for the animation. These examples illustrate that materials inspire creative ideas through their affordances, appearances, and textures helping students make connections with their personal experiences and knowledge. However, we also documented instances when materials or tools constrained what students were able to envision and realize. For instance, when Simon worked on a project using Scratch, he described how "thinking (for a desired action) was as the coding blocks/resources allowed." That is, he recognized that he was constrained by the tool to envision what could be done for his project. Furthermore, Janice suggested how materials were destructive to her thinking process, explaining that she experienced "idea fog" during the chain reaction activity: "I wonder if going to the materials table first is detrimental to the brainstorm process." These examples show how intra-action between materials and students can cause students to focus on the material experiences without taking the opportunity for meaningful knowledge building. Interestingly, some students tried to resist being overly involved in material experiences by setting their own constraints and goals for their activities. For example, Cynthia noted that she actively avoided obvious materials and challenged herself by repurposing unexpected materials available in her environment. These proactive strategies by the students are worth noting to be further examined to enhance material experiences for educational purposes.

(4) Motivation to learn beyond classrooms ⇔ Not enough enticement

The materials inspired students to continue their learning outside the classrooms if they were strongly motivated to interact with the material or tool. Cassandra noted that creative experiences with materials in the classroom provided her with introductory skills and prompted curiosity about the other types of materials that she did not get to interact with during the course. She reflected on the soundscape activity, describing how the interaction with sound and tools made the activity "certainly become feasible" for her, which encouraged her to explore the topic further after class. This highlights that the interaction with materials provides not only resources and skills to continue learning in the contexts outside the classroom but also confidence and mental accessibility to do so. Unsurprisingly, not all activities inspired the same level of motivation or accessibility that would prompt students to continue them beyond this course. For example, Simon noted that he planned to use a laser cutter outside class time to further his final project but had to give up on the idea due to a lack of convenient availability, and potentially also a lack of motivation to make it happen.

Implications

Several implications for university makerspaces can be drawn from this study. First, the material table where the instructors provided various materials played a key role, enabling students and materials to have meaningful relationships and intra-actions. However, since our analysis also noted the potential for too much or too early material intra-action to distract students from meaningful reflection and knowledge building, the timing and ways in which the material table is used in the educational activities need to be carefully chosen. Second, the tool and material affordability, availability during students' schedules, and instructions for students to learn to use the materials and tools were key aspects of makerspace infrastructures that led to intera-actions that inspired new discoveries and understandings. When students find that tools or materials are inaccessible, the resulting tendency is a loss of motivation, lack of deep engagement with the subject, or worse, total elimination of the tools and materials from their learning experiences. The instructors and makerspace facilitators should carefully design the infrastructure and use of materials and tools to ensure they are available for students at all skill levels. Lastly, our study highlighted that this different makeup of activities impacted the ways in which students were able to interact with materials and tools in the space, influencing the discoveries, motivation, and deep thinking students were able to engage in through the activities. While university makerspaces are often open-ended, program-agnostic spaces, activities should be designed so that students can gain the skills they need, and explore ideas for the project.

This study was limited by the data we were able to collect during the course. Future studies should consider video analysis of the activities, which is a method commonly used for posthumanist research studies. This study also highlighted how different materials impacted students' learning experiences in distinct ways. Future studies can explore how different material affordances lead to different relationships that students have with materials and each other, and open up different opportunities for engagement and learning.

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Elementary Teachers’ Endorsement of Deficit Discourses About Mathematics and the Relative Risk of Educational Racism and Sexism

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Abstract: This study explores the prevalence of deficit and anti-deficit discourses among elementary teachers in the US and their relationship to racist and sexist beliefs about mathematics learning. By combining attribution theory and equity scholarship, the research investigates the endorsement of these discourses through survey data. Findings reveal that both deficit and anti-deficit discourses are common among teachers and strongly related to the endorsement of racist/sexist and anti-racist/anti-sexist statements about mathematics learning. Surprisingly, belief in innate mathematical ability is associated with greater endorsement of anti-racist/anti-sexist educational statements, while belief in educational opportunity is not significantly associated with lesser endorsement of racist and sexist statements. The study emphasizes the need for teacher education to address these tangled discourses and suggests that anti-deficit discourses alone may be insufficient to dismantle deficit discourses in mathematics education.

Introduction

Teachers in the US often use deficit discourses when discussing mathematics education. These discourses are comprised of both seemingly neutral and clearly problematic ideas that shape thinking about math ability (Adiredja & Louie, 2020, p. 42). Researchers studying equity in mathematics learning have used interviews and classroom observations to demonstrate the racist and sexist function of ostensibly neutral discourses (Jackson et al., 2017; Martin, 2009; Shah, 2019). In this study, I combine attribution theory from cognitive psychology with equity scholarship as a lens to identify and quantify the prevalence of seemingly neutral deficit discourses. Through survey data and quantitative techniques, I explore their relationship to racist and sexist statements about math learning. This large sample, quantitative approach has the potential to inform teacher education and policy change in new ways.

Background and conceptual framework

Research suggests that merely having good intentions is not enough for equitable instruction (e.g., Rubie-Davies et al., 2006). Teachers' beliefs about the sources of racial and gender differences in math outcomes, or attribution beliefs, may influence their follow-through on equity intentions. Students' learning opportunities are connected to teachers' sense of efficacy which can vary by student (Schwab, 2019). Thus, a teacher’s attribution beliefs shape a student’s opportunities to learn via teaching self-efficacy. Teachers with genetic attribution beliefs may be less motivated to offer instructional support, as they believe struggles result from innate ability beyond their power to change. In contrast, teachers with educational attribution beliefs, who attribute struggles to insufficient learning opportunities, are more likely to adapt or increase instructional interventions.

Deficit discourses in mathematics education connect two types of deficits: students' academic shortcomings and deficiencies within students, their families, or their culture (Adiredja & Louie, 2020). These discourses often overlook students' existing knowledge and the impact of learning opportunities and social contexts on students' struggles or success. The first type of deficit, "narratives about what counts as mathematics," is based on conceptions of mathematics as objective and universal (ibid, p. 43). These conceptions establish standards that can emphasize students' shortcomings rather than their strengths. The still common but debunked view of mathematics learning as a linear process (Blanton & Kaput, 2005) also contributes to this deficit view. The second type of deficit, "narratives about students from marginalized groups" (Adiredja & Louie, 2020, p. 43) includes narratives about deficits in ability, intelligence (Leyva, 2016), culture (Solórzano & Yosso, 2002), and personal effort (Oppland-Cordell, 2014). These narratives focus on individuals membership in marginalized groups, attributing underachievement to the group rather than external, sociohistorical factors such as learning opportunities. Addressing these discourses may help promote more equitable and inclusive mathematics education.

Teachers' beliefs about students significantly influence their judgments and classroom organization (Reyna, 2008). Attribution theory examines how individuals attribute behavior to internal or external causes (Graham, 2020). Teachers often possess attributional biases (Bertrand & Marsh, 2015), and tend to attribute student failure to factors internal to students and external to themselves (Kulinna, 2007). Research further shows that teachers' attributions relate to student variables like gender and race (e.g., Espinoza et al., 2014). Three kinds of attribution beliefs are genetic determinism (Keller, 2005), social determinism (Rangel & Keller, 2011), and school meritocracy (Wiederkehr et al., 2015). Genetic determinism (BGD) posits that innate biological traits primarily shape individuals (Keller, 2005), and is associated with stereotyping and prejudice. Social determinism (BSD) suggests that social factors permanently mold an individual's character (Rangel & Keller, 2011) and is linked to negative stereotyping and prejudice. Belief in school meritocracy (BSM) maintains that school success depends on effort (Wiederkehr et al., 2015), and is related to social inequality legitimization.

I introduce the term "attributions of mathematical excellence" to characterize deficit discourses in mathematics education and make two key contributions. First, it highlights the prevalence and insidious nature of positive language in describing what counts as mathematics. This conceptual stance supports the methodology of examining teachers' implicitly held beliefs through coded, identity-neutral language, which echoes narratives about students from marginalized groups (Louie et al., 2021). The second contribution is to focus on the attributions that underlie deficit discourses, leveraging social psychology research to distinguish different types. Teachers' beliefs about the sources of unequal outcomes in mathematics education are consequential, as certain beliefs may reinforce racist and sexist outcomes, while others could help disrupt them. Notably, anti-deficit attributions of mathematical excellence recognize the role of schooling and its social and historical context in shaping student outcomes. This perspective suggests that anti-deficit attributions can create space for teachers to engage in anti-deficit noticing, which deliberately challenges deficit discourses and intentionally elevates the humanity, intelligence, and mathematical abilities of marginalized people in routine instructional interactions (Louie et al., 2021).

In this study, I focus on genetic and educational attributions of mathematical excellence and address the following research questions.

1. How common are deficit discourses—and anti-deficit discourses—about mathematics? How commonly do teachers endorse explicitly racist and sexist statements—and anti-racist/anti-sexist statements—about mathematics learning?
2. How are identity neutral deficit discourses (and anti-deficit discourses) related to analogous racist and sexist statements (or anti-racist, anti-sexist statements) about mathematics learning?
3. What is teachers' risk of endorsing racist or sexist genetic statements (or anti-racist or anti-sexist educational statements) about mathematical learning relative to their identity neutral attribution of mathematical success to innate ability or to education?

Methods and procedures

The study involved 313 participants, including 223 practicing teachers and 90 preservice teachers from a midwestern state, who were predominantly white (96%) and female (89%), reflecting the regional demographics of elementary teachers. Participants answered 64 survey items across four attribution categories, with each category containing eight pairs of identity-neutral items and identity-specific items expressing racist, sexist, anti-racist, or anti-sexist attributions (Jacobson et al., 2022). Participants rated the truth of each attribution on a 7-point scale from 1: Completely true to 7: Not at all true. Responses were dichotomized into endorsement (1-5) and non-endorsement (6-7). The survey was administered online via Qualtrics, and participants received gift cards as an incentive. Data collection concluded after a two-week period, with two follow-up email reminders sent. All participants provided informed consent, and the study was approved by an Institutional Review Board.

Relative risk, a technique borrowed from medical sciences, was used to analyze the survey data. Exposure was operationalized as a teacher's endorsement of an identity-neutral genetic attribution statement, indicating exposure to the corresponding deficit discourse. The consequence was the teacher's endorsement of an explicitly racist or sexist statement. The same interpretation was applied to teachers' endorsement of an identity-neutral educational attribution statement (exposure to anti-deficit discourses) and endorsement of an anti-racist or anti-sexist statement (consequence).

Findings

To answer the first research question, I examined the distribution of endorsement for each attribution item. All but one of the identity neutral genetic items were endorsed by a majority of participants, with endorsement ranging from 52% to 77%. Endorsement of the last item was 38%. By contrast, the identity specific genetic items were endorsed by a minority of participants, with endorsement ranging from 13% to 43%. All the neutral educational items were endorsed by most of the participants, with endorsement ranging from 79% to 88%. Similarly, all the identified educational items were endorsed by most participants, with endorsement ranging from 50% to 80%.

Thus, endorsement of either the genetic or the educational items was not uncommon for participants in this sample, whether the items were identity neutral or identified.

For the second research question, I computed the relative risk of a teacher endorsing the identified item given their endorsement of the neutral item in each item pair. For example, teachers who endorsed the identity neutral item (*I think that basic genetic differences determine to a large degree who becomes a professional mathematician.*) were 2.49 ($p < .0001$) times as likely to endorse the identified genetic attribution (*I think that basic genetic differences explain why there are far more male than female mathematicians.*) than others. In a second example, teachers who endorsed the identity neutral item (*In my view, students who excel in mathematics usually have more educational opportunities than students who do not excel in mathematics*.) were 1.86 (p = .0019) times as likely to endorse the identified educational attribution (*I believe that Asian students who excel in mathematics have more educational opportunities than students from other groups who do not excel in mathematics.*) than others. Across the seven genetic attribution item pairs, the relative risk of endorsing the identified item was always statistically significant ($p < .01$) and ranged from 1.90 to 10.67. Across the seven educational attribution item pairs, the relative risk of endorsing the identified item was always statistically significant ($p < .01$) and ranged from 1.73 to 3.05.

For the third research question, I used the median to summarize each teacher's endorsement ratings for the educational and genetic items. This enabled me to compute the overall relative risk based on summaries of both kinds of item in each attribution category. Teachers with median endorsement of identity neutral educational items (anti-deficit educational discourses) were nearly eight times as likely (p < 0.001) to endorse identified educational (antiracist) statements. Teachers with median endorsement of identity neutral genetic items (genetic deficit discourses) were more than 12 times as likely (p < .0001) to endorse identified genetic (racist and sexist) statements. Teachers with median endorsement of identity neutral educational items (anti-deficit educational discourses) were 12% more likely to endorse identified genetic (racist and sexist) statements, but this relative risk was not statistically significant (p = .3824). Teachers with median endorsement of identity neutral genetic items (genetic deficit discourses) were 25% more likely (p = .0044) to endorse identified educational (antiracist) statements.

Discussion

This paper uses survey methods to explore the prevalence of elementary teachers' deficit discourses about innate mathematical ability and anti-deficit discourses about the central role of educational opportunity in mathematical success. I also examined the risk of endorsing racist and sexist statements about mathematics learning relative to these deficit and anti-deficit discourses. The findings show that (1) deficit and anti-deficit discourses are both common, (2) deficit and anti-deficit discourses are strongly related to the teachers' endorsement of racist/sexist and anti-racist/anti-sexist statements about mathematics learning, respectively, and (3) deficit and anti-deficit discourses are distinct from each other in the sense that belief in innate mathematical ability is counter-intuitively associated with a greater endorsement of anti-racist/anti-sexist educational statements and that belief in educational opportunity is not significantly associated with lesser endorsement of racist and sexist statements about mathematical ability.

Attribution beliefs provide a useful lens for analyzing deficit and anti-deficit discourses in mathematics education. The first finding confirms the pervasive nature of both genetic and educational attributions for mathematical success. The methodological choice of using two versions of the same attribution statement (which differed only in whether race and gender were explicit) highlighted the strong relationship between common place, often unquestioned "threads" of discourse about mathematics ability and the more obviously problematic, explicitly racist and sexist "strands" that together make up deficit discourses in mathematics education. From a theoretical perspective, these results make plausible the claim that these apparently separate discursive elements are not actually distinct but are "tangled" together to form discursive "webs" that are challenging to navigate or extricate (Adiredja & Louie, 2020). The results also provide a sobering implication for teacher education: participating in both deficit and anti-deficit discourses evidently does not cause an internal contradiction for many teachers. If teacher education is going to unravel the webs of deficit discourses, anti-deficit discourses alone are likely an insufficient tool to dismantle deficit discourses.

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Detecting Patterns of Constructed Collaborative Novelty in Online Discourse in Knowledge Building Communities

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Abstract: Investigating how students collaboratively advance online discussion has much value in understanding the mechanisms of novelty. Extending creative discourse by broadening adjacent novelty with new ideas is an essential benchmark to expand the community's knowledge in a knowledge building community. This study aims to continue the investigation of the mechanisms and novelty momentums behind the discourse in students' knowledge building online discussion, with a new novelty framework to understand students' collaborative discussions. Results show a promising understanding of the discussion patterns from this new perspective.

Introduction

Novelty is a crucial element in advancing the field of knowledge to make breakthroughs. In recent decades, the novelty has been investigated from individual to collaborative levels. A new trend in understanding novelty is the social process developed by transitions between persons sharing a context that technology can support (Bereiter & Scardamalia, 2014; Slotta et al., 2014). The study of novelty expands from both eccentric personalities to a competence that can be learned and developed over a life span (Romero et al., 2012) with the support of technology. The concept of novelty is receiving growing attention in Computer-Supported Collaborative Learning which is often defined as "new and not resembling something formerly known or used" (Merriam-Webster, 1991). While the collaboration format also reveals a significant increase in creativity. For instance, collaboration in design, where collaborative stimulation (prompting, seeding, clarifying, and correcting) occurs while designing entities or questions, stimulating the generative cognitive process. Moreover, it has been shown that collaborative stimulation for seeding and correcting could result in the most significant increase in the novelty of design entities (Sauder et al., 2013). While aggregate and process models provide valuable insights into collaborative creativity, they also have limitations. One limitation of aggregate models is that they tend to focus on the individual characteristics of team members rather than the social and cultural context of collaboration. This may overlook important factors such as power dynamics, group norms, and social identity that can impact creativity in a collaborative setting. On the other hand, process models may oversimplify the complex nature of collaboration by reducing it to a set of discrete interactions. This may overlook the role of context and the non-linear nature of collaboration, where creativity can emerge from unexpected sources and pathways. Our research question asks: what patterns of students' online knowledge building discourse are based on novelty analysis?

Novelty framework:

We created a novelty framework (2021, Yuan et al.,) and analyzed idea novelty based on the content of students' online posts that contained unique and relevant information extending their current understanding. The analysis led to a refined coding scheme that includes six dimensions (main categories). The quality of each type of new contribution was further assessed based on three levels: 0-not new and not substantial, 1: new but not substantial, 2: new and substantial. The levels are determined in a temporal context based on how a specific note compares against the previous notes. Thus, the code of 0 does not mean that note has no rich formation, but it indicates that no new information is provided in that specific note compared to the previous posts under a measurement dimension. Below we explain each dimension.

A) New concept

Definition: In this framework, the new concept is defined in three aspects: 1) adding new topics that have never appeared in the discussion before; 2) adding to or expanding a piece of information on an existing topic/theme; 3) adding different opinions to show alternative thinking. If a note qualifies any of the criteria, we further determine its level of substance; otherwise, we code it as 0.

Substantial or not: We define a note as substantial when it adds detailed information about the topic/theme/concept or it contributes to progress in explaining the topic. We define a note as 0 when it contains only several words or repeated information.

B) New connection

Definition: The new connection is defined as 1) connecting a new conceptual construct to an existing conceptual construct; 2) adding a new connection between two new/existing conceptual constructs that has not been shown before.

Substantial or not: A current note is substantial when it adds an essential connection between two new or existing conceptual constructs with a sufficient explanation. If the connection is only about two concepts briefly, or simply mentions the concept, or if no further explanation is provided, we code it as not substantial.

C) New rise-above

Definition: The definition of new rise-above is: 1) it has a new integration of the previous information at a new/higher/finer level, which means that the note contains synthesized ideas without redundancy; 2) the note adapts to the changes of the progressive set of ideas.

Substantial or not: When the current note shares a higher-level of understanding about the learning concept/topic, or makes a comprehensive integration of the previous information, or summarizes the previous discussion at a higher level with sufficient information, it will be counted as substantial.

D) New question

Definition: The definition of a question is quite clear when the note proposing a new question(s) starts with what, why, how, when, or do, as a sentence starter indicating it is a question.

Substantial or not: A substantial question should: 1) ask a new open-ended question with deeper insights; 2) ask several questions with detailed information. If the question only contains a few words or closed-ended questions, it counts as not substantial.

E) New source

Definition: A note shares non-redundant resources, such as books and websites.

Substantial or not: When a new resource type is shared with links and other explanations, or a summary related to the current topic, it will be counted as 1. If a new resource type is shared with only a link, without any explanation, it will be counted as 0.

F) New context

Definition: This column focuses on whether a new learning environment is mentioned or a different context is connected or compared to the previous concept.

Substantial or not: The new note will be counted as substantial when a new learning environment or context is mentioned/connected/compared with the same discussion topic and with detailed explanations.

Method

Contexts

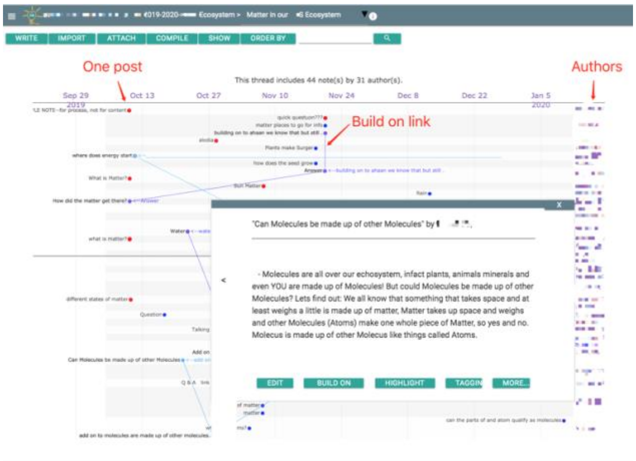
This study was conducted during two consecutive school years (2018-2019 and 2019-2020) at a public elementary school in the Northeastern U.S. Each year, four Grade 5 science classrooms participated—each of two experienced teachers taught in two classrooms. The participants were 163 students, 84 in the first year and 79 in the second year. Students of each year studied ecology from September to December. Their science learning was implemented using a knowledge building pedagogy (Bereiter & Scardamalia, 2014) supported by a collaborative online platform, Idea Thread Mapper (ITM, Zhang & Chen, 2019). Each year, the class began with a set of kick-off activities (e.g., schoolyard observation of living and non-living things) that triggered student interest in the unit topic. Students generated initial questions and shared them in the classroom and online conversations. They had face-to-face metacognitive meetings in classrooms, where they collaboratively built on ideas, explored problems, reflected on collective idea progress, and identified knowledge gaps for further study. They continued the collaborative conversation in ITM (Figure 1). As students expanded questions about overarching inquiry goals (e.g., the interaction of living and non-living things), teachers added wondering areas (overarching question or branch of inquiry) with temporal idea threads in ITM. The online discourse was organized in the idea threads. In each idea thread, students posted a series of notes (discourse entries) addressing a topic of inquiry and built on ideas in the notes connected by links. Students were encouraged to participate in the collaborative discourse in any wondering areas based on their interests. They used multiple resources, such as books, websites, and online videos, and conducted hands-on observations.

Data sources and analysis

The data source was students' notes in ITM over the two school years. In total, we collected 899 notes with an average of 38.62 words per note. A combination of qualitative analysis methods was used to investigate students' online discourse aligned with their face-to-face work over time, which was to develop and test an analytic framework for measuring students' idea novelty, A grounded theory approach (Strauss & Corbin, 1998) was conducted for identifying various creative input types concerning prior and subsequent discourse entries. The authors of this paper read and reread the ITM notes in the context of the classroom inquiry to learn the overall progress of students' ecological understanding and idea creation. The developed coding scheme was employed to conduct content analysis (Chi, 1997) for analyzing the notes and characterize the types and levels of creative contributions involved. To further understand how the community build-on notes relate to the novelty, researchers coded 184 notes from 9 views which contain more than 10 notes, and used Epistemic Network Analysis (Shaffer et al., 2009) to find the relationships among the 6 novelty coding schemes.

Figure 1

An example of Idea Thread in ITM. Each dot represents a post (note), and a line linking two posts shows a build-on response.



This thread includes 44 note(s) by 31 author(s).

"Can Molecules be made up of other Molecules" by [redacted]

- Molecules are all over our echosystem, infact plants, animals minerals and even YOU are made up of Molecules! But could Molecules be made up of other Molecules? Lets find out: We all know that something that takes space and at least weighs a little is made up of matter, Matter takes up space and weighs and other Molecules (Atoms) make one whole piece of Matter, so yes and no. Molecus is made up of other Molecus like things called Atoms.

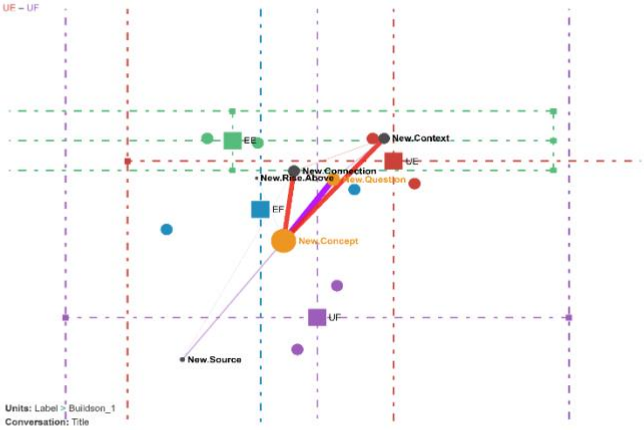
Results

RQ: What patterns of students' online knowledge building discourse are based on novelty analysis?

To understand the pattern of students' online discourse in the six novelty dimensions, researchers conducted an Epistatic Network Analysis based on the novelty coding.

Figure 2

Build-on notes only: plot Unelaborated Fact. The New Question and New Concept show a correlation of 0.85.

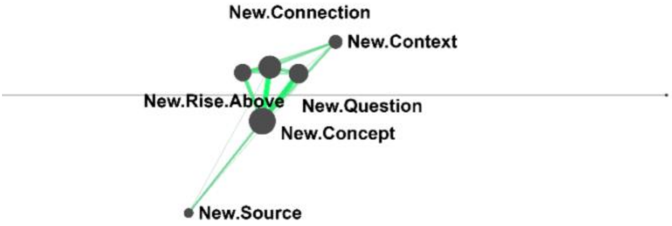


The results of the Epistemic Network Analysis show that among the build-on notes, the cluster of the most frequently contributed note indicates the quality of *Unelaborated Fact*. The connection between New

Question and New Concept shows a correlation of 0.85, which means that students tend to post a simple note with questions and new concepts to extend the conversation at the basic level. However, three coding pairs show a close connection within the cluster of the highest-quality notes (Elaborated Explanation). The New Question and New Concept with a correlation of 0.46, New Concept and New Connection (0.46), and New Concept and New Rise-above (0.36), in dictating the multiple aspects students contribute to extending the conversation at a deeper level.

Figure 3

Build-on notes only: plot notes of Elaborated Explanation, the correlation between the New Question and New Concept is 0.46, New Concept and New Connection (0.46), New Concept and New Rise-above (0.36).



Conclusion

This study implied a new novelty analytic framework in a new dataset, which was applied to understand the temporal patterns and progress of students' idea development in the online discourse of knowledge building communities. The Epistemic Network Analysis reveals patterns of students’ novelty contribution during online discussion. Researchers and educators may use this analytic framework to investigate students' collaborative discourse in a way that captures the progressive changes of students' novel contributions. This analytical framework may also serve as a foundation for creating classroom rubrics and generating formative feedback on students' collaborative discussions.

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Supporting Diversity, Equity, and Inclusion Through Productive Disciplinary Engagement and Expansive Framing

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Abstract: Productive disciplinary engagement (PDE) and expansive framing are among the most widely used educational design principles grounded in situative theories of cognition. Because they insist that learners "problematize" content from their own perspective, these principles are compatible with contemporary "asset-based" efforts to support diversity, equity, and inclusion. This paper systematically reviews scholarship advancing that claim. The reviewed body of work shows how educational practices that sustain the unique competencies of historically marginalized groups can also support "generative" learning that transfers readily and widely to dominant *and* non-dominant contexts for learning, achieving, working, and living.

Introduction

How People Learn II (NASEM, 2018) argued that education should be "relevant and responsive to the languages, literacies, and cultural practices of all students" (p. 137). As a consensus report, however, *HPL II* endorsed these asset-based approaches to diversity, equity, and inclusion (DEI) without detailing how they might look in practice. This paper explores one promising strand of DEI scholarship based on design principles developed by Randi Engle (1965-2012) and colleagues for *productive disciplinary engagement* (PDE) and *expansive framing*. While their initial work did not address DEI directly, several scholars (including Engle herself) acknowledged that potential and began exploring ways to pursue it. This paper systematically reviews the body of research applying PDE and expansive framing to matters of equity.

Engle and Conant (2002) introduced PDE as a situative framework for characterizing sustained student inquiry and debate. They proposed that four "guiding principles" help foster PDE: *problematizing content, conferring students authority*, *holding students accountable*, and *providing relevant resources*. Engle (2006) further analyzed the PDE data to consider *generative* learning that transfers readily and widely. She argued that transfer would be more likely when learners establish *intercontextuality* between the learning and transfer environments. Transfer is further supported by positioning students as *authors* of disciplinary ideas, participating in a broader intellectual conversation that extends over time (see also Engle et al., 2012).

Expansive framing may enhance PDE and vice versa. For instance, building students' authority is central to both frameworks. Further, problematizing topics often entails *transferring in* knowledge from out-of-school; problematizing also entails seeing a topic's wider import. Seen together in this light, the two frameworks align with asset-based approaches that "support young people in sustaining the cultural and linguistic competence of their communities while simultaneously offering access to dominant cultural competence" (Paris, 2012, p. 95). Subsequent work on PDE and expansive framing has taken up this pursuit to make learning environments more culturally *relevant* (Ladson-Billings, 1995), *responsive* (Gay, 2000), and *sustaining* (Paris, 2012).

Method

As part of a larger systematic review, we used Google Scholar to identify 2714 publications (as of June 2022) containing the terms "productive disciplinary engagement" or "expansive framing" or citing Engle's scholarship. Two team members independently coded each publication as unpublished/irrelevant/inaccessible (450), not in English (287), passing reference to Engle's work (800), supporting reference (803), not peer-reviewed (177), or include (197), with an interrater agreement of 78% (Cohen's kappa = .72). Publications marked for inclusion engaged substantively with PDE, expansive framing, or both. We determined that 32 of these focused on DEI. One reviewer then further coded these 32 publications for the features and categories described below.

Findings

Most of the included publications (23) concerned PDE, while nine concerned expansive framing. School levels included secondary (19), elementary (7), postsecondary (5), and multiple grades (1). Academic disciplines included science (13), mathematics (9), composition (3), engineering (2), computer science (1), and multiple (4).

Most of the publications (24) reported research conducted in the USA, while three were from Norway, and one each were from France, Sweden, South Africa, South Korea, and international.

Our review further revealed that the research fell into four categories. The first of these, *using PDE principles to engage marginalized students*, we omit here due to space limitations and refer interested readers to Freedman et al. (2023). Studies in this category used the PDE principles to aid and empower students from historically oppressed communities, usually in the context of mathematics education. The studies left unexplored, however, whether all students benefitted equally from these learning opportunities.

The second category of work, *confronting inequitable access to PDE*, took up this latter issue. Engle et al. (2014) re-examined the original PDE data to determine which students were contributing to discussion and why. The resulting *influence framework* explained students' differential engagement using five socially negotiated components: *degree of influence, merits of arguments, intellectual authority, access to the conversational floor*, and *access to interactional space*. The framework explained why one male student won over most peers to his position despite making the weakest arguments. Langer-Osuna (2016) likewise showed how a teacher positioned one math student as the intellectual and directive authority at the expense of another, leading the one to accept the other's flawed ideas as correct. In a subsequent review, Langer-Osuna (2018) noted that students often position each other as high or low authority based on racialized and gendered scripts. Shah and Lewis (2019) showed how, even within participant structures designed for equity, more competent or self-assured students can still marginalize peers—in this case, by telling a computer programming partner exactly what to do.

Other studies in this category include Zuiker et al. (2016), who used elements of the PDE framework in concert with complexity theory to explain how a collaborative group grew dysfunctional. The students positioned one student as holding far more authority and accountability than the others, resulting in a group-level pattern of "orienting to the leader" (p. 86). Conversely, Han and Gutierez (2021) used the PDE framework to show how a passive female science student came to experience curiosity and joy as she grew more confident in her abilities and accepted by her groupmates. Finally, Haverly et al. (2020) used the framework to examine how novice teachers can make space for "equitable sense-making" (p. 63). They suggested that teachers need more support to avoid mistaking problematizing for confusion or misunderstanding, especially with marginalized students.

In summary, these studies identified factors that either undermine or support equitable access to PDE, offering a corrective to work that tracks engagement only at the group level. But these studies (and those in Category 1) focused on accessing dominant cultural forms—not on elevating the status of other ways of knowing.

The third category of scholarship, *widening PDE to include cultural and community knowledge*, aimed to expand the meaning of "disciplinary." Thompson (2014), for instance, refined a Lunchtime Science (LS) intervention for minoritized female students. The program combined the PDE principles with identity work that involved "laying stories alongside curriculum" by asking students "who I am and who I am becoming…in order to build a sense of belonging" (p. 404-405). While passive in their regular science courses, most became passionate and productive during LS as they brought in community funds of knowledge. For example, four girls "described how their LS experiments were fueled by unanswered health-related questions in their families" (p. 422).

In a similar manner, Agarwal and Sengupta-Irving (2019) offered new themes of *epistemic diversity* and *historicity & identity*, asking "what knowledge is and who has claims over it to broaden the normative perspectives on disciplinary learning" (p. 350). With their new framework, *Connective and Productive Disciplinary Engagement* (CPDE), they argued that *problematizing* ought to involve analysis of sociopolitical controversies and the use of alternative epistemologies (e.g., Indigenous, feminist, etc.). CPDE expanded *authority* "by inviting [students] to draw on their history of experiences with disciplinary ideas beyond school" (p. 354). CPDE expanded *accountability* to include a broader array of people and ideas to whom students should be responsive. Jordan et al. (2021) drew on the CPDE framework in a project where Latino/a students designed a community-based solar energy innovation. The authors concluded, "problematizing is unlikely to induce grappling with deep disciplinary uncertainties; the emotional demands of risky design work may not be sustainable without the commitment and identity inherent to real work with real consequences" (p. 251). Suárez (2020) likewise expanded the PDE framework to study translanguaging in STEM, while Brodie et al. (2021) expanded it to study mathematical sensemaking about the COVID-19 pandemic.

In summary, this third set of studies widens the definition of "disciplinary" to include knowledge derived from the worlds that marginalized students inhabit. Doing so seems a promising way of "sustaining the cultural and linguistic competence of their communities" (Paris, 2012, p. 95). Short of considering expansive framing and transfer directly, these interventions likely fostered intercontextuality by helping students find personally relevant connections across school, home, and community. Supporting our core argument, the resulting learning should therefore transfer more readily to those non-dominant contexts, in addition to more dominant contexts.

The fourth category of scholarship, *using expansive framing to define diverse transfer contexts*, addressed this matter more directly. Like Category 3, these studies expanded the nature of disciplinary knowledge.

But they were more explicit in defining transfer contexts that derived from students' lived experience with oppression, conflict, and activism. McCoy (2017), for instance, applied expansive framing in college composition, where students were writing for social justice (e.g., from a Black feminist perspective). McCoy (2020) later presented additional writing prompts that might create "pathways for successful knowledge transfer from the learning environment of the classroom to the learning environment of the street" (p. 28). Coupled with McCoy's (2021) extensions of Engle et al.'s (2012) five explanations of transfer, this work offers a compelling example of promoting transfer to both dominant and non-dominant contexts.

In the same vein, Doucette et al. (2022) described an *underrepresentation curriculum* that used expansive framing to "develop intercontextuality and make connections between the context in which [students] are learning and the communities in which they live" (p. 303). Curricular units set the stage for talking about equity, questioning scientific objectivity, and engaging in social action. Harris et al. (2020) studied efforts to expansively frame youths' participation in "citizen science" efforts where they gathered data "nested" in actual scientific investigations. Finding that these framing contexts were invisible and/or unbelievable to some participants, the authors offered strategies to overcome such impediments. Several studies conducted in Norwegian classrooms highlight additional challenges teachers and students face in drawing on cultural and communal knowledge to support learning (Rocksén & Olander, 2017; Silseth, 2018; Silseth & Erstad, 2018; Wiig et al., 2018).

In summary, as compared to PDE, fewer studies extended expansive framing to support DEI. But we find such studies crucial because of their explicit attention to *transfer*. For schooling to carry meaning beyond the classroom, the material explored must resonate with students' cultural and communal knowledge—and strike them as relevant to those communities' past, present, and future.

Conclusions and next steps

We conclude that these four categories of studies document a range of consequential efforts to apply Engle's ideas in support of DEI goals. More than just providing instruction that is culturally *relevant*, this work uses PDE and expansive framing to sustain (i.e., transfer) the ways of knowing present in historically marginalized communities, while also providing access to disciplinary discourses associated with power and prestige. We also see potential for synergy across the four categories. Widening disciplinary knowledge (Category 3) naturally frames learning more expansively (Category 4), making transfer more likely to both dominant (Category 1) and non-dominant contexts, with the caveat that unequal access (Category 2) makes this work challenging.

One goal of our systematic review was to locate traditionally "rigorous" applications of Engle's ideas to DEI. Most of the corpus fell short of this mark. Of course, we acknowledge that DEI scholars often rely on interpretive methods and many question the generalizability of experimental designs and the validity of externally developed tests. Admittedly, we find ourselves conflicted in this regard. Our main goal, however, is providing a useful starting point for others wishing to continue this important line of work. The scholarship reviewed here suggests that PDE and expansive framing hold great potential for pursuing diversity, equity, and inclusion.

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High School Students’ Evidentiary Reasoning in a Hominid Evolution Lab

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Abstract: NGSS calls for engaging disciplinary core ideas in the practice of science learning. This study explored high school students’ evidentiary reasoning in a two-week hominid evolution laboratory investigation. Students compared morphological characteristics and age data for a set of hominid skulls and constructed a phylogenetic tree from the data representing hominid evolution. The study interviewed twenty high school students (sixteen 9th graders and four 12th graders) to understand their evidentiary reasoning in human evolution context. The results suggested that students used multiple lines of evidence to support their claims. However, students showed limited understanding of the constraints of evidence. The research suggests a need to help students understand the boundedness and limitations of inferences from evidence through laboratory inquiry.

Problem statement

Students’ ability to reason with evidence is an emphasis in modern science education. Next Generation Science Standards (NGSS, 2013) provide guidelines for three dimensions of science learning, “disciplinary core ideas,” “crosscutting concepts,” and “science and engineering practices.” Standards related to each dimension are specified for grade bands and content areas of science. A key aspect of science that is emphasized across scientific practices, such as explanation, argumentation, inquiry, and modeling, is reasoning with evidence.

Sandoval (2003) defines *evidence* as data that is connected to a knowledge claim through explanation or argumentation. Building on these ideas of evidence, the Conceptual Analysis of Disciplinary Evidence (CADE) framework elaborates on the relationships between evidentiary reasoning and disciplinary knowledge through cycles of inquiry (Liu et al., 2022; Samarapungavan, 2018). This short paper aims to understand students’ learning about biological evidence from their reflections on their work in the hominid evolution lab. There are two main research questions in this study: 1. How did students use skull data from their laboratory investigations to support conclusions about hominid evolution? 2. More broadly, how did students describe the relationship between evidence and scientific knowledge?

Methods

Table 1
Interview Questions by Theme

Theme	Interview Questions
1. Use of skull data to support conclusions about hominid evolution	Q1 What did the data from your laboratory tell you about human evolution?
2. Broad understanding of the role of scientific evidence in building scientific knowledge	Q2. Do you believe that data from fossil records can provide evidence for ancestral relationships among species? Q3. How did working on these tasks affect your understanding of the role of scientific evidence in relation to biological knowledge?

The data source was from an NSF-funded project to study students’ understanding and use of biological evidence in laboratory investigations (Samarapungavan et al., 2017). In this laboratory, students measured and compared various dimensions of a set of hominid skulls (e.g., morphological and age data) to construct an evolutionary tree showing the common ancestry and divergence of the hominid species they had investigated. The hominid skulls used in the investigation were life-size replicas of skulls in the Smithsonian collection.

Students also had access to skull dating data as well as biogeographical data (e.g., regional distribution of food sources). Students' evidentiary reasoning about data was scaffolded with written prompts helping them connect content knowledge about evolution to the data. Twenty high school students (sixteen ninth graders and four twelfth graders) were interviewed after task completion to interpret evidence for evolution and discuss their understanding of the relationship between evidence and theory. Qualitative content analysis was used to analyze students' interviews (Chi,1997). Table 1 categorizes the interview questions by the two key themes related to our research questions (see above): (1) use of skull data to support conclusions about hominid evolution and (2) understanding of the role of evidence in a scientific investigation. Tables 2 and 3 show the coding of student responses for the two themes related to our research questions. To establish coding reliability, the interviews of a subset of five randomly selected students (two twelfth graders and three ninth graders) were coded by an additional independent coder. The interrater agreement was 93%. Disagreements were resolved by discussion.

Table 2
Coding Scheme by question for Theme 1 with response examples

Questions	Codes	Response Examples
Q1. What did the data from your laboratory tell you about human evolution? Q2. Do you believe that data from fossil records can provide evidence for ancestral relationships among species?	Only describe data collected from the laboratory.	*"… we measured like the distance between the eyes for the skulls and the length of the canine teeth . . ."*
	Only state a conclusion; do not explain how data provide evidence for the conclusion.	*"… [evolution process is] not a straight line, there are other species [that] branch off, go distinct."*
	Connect data on changes in one trait to a conclusion about evolutionary change.	*"I feel like skulls get bigger because human skull[s] [get] bigger when they are older, like brain sizes."*
	Draw on varied data about how changes across multiple traits support conclusions about evolution over time.	*"As the skulls came to more recent, different data [is] like differ, so as they got more recent, the forehead is a way bigger. They canine gets smaller. All of these is new. … "*

Table 3
Coding Scheme by question for Theme 2 with response examples

Questions	Codes	Response Examples
Q3: How did working on these tasks affect your understanding of the role of scientific evidence in relation to biological knowledge?	Assert that biological knowledge is based on evidence: no elaboration.	*"Evolution is real, there is evidence for that. Biology changes … We have evidence. Based on evidence, we have conclusions and facts."*
	Illustrate how evidence is used to support conclusions with examples from laboratory activity.	*"Working in the laboratory . . . [has helped me to] get in [the] mind of biologists. It helped me to look at and identify different features; like I had my hypothesis, what the order would be, and just working … [on the] laboratory help[ed] me identify what the order actually was by looking at key differences."*
	Discuss uncertainty and limits of evidence and how institutional/communal processes of verification and feedback contribute to the growth of knowledge.	*"A lot of times, they have to take different [pieces of evidence] because in our laboratory, we only have the head; we weren't able to look at the entire body. Scientists should work [with] what they have and what they are given..."*

Key findings

Table 4 shows students' performance interpreting the relationship between evidence and conclusion. Most students are able to use multiple lines of data to support their evidentiary reasoning about the relationship between evidence and their conclusion. The performance of twelfth graders is better than ninth graders. For example, in response to the question, "What did the data from your laboratory tell you about human evolution?" one student said, "*It showed that possibly the diet changed, the size of the canines, was not as large as time goes on... the crests are disappearing as strong as jaws. The size of the brain is increasing means they are increasingly intelligent as well. They can get an idea of how they changed from the beginning to where we are now.*" Students not only looked at the change in physical features but also biogeographical factors such as changes in food sources.

Table 4

Results for theme 1 reflections on the skull evolution laboratory

Theme 1 codes	9th grade	12th grade	Total
Describe one piece of data from the laboratory but do not explain how it provides evidence of evolution.	3(18.8%)	-	3(15%)
Describe a conclusion about evolution such as the branching of new species from a common ancestor but do not explain how the laboratory data provide evidence for the conclusion.	4(25%)	-	4(20%)
Connect data on changes in one trait to a conclusion about evolutionary change.	3(18.8%)	1(25%)	4(20%)
Draw on varied data about how changes across multiple traits support conclusions about evolution over time.	6(37.5%)	3(75%)	9(45%)
Total	16(100%)	4(100%)	20(100%)

Note. Fr. = frequency

However, with regard to our second research question, students had difficulties understanding the role of scientific evidence in developing biological knowledge. For example, Table 5 showed the result indicating that only 15% of students understand the role of uncertainty and boundedness of evidence in the development of knowledge.

Table 5

Results for theme 2 Broader understanding about the role of evidence in science investigation by grade

Theme 2 codes	9th Grade Fr. (%)	12th Grade Fr. (%)	Total Fr. (%)
No answer	1 (6.25%)	-	1 (5%)
Assert that biological knowledge is based on evidence: no elaboration.	9 (56.25%)	2 (50%)	11 (55%)
Illustrate how evidence is used to support conclusions with examples from the laboratory activity.	4 (25%)	1 (25%)	5 (25%)
Discuss uncertainty and limits of evidence and institutional/communal processes of verification and feedback.	2 (12.5%)	1 (25%)	3 (15%)
Total	16 (100%)	4 (100%)	20 (100%)

Note. Fr. = frequency

Directions for future research

The study results suggest that engaging students in authentic inquiry practices grounded in disciplinary knowledge enhances evidentiary reasoning and helps students use multiple lines of evidence to build biological knowledge. Hogan and Maglienti (2001) suggest that using multiple lines of evidence is critical for novice learners working toward scientists. However, many students need help considering the limitations of the evidence. Duncan et al. (2022) argued that science education should prepare students to evaluate the evidence critically in this complex real world. The scaffolded guiding questions could be applied to help students think about the limitations of evidence in future study and practice.

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Computational Thinking Practices at Play in an Early Childhood Microworld

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Abstract: Recently there has been increased interest in exploring computational thinking (CT) concepts and practices in preK-12 teaching and learning. Few studies, however, have explored how CT learning experiences are implemented in play-based early childhood classrooms. The current study explored the design and implementation of a hands-on and play-based microworld in preschool classrooms. Framed in the context of a professional development program with Head Start educators, we designed an activity to engage preschoolers in designing and building mazes for a bristlebot bug to navigate. We collected data in the form of classroom observations, teacher surveys, and interviews. Findings showed that children engaged in CT practices as they collaboratively designed and modified paths for the bug to travel. These findings suggest that microworlds with carefully chosen physical objects may give preschoolers opportunities to develop CT practices while experiencing the benefits of free and collaborative play.

Introduction

Research has suggested that engaging young children in computational thinking (CT) can lead to positive attitudes toward computing and the development of CT skills (Israel et al., 2015). Studies have shown that some of the core concepts of CT such as sequencing, algorithmic thinking, and debugging may provide children unique opportunities to apply their creativity and problem solving skills (Bers et al., 2014; McCormick & Hall, 2022). CT experiences have also been shown to help young learners develop both social and motor skills as well as increase competency in other academic subjects (Hunsaker et. al., 2019).

Studies have focused on identifying the essential elements of CT for teaching and learning within the elementary grades (Yadav, Hong, & Stephenson, 2016), as well as teachers' conceptions of developmentally appropriate CT instruction for young children (Rich, Yadav, & Schwartz, 2019). However, more work is needed to adequately examine the opportunities for CT in play-based early childhood classrooms (McCormick & Hall, 2022). This is especially important, given that efforts to articulate developmentally appropriate practices for learning suggest that young children should "engage in sustained play, investigation, exploration, and interaction with adults and peers" (NAEYC, 2009, p. 18). Play-based learning environments are well-suited to provide opportunities for CT practices such as those outlined by Brennan and Resnick (2012): (1) being incremental and iterative, and (2) testing and debugging. In their recent review, however, McCormick and Hall (2022) found that few studies have examined children's free play with CT tools. Given that many early childhood educational programs view children's play as an essential component of development and learning, more research is needed on children's play-based CT experiences. The present study seeks to understand the potential of play-based CT experiences to support young children's engagement with computational thinking practices.

Theoretical framework

Play-based CT experiences draw on the affordances of play-based learning that offers children opportunities to explore materials, repeat ideas, and follow emergent goals. Vygotsky (1978) proposed that in play, children develop their own rules and norms as they negotiate their actions based on situational constraints, such as limits imposed by physical objects or environments. Play provides opportunities for children to voluntarily engage in activity, encounter constraints, and resolve them in playful and imaginative ways. Guided play (Weisberg et al., 2016), as a middle approach between didactic instruction and free play, suggests that adults can actively and intentionally support children's learning through co-play, questioning, and reflecting with children during play. Guided play centers children's agency and interest in the play experience, while offering teachers opportunities to advance learning goals.

We also draw on interactive constructionist microworlds (Papert, 1980) as contexts for offering children play-based opportunities to develop computational thinking practices. "A microworld, like a playground, is a subset of reality that presents itself with structures carefully chosen to encourage children to encounter a particular set of powerful ideas" (Bers, 2020, p. 34). We see potential for microworlds with physical objects to align with play-based early childhood environments as they allow children to explore freely, follow emergent goals, test and repeat their ideas, and problem solve.

Methods

This study is part of a larger professional development (PD) project that introduced preschool educators to play-based activities to support their own developing understanding of CT. In turn, educators then implemented and adapted these activities in their Head Start classrooms with preschoolers (ages 3-5). For this study, we explored how one of the activities—a designed microworld—engaged preschoolers in two CT practices proposed by Brennan and Resnick (2012): (1) being incremental and iterative, and (2) testing and debugging. In this paper, we describe the design and implementation of the microworld and report initial findings from our implementation.

Setting, participants, and professional development

A total of 26 Head Start preschool teachers and teacher-assistants participated in the PD project. These educators teach a total of 131 preschoolers in eight classrooms, each classroom having between two to four teachers.

We organized the PD into five modules, with each module spanning one month of the calendar year and focusing on a different theme: patterns, spatial communication (including directional language), movement, board games, and programming robots. Each module included a two-hour PD session, follow-up classroom coaching, and activities for classroom and home use. In each module, teachers and children were encouraged to use natural, intuitive, and play-based ways to explore ideas.

The microworld activity described in this study was nested in the robots module and was centered around a bristlebot bug. The bristlebot is a simple robot that uses a vibrating motor and rubber bristles to move around in a bug-like manner and is confined to the environment in which it travels. The microworld environment for the bug is created as a maze with various construction materials such as blocks, DUPLO bricks, cardboard tubes, clear tubes, and other found objects. Teachers first explored the microworld and bristlebot bug during the two-hour PD session before implementing the activity in their classrooms. Throughout the month, teachers encouraged children to explore the bristlebot bug and use the construction materials to create a maze for their bug (See Figure 1). Children programmed the bug by designing physical constraints; as children modified the constraints, the bug's movement changed.

Figure 1
Opportunities for Constructive Exploration within the Bristlebot Bug Microworld

Data sources and analysis

We collected data in the form of written PD reflections from teachers, notes from classroom observations, photos and videos of children's activity, and teacher interviews. We used interpretivist methods to understand how teachers and children engaged in CT practices when exploring the microworld. We then used thematic analysis to code and categorize children's activity.

Findings

Our findings are organized around children's use of CT practices when exploring the microworld, including how they playfully engaged with the bug and the environmental materials. We also describe what teachers noticed about children's activity and their own facilitation through the lens of one participating teacher's observations.

As children were introduced to the bristlebot bug, they quickly became acquainted with the bug's movement. When holding the bug in their hands, children were delighted with the quirky and unpredictable movement. When placed on the table or the floor, the bug quickly moved in random directions, with children often trying to corral the bug with their hands. The other materials available to children, such as wooden blocks, were then introduced by teachers as potential environmental constraints or boundaries that could guide the bug's movement (See Figure 2).

Figure 2
Physical Materials Provide Movement Constraints

In creating their mazes, children engaged in *incremental and iterative* activity as they began to assemble materials to guide the bug (Table 1). They found that certain materials were helpful in moving the bug in a straight direction forward, while other combinations of materials allowed for right or left turns. In one instance, a group of four children connected tubes sequentially to provide a long path for the bug. In doing so, they explored the potential of narrow paths to guide movement toward a desired location. Wider spaces, in contrast, allowed for random movement and turn-arounds (this type of movement seemed more "buglike" and delightful to children). During their play, children engaged in spatial communication and dialogue as they explored what materials to use to accomplish their goal. Teachers noticed that children incrementally tried things out based on their ideas, then adapted their constructions based on their experiences. Teachers also encouraged children to attend to the physical resources in their planning, such as suggesting that children make the bug travel according to the directional arrows marked in the half-tube shown in the lower right corner of Figure 2.

Table 1
Correlation of Bristlebot Bug Microworld to CT practices (Brennan & Resnick, 2012)

CT Practices	Evidence from Children's Activity	Evidence from Teacher Interviews
being incremental and iterative	Children designed mazes for bugs in parts, adding sections onto existing structures and adapting existing mazes based on evidence from prior mazes	"I just put the materials out, and I just left them there… and said, 'How are we going to do this?' you know, instead of constructing it for them…and they were like, 'Well, we could do this, and we could,' it was like, it just stimulated their brain to figure it out." "Um the children also, too, they would always bring in different supplies, 'Well, let's try this,' you know, 'well let's try that,' um, so they have their own ideas, and brought in their own ideas and experiences, too."
testing and debugging	Children tested how various materials affected the bug's movement and fixed existing problems; for example, when the bug's path was interrupted between tubes, children used painter's tape to connect tubes	"They will set up like, different toys, put it around there, and just put the bugs, the hex bugs, and see if they are going through, or are they going into the tube, or they can't escape from the table when they put a toy blocking it like a maze." "A little girl came up and said, 'We can do races with those tunnels, with the bugs,' you know, and so that was interesting. She came up with that, 'so we could make a maze on top of the tunnel, and, um, we can see if the bugs can go through.'"

A second CT practice observed was *testing and debugging*. This practice was evidenced when children were pursuing particular goals and their constructions did not work exactly as intended. For example, when children wanted to see how far they could make the bug travel, they arranged a path with materials, released the bug to travel the path, collected the bug, rearranged or modified the path, then rereleased the bug. Other small groups of children worked through trial and error efforts as they created races with other bugs.

Discussion and implications

Our findings suggest that the designed microworld engaged young children in computational thinking practices as they programmed their bug through the physical construction of a microworld maze. In contrast to CT robotic experiences which require a programmer to direct a robot by telling it how to move, the bristlebot bug microworld required children to introduce environmental constraints. We suggest that the microworld served as a rich playground for the merging of computational thinking practices with play-based learning affordances; for example, our findings showed numerous instances of children's playful repetition as a catalyst for *incremental and iterative* maze construction. In addition, children's pursuit of emergent goals led to cycles of *testing and debugging*. For teachers, the microworld provided opportunities to engage with children during play in ways that supported children's iterative processes and constructions.

One particular line of research worth pursuing further involves the careful selection of physical materials within the microworld. Because the bug microworld engaged children in hands-on play with physical materials only, we are interested in examining the role of these materials themselves as action-oriented substructures. Rather than using symbolic features such as arrows to communicate commands, the physical materials themselves became associated with actions: the clear or cardboard tubes caused straight and efficient movement; "L" shaped constructions made from DUPLO blocks caused turns; "U" shaped corrals constrained the bug but allowed for exit; square shaped configurations constrained the bug indefinitely. As such, the physical materials of this particular microworld show promise in serving as intermediary bridges between the physical and symbolic. Other materials may provide for additional variations to maze construction, such as inclines and declines.

Our future work will continue to examine the designed features of this microworld, as well as others, to help us further understand the opportunities young learners have to engage in CT practices in play-based learning settings.

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Using Social Network Analysis to Evaluate the Functioning of a Class With Multiple Collaborating Groups

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Abstract: This study uses Social Network Analysis (SNA) to evaluate the Communities of Practice (CoPs) formed around a multidisciplinary graduate course in which students work in small teams to complete a class project. Each team has an assigned subtask for the larger project. Students must collaborate within teams to produce their designated component and coordinate across teams to integrate the larger project. Coordination and communication within and across teams were done through the Slack platform. We analyzed messages sent on Slack via SNA, allowing us to evaluate the class participation, communication, and interaction. In this analysis, we identified the three types of group-group interactions described by CoP theory: overlaps, boundary practices, and peripheral connections. We also used the message dates to analyze how group-group interactions and communication changed throughout the course. Researchers can use this methodology to analyze and evaluate courses with multiple collaborating groups and instructors to monitor and improve their classes.

Introduction

In order to pursue a successful STEM career, it is necessary to develop not just technical skills but organizational skills such as collaboration and communication (World Economic Forum, 2017). However, gaps persist between industry expectations and students' skills upon graduation, leading recent graduates to experience frustration, nervousness, and anxiety when entering the professional world (Kolmos & Holgaard, 2019).

In response to this need, we analyzed an existing STEM course: Design of a Robotic Computer Vision System for Autonomous Navigation (RCAN). In contrast to many courses, this one is designed to emulate a professional environment. Students in this course work in teams to develop subcomponents of a larger robotic platform. The students must collaborate within their team on their assigned task and coordinate across teams to integrate the larger project. Social network analysis (SNA) offers a suitable methodology to evaluate intra- and inter-group collaboration and it has been applied successfully to assess interaction and participation within CoP or highly collaborative environments (e.g., Williams et al., 2013; Ma et al., 2019)l; among educational researchers (e.g., Queupli & Muñez-García, 2018); and in teaching-focused communities (Ma et al., 2019), among others. In the present context, the students communicated using the Slack platform which offers a natural medium for our analysis. Our work is grounded in the CoP theory and uses SNA methodology for our analysis.

Background

Theoretical framework: CoP theory

Wenger developed the idea of a community of practice as a group of people who share purposes and methods, which emerge from the needs of a context, with the negotiation of shared meaning and forms of participation, including tools, symbols, concepts, procedures, criteria, etc. (Lave & Wenger, 1991; Wenger, 1998). The CoP framework has been successfully applied in different settings including cross-institution communities (e.g., Kirkman et al., 2013) and informal educational contexts (e.g., Kim et al., 2020). However, few studies have used this theoretical framework to develop or research experiences in a classroom context in part because there are limited strategies for evaluating the practical impact or group structure (McKellar et al., 2011; Díaz et al., 2022a), and existing methods rely on qualitative methods and are extremely time-consuming.

Social Network Analysis (SNA)

Social network analysis is a quantitative analytical technique commonly used in education to analyze and visualize communication networks or group environments (Cela et al., 2015). SNA allows us to capture the interaction, communication, and support that occurs within and across teams by representing the communication structures as graphs where individuals or groups are represented as nodes and the edges between them represent communicative acts, exchanges, or other implicit or explicit social relations. A literature review of SNA in higher education noted that: “We need to study and test the roles of committees and other meaningful subgroups” (Kezar, 2014, p.112).

Answering that call, our research examines the following research questions using the data from the RCAN course:

1. How did students communicate within and across groups?
2. How did the class communication patterns change during the semester?

Methods

Context and setting

The course was taught in the Spring 2017 semester at a large public research university in the Southeastern USA. Twenty-six students were assigned to seven teams by the instructor based on their preferencesEach team was charged with developing one subcomponent of the robot. The SLAM teams were devoted to machine vision, and included the two monocular vision teams SLAM-A and SLAM-B and the stereo vision team SLAM-S. CTX teams focused on context awareness to facilitate navigation. The HARDW team was responsible for the robotic parts, sensor control, and computer integration, and the CONTROL team was responsible for the path planning and navigation of the robot.

Data sources

Students in the course were required to communicate primarily through Slack. At the beginning of the course, the instructor created eleven default channels: seven single-team channels; one channel for the entire class (GENERAL); one for team leaders (TEAMLEADER); one to facilitate the communication among the SLAM teams (SLAM-OVERVIEW), and one between the CTX teams (CONTEXT AWARENESS). Direct messages were discouraged by the instructor and students were guided to use the public channels as much as possible.

Data analysis

We downloaded all of the public messages as transcripts in JavaScript Object Notation (JSON) format using object literals of JavaScript. The downloaded messages record all of the information within a server, including when they were sent, who sent them, what channel they were sent to, and whether the messages were the start of a conversation or a reply. Using a combination of Neo4j (https://neo4j.com/product/bloom/), Cypher (openCypher, 2017), and Python we can create complex queries for the database and extract knowledge about how team members communicated. We generated descriptive statistics for the messages sent by each student within their group and to other groups. We generated graphs showing the social network using Gephi (https://gephi.org/).

Results and discussion

How did students communicate within and across groups? (RQ1)

Students sent a total of 5,969 messages. 72% of the messages (4,269) were exchanged within team channels, and 28% across teams. This suggests that tasks involving internal teamwork - setting up the team's designated subcomponent - required more frequent discussion and likely more effort than cross-team coordination tasks.

The teams that had the most frequent internal communication were SLAM-B (1,350 messages) and SLAM-S (914 messages). By contrast, the HARDW team had the fewest messages both within and outside their team; this finding aligned well with observations by the instructor and interviews with class participants (reported elsewhere) that the team was isolated and not very responsive to other groups.

To shed light on cross-team interaction, we generated network graphs with each team channel as a node and cross-team messages as directed arcs with direction indicating the sender and recipient of the messages (Fig. 1b). To facilitate interpretation we only show connections with five or more messages. The thickness of the arcs is proportional to the number of messages sent. Purple outlines show areas of greatest interaction across teams.

The strongest connections were between teams with similar tasks and who used similar instruments: the CTX cluster at the top and the SLAM cluster at the bottom left. The CTX cluster includes the single-team channels CTX-A and CTX-B and the ContextAwareness channel. The SLAM cluster includes SLAM-A, SLAM-B, SLAM-S, and the instructor-created channel for communications coordinating these three groups, SLAM-OVERVIEW.

Consistent with CoP, we identified the connections within the CTX cluster and within the SLAM cluster as "overlap" connections, which are generated when teams share similar objects, challenges, and procedures within their communities. The SLAM teams, for example, are jointly in charge of designing and implementing the robot's vision system. They have common goals and tools but also some differences, e.g., lasers vs. cameras for object detection. When designing a course with intra- and inter-group cooperation, having similar learning objectives and common tools across teams will ease coordination.

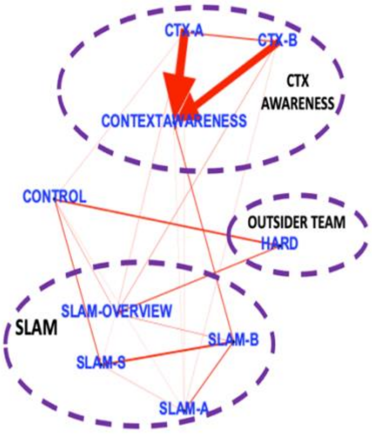
Figure 1

(a) Distribution of Messages Sent by Teams During the First and Second Part of the Class and (b) SNA of Connections Across Teams, Showing Areas of Greatest Interaction

	Part 1				Part 2			
TEAM	Within	Across	Ratio*	Total	Within	Across	Ratio*	Total
CONTROL	302	80	3.78	382	171	201	0.85	372
SLAM-A	103	34	3.03	137	69	152	0.45	221
CTX-A	158	133	1.19	291	219	218	1	437
SLAM-B	502	111	4.52	613	848	172	4.93	1,020
HARD	317	45	7.04	362	178	80	2.23	258
CTX-B	120	94	1.28	214	368	151	2.44	519
SLAM-S	420	95	4.42	515	494	134	3.69	628
TOTAL	1,922	592	3.25	2,514	2,347	1,108	2.12	3,455

*Ratio was calculated as Within/Across messages.

(a)



(b)

The arcs *across* the SLAM and CTX clusters reflects "boundary practice" connections. This type of connection is established between communities engaged in different but connected activities. The CONTROL team has a peripheral connection with the CTX and SLAM teams. Connections of this type develop when the CoPs increase the permeability of their groups to allow a selective exchange of information. From the teacher's perspective, these results were expected and aligned with the tasks developed in the CONTROL team.

Finally, our network diagram shows that the HARDW team was an "outsider", with comparatively low participation and communication. The class was not designed to have an outsider group, so this represents a challenge for the project and instruction. Recognizing outsider teams with a practical methodology like SNA on Slack data will allow teachers to design timely interventions fostering greater participation by students and teams.

How did the class communication patterns change during the semester? (RQ2)

For this analysis, we divided the messages into two sections. The first section was from the start of the class to the first trial of the integrated robot, during Week fifteen of class, and the second was from after demo 1 to the end of the class. Figure 1 a) shows the distribution of messages by team sent within each section.

More messages were exchanged in the second half of the course than in the first (3,455 vs 2,514). In both halves of the course, intra-team communication was more frequent than inter-team communication, but the proportions varied. In the first part, 76% of messages were within a single team, and in the second part, 68%. These results were expected since, at the beginning of the semester, the students were primarily working to solve challenges as teams. As the course progressed, however, integration of the components became an essential task.

Interestingly, the participation patterns of the teams were broadly similar in the two periods analyzed. The teams that exchanged a greater number of messages in the first half of the course were the same ones that had a greater exchange of messages in the second half. One major difference between sections of the course was that the communication was more diverse and evenly distributed in the second half. If SNA analyses had been conducted while the course was being taught, it would have provided valuable diagnostic information to the instructor. For example, the instructor could have intervened to elicit greater integration with the HARDW group.

Conclusions

To prepare students for a professional career, we must improve their preparation in communication and collaboration. To that end, we designed and implemented a course requiring intra- and inter-group collaboration course. The scarcity of tools available for the practical, real-time evaluation of CoP functioning led us to use the quantitative tool of SNA based on Slack messages. Applying CoP as a lens to interpret the results of the SNA allowed us to understand what kind of connections were developed between the teams and how the course functioned in general. Separating the data by date also allowed us to analyze whether and how the communication patterns changed across the semester. Our research introduces a general methodology which can be used by instructors to evaluate their class communication; diagnose specific issues such as isolated teams or uncommunicative individuals; and assess the fit to formal theories of team organization such as CoP. This in turn can support better classroom practices and timely interventions to allow the participation of all students and the appropriate development of collaborative skills. Finally, knowing the patterns of participation of the teams within the class will allow the instructor to design new or modified tasks for each team that allows generating team inter-dependency, supporting equitable participation for all.

Limitations and future work

The primary limitation of this work is that it takes place within a single course and was not evaluated across multiple classes. An additional limitation is that we were not able to capture the in-person interactions that took place in the classroom. While the classes were of fixed duration and were focused on seminars not team communication it is possible that some relevant communications were missed. We are researching subsequent iterations of this course, as well as other graduate engineering courses, in order to generalize our findings.

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Designing for and Characterizing Critical Navigation of Disciplinary Values in an Undergraduate Computational Biology Course

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Abstract: We describe a process of designing for equity-oriented learning outcomes in an undergraduate computational biology course. Our focus is designing for critical navigation of disciplinary values. We build on prior work that has articulated how mismatches between students' identities and disciplinary values create barriers to full participation. We describe how in our work our orientation towards equity evolved to include how navigating disciplinary values could not only support students in envisioning themselves as part of the discipline but could also function to allow students to consider the processes through which disciplinary values change, including the possibility of their own participation in resisting established disciplinary ideas and norms. We use conjecture mapping to trace the emergence of a conjecture related to critical disciplinary navigation and analyze students' responses for evidence of how they identified and navigated disciplinary values in one focal assignment.

"I hope one day I can [be] someone who can share and show the power people of all walks of life have in science. In the paper, I thought it was really interesting how they discussed the potential evolutionary basis of the heteronormative and patriarchal Euro-American cultural norm and how this is viewed as the natural order which I think brings out more questions and shows some biases."

Introduction

In this quote, from a response to a "spotlight" assignment in an undergraduate computational biology course, a student describes how cultural norms shape knowledge construction in a disciplinary community. The student references the work of Monk and colleagues (2019) who argue that the long-standing assumption that different-sex sexual behavior, as opposed to same-sex sexual behavior, is the ancestral condition for animals is rooted in heteronormative and patriarchal Euro-American cultural norms. The student uses this example to illustrate "the power people of all walks of life have in science" and position themselves as hoping to contribute to such efforts.

The inclusion of spotlight assignments was part of an effort to design an undergraduate computational biology course to support learning outcomes that would enhance equity in students' learning and participation. In prior work, spotlight assignments have been used to counter stereotypes and to support students from marginalized groups to see themselves as possible participants in scientific fields (Schinske et al., 2016). In this paper, we describe how some of these assignments, which we call *resistance* spotlight assignments, functioned to support the process of critical disciplinary values navigation. We describe how this mediating process emerged from equity-oriented conjecture mapping. We then present an analysis of students' responses for evidence of how they identified and navigated disciplinary values in one focal resistance assignment to address the research question: *What are the ways in which a resistance spotlight assignment mediated students' critical navigation of disciplinary values?*

Theoretical framework

Disciplinary learning can be understood as a process of becoming enculturated into a community of practice (Lave & Wenger 1991). In STEM disciplines, the process of gaining entry into these communities has not been equitable (e.g., Garrison, 2013). Students belonging to minoritized groups continue to experience barriers to participation in STEM learning spaces and ultimately in STEM careers. One barrier to equitable and full participation centers on interactions between students' identities and values and what they perceive to be valued in legitimate disciplinary participation (Margolis, J. & Fisher, 2002; Nasir, 2012; Vakil, 2020). Whether or not they are made explicit, disciplinary communities are governed by sets of values that specify the conditions for successful entry and participation. Disciplinary values describe the sanctioned disciplinary practices (e.g., use of computational tools,), forms of participation (e.g., authorship in peer-reviewed publications, podcasts), ideas (e.g., objectivity, complex systems theory), and relationships between the discipline and society (e.g., the use of technology for social good). A perceived mismatch between students' and disciplinary values can position students as outsiders and discourage them from disciplinary pursuits (Vakil, 2020). Even for those students who do persist, disciplinary values may function to put constraints on both participation and identity (e.g., McGee & Martin, 2011).

In considering how to design a course that can engage undergraduates in critical navigations of disciplinary values we build on Vakil's (2020) idea of *disciplinary values interpretation*—a process by which students reflect on the values of a disciplinary domain, as well as who they are and might become in that domain. Vakil's analysis featured students' sense-making about the dynamics of how disciplinary values are negotiated and shaped in disciplinary communities and students' identification with available roles in those communities. We use the term *critical disciplinary values navigation* to extend from this work and emphasize designing for disciplinary learning that allows students to not only gain entry to participation in disciplinary communities *as they are*, but also affords them with the agency to *reshape disciplinary values and participation* towards equity and justice (Calabrese Barton & Tan, 2020).

College students are at a critical juncture in their learning as they are preparing to transition from classroom learning to learning in disciplinary spaces, academic or otherwise. For these students the need to anticipate and prepare to navigate their own participation in disciplinary communities is critical.

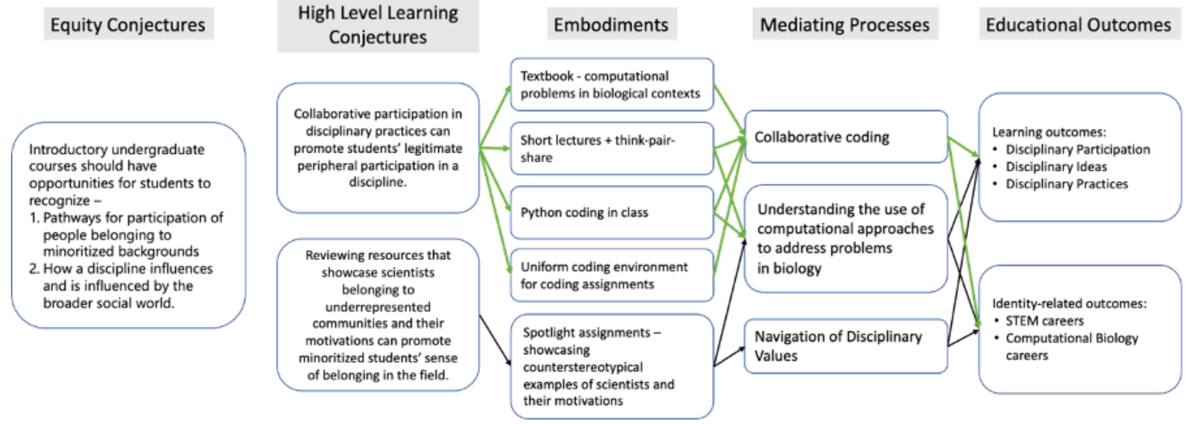
Research context and methodology

The CompBio (pseudonym) course was designed and taught by Author 3 in the Fall of 2021 at a university in the United States. Reported demographics at the university is 46% non-male and 47% non-white students. Less than one-third of students responded to demographic survey which makes it impossible to report on the course participants demographics. However, field observations indicate that the course demographics were roughly similar to university demographics. A significant aspect of the course design was a series of twelve required "spotlight" assignments that featured the computational research of diverse scientists, as well as those scientists' experiences with racism and sexism, and ethical dilemmas in the academy. For each assignment, students reviewed academic papers, interviews, podcasts, or other materials and wrote an open-ended one-page reflection on these materials. In this paper, we focus on a resistance spotlight assignment that featured the work of evolutionary biologist and ecologist Dr. Amika Kamath (Spotlight AK). Students read the research article, 'An alternative hypothesis for the evolution of same-sex sexual behavior in animals', co-authored by Monk, Kamath, and others (2019), and listened to a podcast in which Kamath recounts her experience as a woman and feminist scholar in the field of ecology and evolutionary biology. Kamath describes how she drew on her training as a biologist and feminist to challenge established ideas about animal behavior rooted in patriarchal logics. The prompt asked students to write about what they found interesting, what they learned about the subject matter, or insights into the motivations of people that do computational biology.

Equity conjecture mapping

Author 1 and Author 2 designed an equity conjecture mapping interview protocol (Lee et al., 2022) to interview the course instructor (Author 3) and constructed a conjecture map (Sandoval, 2014). The interview included questions about expected course outcomes and how the instructor expected design choices, related to curriculum and tasks, participant structures and classroom interactions, would produce those outcomes. The instructor was interviewed twice to capture his evolving understandings of the course design and outcomes. We coded interview responses and organized them into an equity-oriented conjecture map (Figure 1).

Figure 1
Conjecture map of the CompBio course.



An initial conjecture map based on the instructor's interview revealed two paths intended to support equitable participation in computational biology: 1) Learning to use computational approaches to solve problems in biological contexts (Figure 1, Green arrows), and 2) Learning about practices and participation of scientists from underrepresented communities(Figure 1, Black arrows). In this paper we focus on Path 2, which uses spotlight assignments to support students' disciplinary values navigation, a process that we conjecture can ultimately impact outcomes related to both learning how to participate in the discipline and identity development. The initial high-level learning conjecture for this path was inspired by claims by Schinske and colleagues (2016) that spotlight assignments can counter disciplinary stereotypes. The path was revised to include the instructor's intention to include examples of resistance work by scientists that could stimulate interest in the field, particularly for students from marginalized groups. The instructor's revised design conjecture can be stated as, showcasing examples of scientists belonging to underrepresented communities who challenge the norms of the field would lead to students' critical navigation of disciplinary values.

Critical disciplinary values navigation in student responses

We (Authors 1 and 2) used a combination of deductive and inductive coding (Miles et al., 2018) to analyze the written responses to spotlight assignments for consented students (n = 24). Using a deductive coding approach, we first coded all the responses for six categories: Connections to Prior Lived Experiences, Personal Participation, Disciplinary Sense-making, Disciplinary Practices, Disciplinary Values, Critical Considerations of Power and Privilege. This first round of coding allowed us to identify disciplinary values and their co-occurrence with other themes.

We further inductively coded identified parts (n = 56) in students' written responses that were about disciplinary values. For this second round of coding, we generated five categories of themes that corresponded to disciplinary values in student responses. These categories were: Objectivity and Bias Avoidance, Diversity, Resistance to disciplinary ideas, Resistance to cultural norms, and Social Implications. Seven instances in student responses did not fall into any of these themes. The combination of deductive and inductive coding was instrumental in the development of themes. For example, *critical* navigation of disciplinary values emerged from co-occurrences of Disciplinary Values and Critical Considerations of Power and Privilege.

Findings

We analyzed student responses to Spotlight AK. All the student responses to the assignment were coded positive for *disciplinary values* by both coders. This means that all the students who submitted their written responses engaged with navigation of disciplinary values to some extent. We present two examples of *critical* disciplinary values navigation (critical DVN), which we operationalized as students' reflections on values of a disciplinary domain that considered dynamicity of disciplinary participation (changes in who gets to participate and how) from an equity and justice perspective.

Valuing resistance to social norms to strengthen objectivity

The following response is an example of a student navigating how 'objectivity' and 'resistance to social norms' were perceived as disciplinary values in connection with Dr. Kamath's work.

> *"By presenting a shifted lens through which to explain the prevalence and patterns of SSB [same-sex sexual behavior] and DSB [different-sex sexual behavior], Kamath shows how science can be improved when its practitioners try to question dominant social norms and their effects on previous scientific research and theory. The same principle is clear in her talk: how people interpret the world cannot be fully 'objective' but is influenced by their different identities and places in it. Realizing this is good for both science and society."*

In this quote, the student is claiming that both objectivity in science and impacts on society can be improved when scientists actively question the role of social norms in upholding disciplinary knowledge claims.

Valuing diverse perspectives to remove bias

In the response below we see a student articulating the value of diverse perspectives in science.

> *"The first step [in removing bias] is including a diverse range of people in the science community, because as Ambika Kamath mentioned in the podcast, people will approach topics differently based on their prior experiences. To acquire the most accurate and diverse bank of scientific knowledge, it is crucial to have researchers with different backgrounds included, as everyone will bring a different viewpoint to the table."*

In this quote, the student is recognizing how diverse backgrounds bring diverse perspectives that ultimately improve science by removing bias.

Discussion

One possible function of design features such as spotlight assignments is to showcase the works of people belonging to underrepresented groups with the aim of helping students from minoritized populations “see themselves” as possible participants in the discipline (Schinske et al., 2016). In our work, this initial conjecture was revised and expanded to include cases of how practitioners of the field can engage in resistance work. Challenging ideas and practices rooted in patriarchal, heteronormative, Eurocentric logics is an important part of rightful participation in the discipline (Calabrese Barton & Tan, 2020). We have called this process *critical disciplinary values navigation*.

Our findings from the analysis of student responses the Spotlight AK support the design conjecture that this assignment supported students’ critical DVN and contributed to emerging justice-oriented understandings of disciplinary participation. Students interpreted disciplinary values, such as objectivity, and also navigated understandings of how those values are enacted in disciplinary practice. Students’ critical DVN included identifying where a problem is located related to a value (e.g., objectivity is difficult to achieve) and how it can be addressed by another disciplinary value such as resistance to cultural norms, or inclusion of diverse perspectives.

Overall, we argue that the opportunity to review works of scholars belonging to underrepresented groups that challenge established ideas and unjust social norms (Resistance Spotlights) can provide new resources for critical DVN that can ultimately have significant implications for how students view their participation and their possible futures within the discipline of computational biology. This process entails grappling with questions such as: *How have disciplinary values been shaped by cultural/historical processes? Which values are up for negotiation? By what processes can disciplinary values change? What are the implications of different disciplinary values for participation, knowledge building, and societal impact? What might be my role/responsibility in shaping disciplinary values?* This research contributes to questions about supporting identity development and challenging inequity in education and has implications for ethical theories of learning.

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Probabilistic Motivation Profiles and Student Behaviors in Log Data

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Abstract: Motivation is a multi-faceted construct that has complex relationships with behavior. To better understand student motivations in a large introductory statistics course, we cluster different aspects of student motivation and investigate their link to observed student engagement in an online textbook. A soft clustering method reveals three distinct motivation profiles in students: reluctant, motivated, and confident. Membership in the confident group is associated with GPA and financial difficulties, but not with engagement metrics that reflect student choice, such as time spent. Contrary to the simple hypothesis that better motivation will lead to higher engagement, students with "reluctant" and "motivated" profiles seem to spend similar amounts of efforts for course preparation but spend less of it progressing with learning, and more time struggling.

Introduction

Numerous theories link learner motivation to engagement, a precursor to successful learning (e.g. Elliot & Harackiewicz 1994; Ryan & Deci 2000). While studies have utilized self-reports to empirically establish the link between motivation and adaptive student behavior (e.g., Hendy, Schorschinsky & Wade, 2014), self-reports can be biased and may be prone to recall error, particularly when probing low-level behaviors. Thus, an alternative method of inquiry for computer-assisted learning environments has been to take advantage of the digital log traces that occur with student activities (e.g. clickstream) to track their behavior (e.g., Xu & Yang, 2016; Schoor & Bannert, 2011).

The current study adopts this approach to study a context where motivation is expected to vary, and is crucial for success: a large introductory statistics course where college students engage with an online textbook in a self-directed manner. Motivation is operationalized using the expectancy-value theory of motivation (Eccles et al., 1983), which has been previously successfully applied in the context of learning analytics for the goal of finding student profiles, in studies such as Schumacher & Ifenthaler (2018) as well as Templaar and colleagues (2018).

Two methodological considerations are made in response to calls for change in associated fields: the use of a person-centered approach in motivation profiles, and the use of engagement metrics that go beyond click counts. The use of a person-centered approach in estimating student motivation have been increasingly endorsed by researchers as a way of allowing how patterns of variables related to motivation have an intricate relationship with one another at the level of the individual (Linnenbrink-Garcia & Barger, 2014). The use of more sophisticated log data metrics that measure engagement and student learning behavior in ways other than summative count has been raised time and again, such as in Knight & Shum (2017), Lodge and Lewis (2012), and Fincham and colleagues (2019).

With such considerations in mind, we hope to answer the following research questions:

1. What types of distinct student motivation profiles exist in an introductory statistics course?
2. Are the probabilities of belonging to a certain motivational profile impacted by student factors, namely gender, race, GPA, and economic hardship?
3. Do the ways in which students engage with course material differ by motivational profile?

Setting and data

Log data was collected from an online textbook used in a large introductory statistics class in a U.S. research university with a highly competitive undergraduate program. The online textbook was a central component in the course. Students learned the material by working through assigned chapters in the textbook every week before coming to lectures. The log data includes all student interactions with textbook elements, such as reading material, graphics, videos, R coding exercises, and formative assessment questions. Our data comes from 166 students who filled out the pre -course survey, and did not drop out of the course.

The survey data used to create motivational profiles comes from the pre-course survey. The survey contained various demographic questions, as well as a combination of validated measures for the estimation of expectancy, value, and cost from two instruments (Kosovich, et al., 2015; Gaspard et al., 2017). To create a more holistic, person-centered motivational profile, we utilize additional survey questions relevant to discriminating different student motivations for taking a statistics course: the level of self-reported prior experience in statistics, and the level of self-reported intent to persist in statistics learning.

Methodology

Motivational profiles were created by combining confirmatory factor analysis (CFA) with gaussian mixture modeling (GMM). First, confirmatory factor analysis was applied to the previously described survey items to create composite scores. Five factors were created: expectancy, value, cost, prior experience, and intent (to persist in statistics). Model fit indices largely indicated that the CFA had acceptable fit (χ^2=539.481, $p < 0.001$; CFI = 0.830, RMSEA = 0.084, SRMR = 0.077). Then, the resulting factors were normalized and used to create GMM-based student motivation clusters. GMM is a “soft” clustering method, i.e., a probabilistic model that assigns a student a probability of belonging to a certain cluster. Compared to “hard” clustering methods such as k-means clustering, it provides a better theoretical fit in cases where students do not belong to clearly discrete groups. A three-cluster model was chosen based on elbow graphs of fit statistics (AIC, BIC).

Parallelly, the following week-level metrics were created from the log data to understand student behaviors expected to co-vary with motivation: time spent, ratio of questions that the student ultimately did not get correct despite unlimited tries, ratio of questions never attempted, ratio of attempts correct to total attempts, and ratio of time spent on the due date (i.e. cramming) to total time. These metrics attempt to measure not only the amount of effort or engagement the student put forth in a particular week, but also the way in which this time was spent: was a student’s time on the textbook spent fruitfully progressing through the material, or spent making wrong attempts, or rushing to finish work? That is, might student motivation profiles be related to not only the amount of effort, but also the ways in which this effort is expended?

While three distinct clusters are described, subsequent analysis uses a binary variable for membership in the most advantageous cluster, termed the “confident” group (described further in the next section). This is to account for strong class imbalance – the smallest cluster, while mathematically and theoretically distinct, was approximately 1/10 of the size of the “confident” group. Two types of analysis are performed on this binary profile. First, we test whether different student factors, namely race, gender, GPA, and economic hardship, are associated with “confident” group membership. Then, behavioral metrics are connected to this binary variable using linear mixed models (LMM), a generalization of linear regression that allows modeling of random effects of correlated clusters (Byrk & Raudenbush, 1987). Since we have multiple datapoints from each student, and multiple datapoints from each week, LMMs allow us to explicitly model these effects for a less biased estimate of main effect sizes. Lastly, given the importance of prior academic history in determining motivation and student behavior, we introduce prior GPA (a binary variable, 3.5- and 3.5+) as a control variable in LMM analysis. Identical models without the control variable showed the same trends.

Results

RQ1. Student profiles in an introductory statistics course

Our first research question asked whether there are distinct motivation profiles in this introductory statistics course. The results of cluster analysis showed the emergence of three distinct clusters. Based on the inspection of variable distributions, we respectively term them the “reluctant”, “motivated” and “confident” groups. As seen in figure 1, the reluctant group is characterized by a low level of intent to persist in statistics, low expectancy for success, and low value for the course, despite having some prior related experience. The motivated group stands out most for their lack of prior experience, yet they expect to do better than the reluctant group and value the class more, as well as having a higher intent. Lastly, the confident group has the highest intent, level of prior experience, expectancy, and value. The reluctant group includes 12 students, while the motivated and confident groups each consist of 59 and 95 students.

Figure 1

Factor distribution for reluctant, motivated, confident clusters

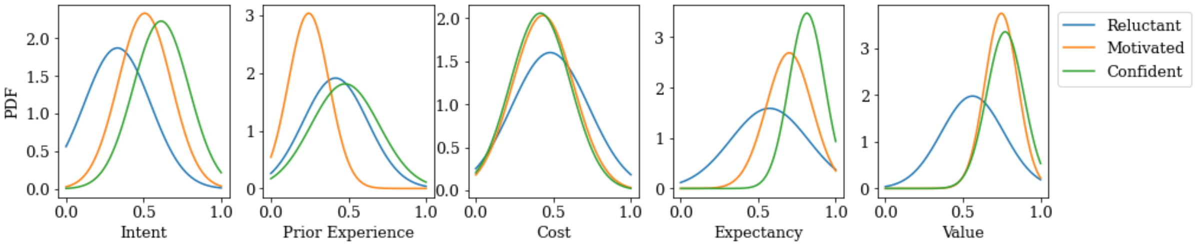

Table 1

Factor means for reluctant, motivated, confident clusters

	Intent	Prior experience	Cost	Expectancy	Value
Reluctant	0.33	0.42	0.48	0.57	0.56
Motivated	0.51	0.24	0.43	0.70	0.75
Confident	0.61	0.48	0.42	0.81	0.77

RQ2. Student factors influencing probabilities of profile membership

Next, turning to our second research question, results of contingency analysis showed that group membership is not statistically significantly associated with either student gender or race; however, they were significantly associated with prior GPA (less or more than 3.5; $\chi^2(1) = 8.039, p = 0.004$) and economic hardship (level of economic hardship reported: high, medium, low, none; $\chi^2(3) = 9.527, p = 0.023$). In the contingency table below (table 2), actual counts are accompanied by expected values in parenthesis. The table indicates that lower GPA students, and students with high- and medium-levels of financial difficulty tend to belong less than chance to the confident group.

Table 2

Contingency table between student factors and motivation clusters.

	GPA		Economic Hardship			
	3.5-	3.5+	High	Medium	Low	None
Confident group	**32 (44)**	132 (125)	**13 (18)**	**46 (51)**	56 (44)	60 (61)
Other groups	52 (40)	104 (116)	22 (17)	52 (47)	31 (42)	59 (58)

* Number in cells indicate observed count (expected count)

RQ3. Connection between student motivation profiles and learning behavior

The LMM regression results showed somewhat surprising results. Many metrics did *not* have a statistically significant association with “confident” group membership. The time spent on the textbook, the ratio of questions never attempted, and ratio of time spent cramming all had statistically nonsignificant associations. However, the ratio of correct attempts to total attempts, and the ratio of questions given up differed between the confident group and other groups. Table 3 summarizes the LMM regression results for these two metrics for which there were significant results. Belonging to the “confident” group was on average associated with a 5-percentage point increase in the ratio of correct attempts, and a 7-percentage point decrease on the ratio of questions never answered correctly, or given up, even after controlling for student GPA.

Table 3

Results of LMM regression analyses

	M1: Ratio of correct attempts	M2: Ratio of questions given up
Belonging in “Confident” group	.05 *** (3.544)	-.07 *** (-4.212)
GPA less than 3.5	-.07 *** (-4.60)	.11 *** (5.728)

*** $p < 0.001$; Satterthwaite approximations used for calculation of t-statistics (in parentheses)

Discussions and conclusion

Our results reveal three distinct profiles of student motivation in taking this introductory statistics course: the reluctant group sees lower value in the course and the subject despite some prior experience, the motivated group is new to the field but has high expectations for the course and for their own performance, and the confident group is surest of their success and the relevance of this course, and has highest prior experience. Bringing contextual information into the model allows us to create realistic profiles that more holistically capture the types of student motivations for taking an introductory STEM course.

These motivational profiles are shown to be related to self-reported student GPA and economic hardship. While these results are hardly surprising, it does bear note that gender and race, influential factors known to be related to motivation in STEM, lose significance in this relatively homogenous population while economic hardship retains its influence, speaking to its salience and perseverance as a barrier to academic success.

Lastly, regression results show that having a "confident" motivation profile at the start of the course may be less related to how student *decides* to engage in course preparation. That is, the time they spend, the questions attempted, and the way they divide the time throughout the week are all choices students autonomously make. Conversely, the ratio of correct attempts, and the ratio of questions given up, both indicators of the quality of experiences a student had during their engagement, differ by motivational profile. While further analysis is needed to fully understand this different experience, it seems that students with the "reluctant" and "motivated" profiles spend similar efforts for course preparation but spend less of it progressing with learning, and more time struggling with the material. This disproves the simple hypothesis that "better" motivation leads to higher engagement; rather, it seems that these holistic motivational profiles are correlated with student resources beyond their willingness to put in effort, which lead to different experiences in the course, despite their best intent.

Future work will focus on creating more sophisticated engagement metrics, making the next natural connection between engagement and performance, and then testing a larger model that includes motivation, engagement, and performance. Ultimately, we hope to understand how students that enter a STEM classroom with different types and levels of motivation engage in learning based on their process data, for the end goal of tailoring feedback for students based on both their motivation and observed engagement.

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Re-Mediating Technology-Facilitated Embodied Activities at a Summer Camp for Youth With Disabilities

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Abstract: This paper describes the implementation of technology-facilitated collective embodied modeling activities at a reverse-inclusion summer camp for children with moderate/severe disabilities impacting communication. Video data of camper interactions, paraprofessional debrief audio data, and researcher field notes were analyzed revealing three barriers to participation unique to children with disabilities in embodied learning activity design: (1) issues of abstraction/overstimulation, (2) needs for control/routine/choice, and (3) limited motivation for collaboration. Each of these barriers is conceptualized as dis/enabling elements of the activity design and informed a set of re-mediations in the activity design.

Introduction

For children with disabilities, embodied learning activities can be sites of pressure, stigma, distress, and shame . Technology-mediated embodied environments in particular are often designed with an able-bodied, neurotypical user in mind. In the learning sciences, there is a lack of research discussing the unique needs and barriers experienced by users with disabilities in these spaces. In this work, I argue that the design of technology-facilitated embodied learning environments should first and foremost prioritize the well-being, dignity, and comfort of learners as a prerequisite to disciplinary outcomes as I investigate the following research questions:

1. What barriers to participation do young learners with moderate-severe communication disorders experience in mixed-reality collective embodied learning activities?
2. How can mixed-reality collective embodied learning activities be re-mediated to reduce these barriers?

Theoretical framework

In the learning sciences, embodied cognition scholars have long positioned the human body as a resource for learners to engage in individual and collaborative meaning-making (Nathan, 2021). However, limited attention has been given to how embodied activities place unique demands, pressures, and messages onto learners and produce settings where attention and value are allocated to those bodies which perform within the strict range of abilities, skills, and characteristics required to succeed (Fitzgerald, 2005).

Activities that explicitly draw attention to learners' bodies in this way often reinforce unattainable traits (i.e. whiteness, motor competence, masculinity, neurotypicality, heterosexuality, etc) as acceptable, desirable, and achievable (Fitzgerald, 2005). Critical disability scholars have sociopolitically contextualized the barriers experienced by learners with disabilities, calling for the organization of learning spaces by focusing on mediation and artifacts such that "we can intentionally organize classrooms to help teachers learn to engage in reflective practices that shift away from static notions of race, culture, and ability" (Connor et al., 2016, p. 108). The concept of "mediation" here is drawn from technology design-oriented work, relying on activity theoretical and phenomenological perspectives (Kaptelinin, 2015). In this work, 'mediational means' include the structures, processes, tools, and scaffolding which shapes how 'subjects' (i.e. campers) pursue their 'objects' within the larger activity system. Further, 're-mediation' becomes a sociocultural approach through which learning ecologies can be socially reorganized and redesigned towards the enabling of learners and shifts how local interactions occur between learners; "[re-mediation] is not simply about changing infrastructure, but changing it so that it can be used to achieve particular political ends[…] for the goals of social justice and equity" (Jurow et al., 2019, p. 83).

Here, 'equitable participation' is utilized as a 'canary in the coal mine' to indicate when re-mediation of the activity system is necessary, with the analytical focus on which particular elements of the activity design are causing some break in the learning ecology. How 'in/equity' is operationalized is highly variable depending on the context; 'seeing' in/equities in the participation of participants requires unique insight into the social infrastructures, histories, and practices of the camp community. In this study, I leverage these perspectives to 'stress test' a series of technology-facilitated embodied learning activities within a reverse-inclusion summer camp context to identify those design aspects which are disabling for non-neurotypical populations and re-mediate the designs accordingly. This study is yet one piece in ongoing efforts to disrupt the hegemonic, ableist narratives, structures, and practices reinforced in western educational settings.

Methods

Camp Comrade is an annual reverse-inclusion (Baker, 2015) day camp in a small Midwestern city directed by a university-affiliated team of speech therapists to service local children (n=27) aged 5-12 with moderate-to-severe disabilities impacting communication and a group of invited 'peer models' (n=10). Over four (video recorded) days, groups of campers and staff participated in multiple 20-minute activities using the GEM-STEP system (GEM-STEP, 2021) with the objective of fostering social competencies and interactions between youth. GEM-STEP is a mixed-reality embodied learning environment through which students' physical movements are tracked via either a system of 'tags' and motion-tracking 'anchors' or an iPad 'character controller' and mapped to a digital avatar displayed on a projection visible at the front of the room. Students' movements then enable them to interact with virtual elements and characters alongside their peers within a hybrid physical and virtual space (see Figure 1).

Figure 1

The projected simulation (a), campers using the GEMSTEP system (b), and room layout (c)

(a) (b) (c)

Four audio and video sources of each activity session, researcher field notes, and audio recordings of paraprofessional debriefs for each activity session were analyzed using Jordan and Hendersons' (1995) guidelines for Interaction Analysis, user experience (UX) design methodologies such as affinity diagramming and solution prioritization, and Sandoval's (2014) conjecture mapping schema. Events were repeatedly watched with attention towards moments of trouble and/or repair within interactions, shifts in camper participation, instances of camper frustration or apprehension, engagement in social competency practices as identified by paraprofessionals. I also engaged in a series of qualitative validation procedures throughout the data collection and analysis processes including member-checking (with paraprofessionals and other camp staff), peer debriefing and collaboration with other researchers, and disconfirming evidence (Creswell & Miller, 2000).

Findings

I describe three barriers to participation experienced by elementary-aged children with moderate/severe communication disorders in technology-facilitated collective embodied modeling activities. For each set of barriers, I provide a description of how these barriers manifested during the GEM-STEP activities at Camp Comrade and a set of proposed design re-mediations lightly modeled after Sandoval's (2014) embodied conjecture mapping approach.

Barrier 1: Abstraction and overstimulation

While campers were often eager to participate, video data and paraprofessional debriefs revealed signs that campers could become overstimulated including (a) frustration around the state of their avatar due to confusion around the causes of these state changes, (b) maladaptive/destructive behaviors, and emotional breakdowns, and (c) behavioral indicators of discomfort (i.e. abrupt movements, repetitive gestures, closing eyes, covering ears, etc.) as noted by paraprofessionals. Traditionally, such expressions of frustration, traumatization, aversion, and anxiety could be interpreted by facilitators as acts of noncompliance and thus, something to be corrected and punished (Goodwin, 2020). Rather than attributing them to the individual and 'correcting' the behavior via individual intervention or conditioning (as is typical of those who rely on medical models of disability), these expressions were interpreted as signals of some disabling factor being present within the activity design thus prompting re-mediation.

For children with particularly high environmental needs (i.e. for environments to be literal, clean, organized, and in line with expectations) activity designs needed to be proactive in their preparation, protective and sensitive to students' sensory triggers, and accommodating of in-the-moment changes as these triggers are revealed. These insights prompted the generation of several design re-mediation options; these solutions varied in scope, technical difficulty, time required to implement, and anticipated immediate payoff for campers and were prioritized accordingly. Solutions that offered a high value to campers were feasible over the course of 2-3 days and a relatively low-technical/financial burden were applied during the latter half of the implementation and were evaluated and reviewed by paraprofessional experts during daily debriefs.

Table 1
A table of proposed design re-mediations to address issues of abstraction and overstimulation

Design Re-mediation	Conjecture
Physically marking virtual positions on carpet	Decreases the level of abstraction between the virtual and physical worlds; improves accessibility of embodiment tasks for campers with spatial / visual / visual processing impairments
Removing superfluous visual elements from projection interface; optimize iPad UI	Lessens effort required for campers enter & participate in system; minimizes breaks in distraction, decision paralysis, and distress for campers with attention challenges & sensory-sensitivities
Activating 'guided access' on iPads (limits functionality)	Minimizes off-task behaviors & need for staff-intervention / supervision
Providing fidgets; Introducing a 'break time' gesture (ASL)	Provides non-destructive outlet for campers to express distress or anxieties; redirects maladaptive behaviors
Replacing the screen with higher-contrast, larger projection; reposition / lower	Improves accessibility, visibility, and salience of simulation events and avatar states; lessens burden for connecting to avatar; improves size-inclusivity of system
Frequently resetting simulation rounds (automated looping)	Minimizes visual clutter and lessens effort required to monitor one's avatar

Barrier 2: Desire for control, routine, and choice

Within the video data, several moments featured children engaging in antisocial behaviors such as yelling, crying, and instigating conflict with other campers. While these episodes lessened as the campers became more familiar with the activities, paraprofessional debriefs clarified how many of the children had a high needs for particular task structures; these needs varied from the need to have control over events/actions, for the activity to follow a predictable and consistent routine, and to have opportunities for choice. This insight informed the following set of design re-mediations:

Table 2
A table of proposed design solutions to address issues of control, routine, and choice

Design Re-mediation	Conjecture
Offering additional character-control options (wearables, holdables, staff as proxies)	Enables campers the opportunity to opt-in to different modes of participation requiring varying degrees of movement, contact, communication, and attention
Presenting choices to individuals instead of the large group via pointing/gestures/AAC	Provides campers time & space to consider options, communicate their choice as preferred, and receive an appropriate response from facilitators
Daily visual schedules; GEMSTEP-specific token boards	Illustrates expected activity flow and schedule to preempt any breaks in routine; provides an (optional) visual set of guidelines/actions as a response to campers' paralysis/overwhelm using the sandbox task structure
Aligning GEMSTEP activities with camp themes/topics	Maintains cohesion, consistency, and predictability of GEMSTEP activities within the context of campers' entire camp sessions
Pre-training facilitators to use a common set of signs (ASL), gestures, and vocabulary	Standardizes facilitator awareness of many campers' preferred mode of communication; streamlines decision-making and needs articulation
Resetting individual avatars without resetting the entire simulation	Minimizes the degree that each individual avatar's progress and state is dependent on others; minimizes disruption to other campers in-simulation goals

While the outcomes of these re-mediations varied for each individual, simply recognizing and validating certain camper's needs for control over their environments allowed facilitators to more effectively and compassionately validate their frustrations and redirect any aggressive behaviors as evidenced in the video and debrief data.

Barrier 3: Motivation for collaboration

A core objective for camp staff and activity designs was to support inter-camper communication and relationship-building; midway through implementation after many technical barriers had been addressed, we noticed how campers often opted to act independently while using GEMSTEP as opposed to initiating collaborations. Furthermore, camper goals and motivations within the simulations often didn't align, and the aforementioned barriers to communication made it difficult for campers to identify and work toward a common goal. Conversations with camp leadership and paraprofessionals generated the following re-mediations:

Table 3

A table of proposed design solutions to address issues of low motivation for peer collaboration

Design Re-mediation	Conjecture
Peer & counselor modeling; graduated prompting/scaffolding	Normalizes bodily movement and promotes campers "joining in" on playful activities; provides a live model for campers to imitate; enhances group cohesion; provides increasing levels of support as needed to complete the task
Implementing a 'buddy' iPad system	Encourages campers to engage in synchronous collaboration, negotiation, turn-taking, and communication to achieve 'success'
Identifying/prescribing dyad & group-level collective goals	Directs campers towards pursuit of common goal; lessens need for camper agreement over misaligned-yet-rigid individually-defined goals
Pre-training facilitators to use a common set of signs (ASL), gestures, and vocabulary	Standardizes facilitator awareness of many campers' preferred mode of communication; streamlines decision-making and needs articulation; limits miscommunication and conflict

Discussion and conclusion

While learning scientists often emphasize designing for collaboration, I argue that the third collaboration-oriented barrier only became visible due to the efficacy of our adjustments addressing the other two barriers. These re-mediations represented a pivotal shift in the rapid iterative design process; it was only after the earlier barriers associated with abstraction, overstimulation, control, routine, and choice had been addressed that barriers to higher-level interactional and collaborative objectives could be considered. In other words, by designing for participants' comfort via the removal of barriers to participation, opportunities for meaningful collaborative meaning-making were 'unlocked.'

This work represents one step towards efforts to not only acknowledge and design for often marginalized students, but shift how the contributions of students outside the 'norm' are valued and legitimized in educational spaces. By critically examining where learners may encounter such barriers to participation, we shift the responsibility for (non)participation away from individuals and onto the activity design itself. By embracing these reflexive design practices in our work, we might conduct transparent, equitable research that is and offer an education that does not come at the expense of learners' comfort, dignity, and humanity.

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Teaching Artist Perceptions of Anti-Racism in an Out-of-School Time Theatre Programs

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Abstract: This paper reports findings from a pilot study that used qualitative surveys to examine how Teaching Artists (TAs) in one Out-of-School Time (OST) theatre organization defined and enacted anti-racist pedagogy. We report on two domains of action TAs described when defining anti-racism and three tactics they used to apply anti-racism to their programs. This paper represents a necessary step towards developing research-based recommendations for arts programs grounded in anti-racism; it also offers preliminary conceptual frameworks for understanding and studying how educators approach anti-racist pedagogy writ large.

Major issues addressed

Teaching artists (TAs) – who have expertise in both the teaching and practice of one or several artforms – are increasingly responsible for providing youth with arts education in the United States as positions for full-time arts teachers in schools have declined (Rabkin, 2012). TAs tend to operate Outside-of-School Time (OST), offering programs through community-based education spaces (Baldridge et al., 2017), private youth arts companies, or artist-in-residence programs. Often, the programs TAs offer are considered valuable and virtuous, because they provide an opportunity to engage young people who might otherwise have no access to formal arts education. Arts learning environments have been conveyed as safe spaces for youth with identities that are marginalized by systemic oppression (Chappell & Cahnmann-Taylor, 2013; Hanley, 2011), and TAs have been charged with acting as change agents in these spaces to empower youth artistically and emotionally (Fitzhugh & LaPadula, 2004). There is, however, little empirical research regarding TAs' confidence, capacity, and preparedness to help youth navigate issues of social injustice in equitable ways.

To be sure, there are countless examples in literature where youth have engaged critically and creatively in OST arts-centered spaces (e.g., Barniskis, 2012; Solomon et al., 2022). However, TAs are rarely emphasized in such examples, and many of the programs reported on in literature are led by researchers, leading one to question whether these examples are the exception rather than the rule across OST arts programs. Furthermore, literature that does directly examine educator attitudes towards race and anti-racism comes predominantly from traditional school settings (e.g., Philip, 2011; Vaught & Castagno, 2008), which have different affordances and challenges than OST arts education spaces, and different practical implications. In this pilot study, we aim to address the paucity of literature on theatre TAs specifically, by directly eliciting their perspectives on anti-racism in OST drama education. The following research questions directed this study: (1) How do teaching artists conceive of anti-racism broadly and in theatre education spaces? (2) How do teaching artists' conceptions of anti-racism align with self-reports of their application of anti-racist pedagogy? This work represents a necessary step towards developing research-based recommendations for arts programs grounded in anti-racism, and it offers preliminary conceptual and methodological frameworks for understanding and studying how educators approach anti-racist pedagogy writ large.

Anti-racist pedagogy and teaching artists

Today, extant literature that takes a critical perspective on race in education is vast, with work in educational ethnography (Fordham, 2016), sociology (Kao & Thompson, 2003), psychology (Lomotey-Nakon, 2018), and curriculum and pedagogy studies (Ladson-Billings, 1995; Paris & Alim, 2017). The notion of anti-racist pedagogy comes from this scholarship; it generally refers to an approach to education that requires ongoing awareness of power and racial dynamics within a learning setting, the inclusion of course content and materials that both recognizes racism and does not ignore or tokenize the perspectives of people of color, and the employment of teaching practices that disrupt uncritical assumptions on race, achievement, learning, and authority (Kishimoto, 2018). However, the majority of scholarship in this area is focused on formal school environments. Although educators in informal learning spaces can and do draw from this literature, they must make sense of how this work applies to their learning context. TAs in informal arts learning spaces find themselves with even less support.

Arts programs are often deemed safe, empowering spaces for youth with marginalized identities, and in turn, TAs are considered capable guides who help youth navigate social injustice by engaging in creative and artistic expression. In reality, TAs are not always prepared to support students most affected by educational and societal injustice. Despite an idealistic narrative about the power of youth engagement in the arts, in practice, TAs "may be entering teaching opportunities largely unprepared to engage with youth and organizations in this capacity" (Hager, 2010, p. 117). There is no uniform education or training process for TAs that can guarantee their engagement with culturally relevant or anti-racist pedagogy. And, as with any OST organization, deficit-based perspectives on youth have the potential to filter into TAs' work and impact the ways they engage diverse populations of learners (Baldridge, 2014). In this study, we asked TAs working in OST theatre and drama settings to examine their own teaching - their areas of confidence and discomfort, and their narratives about their own practice - in order to begin building a base of literature about TA perspectives on anti-racist pedagogy, which can become a foundation for future research-based recommendations.

Methods

This pilot study asks: (1) How do teaching artists conceive of anti-racism both broadly and in theatre education spaces? (2) How do teaching artists' conceptions of anti-racism align with self-reports of their application of anti-racist pedagogy? We invited TAs (N=12) affiliated with a youth theatre organization to respond to an online, short-answer survey. The anonymous online format encourages honesty in responding to a potentially sensitive topic (Deckman, 2017).

The survey consists of definition-based questions and practice-based prompts. The definition-based questions elicit TAs' understanding of anti-racism in society broadly and within drama education specifically. Our understanding of anti-racist pedagogy comes from the critical tradition of educational scholarship described earlier; however, we also recognize that the term "anti-racism" has both academic and colloquial meanings. To capture a wide-range of conceptualizations of anti-racism, we designed the survey questions to be open-ended, and prompted TAs directly to define "anti-racism" in their own words. In the practice-based prompts, we asked TAs to share a story about a time when they successfully applied anti-racist pedagogy, and a time when they either felt uncertain about how to enact anti-racism or failed to successfully enact it. We asked for specific moments so our analysis could be grounded in concrete examples, and encouraged TAs to write in narrative form so they might include relevant context (e.g., setting, relevant characters, etc.). The survey also included basic demographic questions, so we could connect TAs' responses to their self-reported identities.

We approached data collection and analysis through a qualitative phenomenological lens (Creswell & Poth, 2018), and constructed our understanding of the data through themes that emerged from, and were anchored in, the lived experience shared by our participants. Survey responses were analyzed through a multi-step qualitative coding process: in-vivo coding of the data, a memoing process, and then a detailed conceptual and dramaturgical coding phase. In-vivo codes were derived from the specific and direct words and actions of the participant. The prioritization of the actual words and physical actions of the participants makes in-vivo coding particularly useful in generating codes for understanding teachers' experience and expertise within their classrooms. The middle-step, which occurred concurrently across both the initial and secondary coding phases, consisted of generating meaning-making memos to make sense of, explore, and expand on emerging themes in the data. Throughout the memoing process, the research team met to challenge each other's perspectives on the meaning of the data by discussing any discrepancies.

The final step involved identifying patterns and emergent themes in the data which led to generating conceptual codes for the definition-based data and dramaturgical codes for the story-based data. Dramaturgy in theatre focuses on clarifying and understanding the entire dramatic composition; this includes not only the text, but also the Setting, the Objectives and Obstacles that impact the characters, the Tactics characters use to achieve their Objectives (e.g., Cattaneo, 2021). Dramaturgical coding applies conventions from dramatic literary and performance analysis to the story data (Saldaña & Omasta, 2017). Aligning our methodological design across study content, analytical approach, and intended audience allows us to bridge the expertise of the study participants, researchers, and intended audience in order to better communicate the study's findings.

Major findings

Definitional data: Anti-racism as epistemic and pragmatic action

In the definition-based questions, we asked TAs to indicate whether and where they encountered the concept of "anti-racism," to describe in their own words the meaning of anti-racism, and to explain what anti-racism in drama education means to them. In congruence with a recent review on counter-deficit literature in educational research (Kolluri & Tichavakunda, 2022), TAs conceptualized racism as *ideological*—an internalized personal belief at the individual level, or shared racial attitudes at the collective level, and *structural*—material barriers to opportunity and resource disparities that fall along racial and socioeconomic lines. TAs described *anti-racism* with verbs like “promoting,” “dismantling,” “recognizing,” “challenging,” and “listening,” implying action against racism in both its ideological and structural forms.

Our analysis identified two types of anti-racist action in TAs’ survey responses, which correspond with the ideological and structural concepts of racism. The first related to challenging one’s own biases, learning about systemic oppression, and unlearning prejudiced ways of thinking and being. The second related to creating material and generating structural changes in society. We found that these two types of actions resembled Kirsh and Maglio’s concepts of *epistemic actions* and *pragmatic actions* (1994) in embodied cognition, so we re-analyzed the data using these concepts as etic codes to confirm their relevance, and adapted them into *epistemic anti-racist action* and *pragmatic anti-racist action*. Epistemic anti-racist actions are external actions that are performed to change one's cognitive state (e.g., observing and naming microaggressions enacted by ourselves and others). They represent “actions designed to change the input to an [individual’s] information-processing system” (1994, p. 541). Pragmatic anti-racist actions are actions that create “transformations in physical or social space,” performed to change the external world or to bring one physically closer to a goal, even if the goal is to instigate an internal shift in *someone else’s* mind (1994, p. 515). Pragmatic actions can look like changing policies, advocating for others, or critiquing racist media.

The idea of employing reflection and action in dismantling oppressive systems is not new; scholars and activists have asserted the importance of reflection and action in anti-racist work, and have connected them through the concept of *praxis* (for examples, see Freire). Additionally, research has addressed the value of habit-breaking practices to combat internalized implicit race bias (Devine et al., 2012), and teacher sensemaking about racism is well documented (Philip, 2011; Pollock et al., 2010). However, to the best of our knowledge, this specific cognitive framing as a categorization of anti-racist actions is a novel contribution to the field, one which is related but subtly distinct from conceptualizations of anti-racism in the broader public discourse (i.e., individual prejudice vs. institutional racism: Kishimoto, 2018; self-awareness vs. structural awareness: Vaught & Castagno, 2008).

Story data: Dramaturgical analysis and common tactics

The narrative prompts asked TAs to tell stories of successes and failures/uncertainties in the classroom. Through dramaturgical coding, we identified three common Tactics TAs reported using to enact anti-racist classroom practices. These Tactics were largely related to the textual materials TAs used as the centerpiece of a drama classroom, and included: (1) *Naming/ Discussing* problematic elements in materials; (2) *Rewriting/ Replacing* problematic elements in materials; and (3) directing *Student Driven Creation* instead of relying on potentially problematic pre-existing materials. The most significant finding from this phase of analysis is that all three Tactics emerged in TAs stories as examples of perceived success and of perceived uncertainty/failure.

Naming/Discussing emerged in stories about identifying and making space for conversations about racist content in the theatre canon within drama education classes. When TAs provided examples of successfully using this tactic to enact anti-racism, they described actively confronting the history of certain texts or lyrics with their students. Examples of failure typically emerged in stories about avoiding these topics; TAs reported avoiding these discussions due to feeling unqualified to lead such discussions or trying to manage white students’ discomfort. When TAs relied on *Rewriting/Replacing* as a Tactic, they would not only identify racist material in the canon, but then also remove, rewrite, or replace it with new text. TAs expressed uncertainty about the effectiveness of this tactic when they weighed the relative value of naming harmful language with students and recruiting student participation in the rewriting process in contrast to removing harmful language outright. We recognize the *Naming/ Discussing* and *Rewriting/Replacing* Tactics as reactive, meaning they were actions taken in response to pre-existing canonical dramatic materials. The third common Tactic sidestepped the racism inherent in the canon by relying instead on Student Driven Creation. Success stories for this Tactic described students taking agency over their own art-making and generating work from within their own perspectives. Moments of failure with this Tactic were those in which students created work based on content and contexts with which they were already familiar, and in doing so, perpetuated racist stereotypes. The challenge of this Tactic lies in TAs being able to balance the value of Student Driven Creation with productive and safe boundaries, while also helping guide students to new or different understandings and perspectives.

Conclusions and implications

Although our pilot study includes a small sample size, it has provided rich data to build on in future research. The study illustrates that even when TAs voice uncertainty around implementing anti-racist pedagogy, their responses reveal thoughtful reflection and awareness that can be strengthened and translated into more concrete action with more professional support. TAs’ definitions of anti-racism were already grounded in action, namely epistemic and pragmatic anti-racist actions. Though more research is necessary to refine these actions into complete conceptual frameworks, they already offer a common language with which scholars, organization leaders, and TAs alike can discuss possible approaches to anti-racist pedagogy.

Additionally, TAs reported three common Tactics which they used to enact anti-racism in their classroom. These Tactics will likely look familiar to TAs in other theatre organizations; naming them explicitly is a crucial step to enable TAs to think critically about their anti-racist practices and question whether their Tactics are having the impact they want. Moreover, the fact that these tactics emerged in stories of both success and failure/uncertainty suggests there is no single "correct" approach to enacting anti-racism in drama education. Rather, the success or failure of a tactic depends on the specific situational context. By exploring and reporting on how TAs currently understand anti-racist practice, we have begun building a body of literature on anti-racist pedagogy that applies to the highly specific context of OST drama education. Additionally, we offer the *epistemic* and *pragmatic anti-racist action* as a preliminary conceptual framework for describing educators' approach to anti-racist pedagogy writ large, and we encourage scholars to employ dramaturgical coding as a method for analyzing educators' anti-racist practices and communicating to an arts educator audience.

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Appearing and Disappearing in the Data: Emotional Configurations Within Children's Data Modeling Practices

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Abstract: Data modeling is a central science knowledge building practice, entailing amplifying and reducing the world across inscriptional forms. Recent research in science education has elevated how emotion is integral to science knowledge building practices, yet emotion emergent *within* young people's data construction and critique processes remains less understood. In this study, we present findings from a multi-week 5th grade science and data science curriculum. We describe how emotion was often emergent as aspects of the ecological system were made more or less visible - by the data form's structure as well as by the activity structure. We focus in depth on one illuminating case were children falsify their data, detailing how emotion, sensemaking and modeling practices were co-emergent. Building on existing scholarship in data feminism, our findings suggest that transforming the world into data is an inherently emotional endeavor, in turn entangled in young peoples' sensemaking with and about data.

Introduction

Inherent to western science is the process of amplifying and reducing the world (Latour, 1999), moving away from the immediacies of the moment towards varying degrees of abstraction, standardizations and calculations through modeling pursuits and practices. Existing work in Science and Technology Studies (STS) and Feminist Data scholarship has illuminated how data intensive practices are inextricably enmeshed in emotion, whether intentionally repressed or openly embraced (D'Ignazio & Klein, 2020*;* Kennedy & Hill, 2018). Yet to date, there has been limited research on emotion *within* modeling, particularly at the intersections of emotion, data and science sensemaking in K-12 contexts.

In light of calls for enacting more expansive, equitable and meaningful modeling practices in science education (Schwarz et al, 2021), this proposed manuscript seeks to illuminate how emotion is integral to practices of data construction, interpretation and critique, in turn shaping children's sensemaking about interrelationships in socio-ecological systems and the data itself. In this analysis, we focus on children's engagement in collaboratively constructing multiple data visualizations with their schoolyard data: a bar chart of earthworm counts, a two-way table of invertebrate sketches and tallies, and an interactive digital GIS map involving multiple organisms and data formats. We ask, how do children navigate this inherently emotional process of amplifying and reducing the world?

Emotion and data modeling in science and science education

Existing scholarship has documented the longstanding bifurcated depictions of emotion as separate from data modeling and sensemaking in science, part of broader dichotomizing separating rationality, mind and objectivity from emotionality, body and subjectivity (e.g., Haraway, 2020). Such dichotomizing functions to perpetuate social political narratives of science as a dispassionate discipline, where data are merely extracted, transformed and distributed anew around the world. Recent research in science, math and data science education has increasingly elevated the emotional and situated dimensions inherent to data modeling and sensemaking across science, math, and data science disciplines (e.g., McGowen & Bell, 2022; Kahn et al, 2022). Yet much research in this area still focuses on emotion *about* existing data forms (e.g., empathy towards organisms from causal modeling, anger when looking at a particular data visualization), or alternatively, centers around designing data activities and visualizations to deliberately elicit specific emotional responses (e.g., Kennedy & Hill, 2018). As a result, less is known about emotion emergent *within* the data construction and interpretation process, particularly for younger learners newer to these enculturated practices as they build and discuss their data.

Theoretical frameworks

We draw on situated, socio-cultural frameworks to understand how emotion and data modeling are central to science practices. Emotion is understood as emergent *within* science practices, inseparable from social, conceptual and epistemic threads of disciplinary practice (Jaber & Hammer, 2016). Emotion plays a dual role, simultaneously *in/ as* practice, wherein emotion configures and is configured by disciplinary practices (Vea, 2020). Drawing on Latour (1999), we understand western scientific knowledge building practices as inscriptional movements away from locality, particularity, materiality and multiplicity towards increasing forms of standardization, calculation, compatibility and relative universality. We understand young peoples' data practices as intersecting constellations of personal, cultural and sociopolitical layers shaping their sensemaking (Lee, Wilkerson & Lanouette, 2022).

Research context and design

This study is part of a larger multi-year design-based research project that aimed to support expansive science and data science teaching and learning in late elementary school contexts (Lanouette, 2022; Lanouette, Van Wart, & Parikh, 2016). Central to the project design was collectively constructing and visualizing data about their schoolyard together as a whole group, to intertwine children's embodied, historical and material connections in a local socio-ecological system ecosystem in their sensemaking of aggregated data visualizations. Across the multi-month curriculum collaboration with an US elementary public school, a 5th grade class created, constructed and explored patterns in their data in analog and digital forms to better understand who could thrive in their schoolyard, providing multiple opportunities for collectively building and interpreting increasingly complex data forms.

Data sources specific to this analysis include three whole class sessions where multiple data representations were collaboratively constructed, including a bar chart of earthworm counts, a two way table of all invertebrates observed and counted, and an interactive map that included children's data on invertebrates, soil conditions, and schoolyard activities. These three class sessions were selected because they engaged children in physically constructing and interpreting varied aggregated data, involving three different data visualization forms that amplified and reduced varying aspects of the system. In each of these class sessions, video recording from several angles were collected, along with researcher field notes and student/ teacher paper artifacts.

Analysis

We examined how emotion was emergent and entangled within children's constructing, interpreting, and critiquing data visualizations across three different class sessions, accomplished through successive waves of coding video (Derry et al, 2010) using MAXQDA. In the first pass, we focused on children's concurrent sensemaking with and about their data (e.g., coded as *Sensemaking with data*: exploring what earthworms need to thrive, talking about how other invertebrates and kids' movements impact presence of certain plant and animal species, coded as *Sensemaking about data*: noting covariate relationships, attending to outliers, documenting absent or incomplete data). In the second pass, we focused on instances where aspects of the schoolyard socio-ecological system were amplified and reduced, encompassing instances where aspects of the data were shifted towards materiality, locality, and multiplicity or towards standardization, relative universality and calculation (coded as *Appearing/ Disappearing*, drawing on Latour (1999, pg. 71). This code included instances where children were constructing different categories of invertebrates (e.g., roly-polies, centipede), transforming their sketches and tallies into sticker dots representing earthworm counts, or removing layers of data from the interactive maps, bar charts or two way tables. It also included dimensions of the data visualization itself, when the form amplified or reduced particular dimensions (e.g., obscured locality, demanded homogenous categories within set columns, obscured children's names). In the third pass, we focused on *multi-modal expressions of emotion* (Jaber & Hammer, 2016), including verbal reference (e.g., "I just love finding animals!"), paralinguistic markers (e.g., rising accent, pitch, volume, speed), and multimodal expressions (e.g., shared smile, crossed arms, eye rolling). Combined, this multi-phased video coding resulted in identifying entanglements of emotion and data sensemaking alongside instances of appearing and disappearing in the broader modeling activities supported by the data form itself and the class activities.

Findings

Given space limitations, we share one illustrative case involving children collectively building a bar chart together of earthworm counts in their schoolyard. The class session was structured to support insights into what earthworms might need to thrive, in relation to soil conditions, site locations, and children's daily rhythms and routines in the schoolyard. Children use different colored sticker dots to refer to their sampling site's general location - green for the garden area and yellow for the small pond area. We selected this instance because it entailed multiple expressions of emotion and multiple amplifications and reductions.

As children slowly begin building the bar chart though, one pair (Elena and Brian) decide to falsify their data, elevating their tallies just enough to ensure they have the highest earthworm counts among the whole class (21½ worms, despite recording 15 and 15 ½ in their field notes). At the same time, other groups with low and mid-level counts accurately report their data and notably, other groups with zero counts did not share their findings at all or reluctantly with flat expression, given that there is no place for their zeros to go on the bar chart. We draw on adapted Jeffersonian transcription methods (Jefferson, 1984) to capture multi-modal emotional expression.

Ms. A: Brian, come on up, you can build it. Elennnnaa.

Elena: *(quickly making eye contact with Brian while staying seated)* We have 21!

Brian: *(standing up, looking down at Elena)* What?!

Elena: (*rising to her knees*). Yeah (*exhales*). 15 in the garden and 6 in the [pitfall trap] cup. We count it as 21.

Brian: (….) NO, let's just … No, we added those!

Elena: No! It was 15½ so like 16. And then I found other cups, remember? Other worms in the cup. That makes 21!

Brian: (*smiling at Elena*) So 21½?

Elena: (*smiling at Brian*) Yes!

Brian: (*talking to Ms. A*) Can we have like three of them (*referring to the sticker sheets*)?

Brian: *(turning pack to Elena).* But like we already recorded it as 15!

Elena: *(now coming up to standing).* No, it's okay! Let's put it as 21½…It doesn't even go up to 21! (*in a loud voice, raising arm is an upward sweeping motion, Figure 1*).

Figure 1

(a) Elena's arm rising (left) and (b) Elena shouting 21 and a half (right)

Pairs continue adding their stickers, with children counting out loud as they place stickers and coordinate keeping their tallies in the column with their name. After about 30 seconds, Elena and Brian now begin adding their tallies.

Elena: (*walking toward chart)* Are we supp::osed to use 21 stickers? I need to put my name down!!(*holding a marker*) ... I'll do Elena and Brian!

Elena: Brian! We are right here (*pointing to their column*).

Brian: Here? We found a half!

Beatrice: (*crouched low):* You should really start at the bottom because we are all measuring from the top [referring to the ordering of sticker dots on the bar chart].*(Elena and Brian begin placing their stickers onto the chart.)*

Beatrice: Brian, why are you starting at the top?

Brian: 21 and a ½! (*smiling wide*)

Elena: 1,2,3,4,5,6,7,8! (pause) 9,10,11, 12. … Brian, why are you putting them up there?

Brian: We meet in the center!

Elena: *(walking her fingers in marching pattern up the chart*): 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17! *(stretching word)* 18, um 19.

Brian: Wait you did it wrong?

Elena: Twenty!!

Ms. I: Woah you guys, look at the bar chart!

Elan: I know, like in ten minutes it has grown by tens. (*more children are looking at the bar chart, with just Elena and Brian still standing placing their last stickers on the chart*).

Ms. I: I know…

Group: Oh wow! What the heck?!

Elena: 21… 21 and a half! *(Hands raising up)* 21 ½ (*even louder, with smile forming and arm swinging across her chest, see Figure 1b)*

Brian: (*smile forms*)

Mark: Wa:::it! *(springing up and walking up to the chart from back of rug)* Is this also like invertebrates too?

Beatrice: No, Mark! it is JUST earthworms (*shouting out from back of the rug*).

Mark: Then why is that 21?! (*pointing at the chart*).

Elena: 21 and a ha::lf. We found half a worm! (*walking back towards the rug, smiling spreading*).

Mark: You found 21 worms?! (*louder, eyebrows raised).*

Elena: Yes, 21 worms and a half (*louder*). Right there (*quieter, pointing towards the bar chart*).

Brian: The fraction is important (*smiling)*.

Over the course of several minutes, as they make their way up from the rug toward the bar chart, with expressions of celebration and smiles increasing as their tallies grow bigger - numerically and physically, Elena and Brian falsify their data. We see emotional expression related to personally showing up in the data itself, from ensuring their column has their name on it to increasing their data to have the most in the class. We posit that the class activity structure of collectively aggregating pairs' data as a whole class and having earthworm tallies grouped by children's names amplified the personal, numerical and comparative aspects of modeling activity. At the same time, the structure and history of the bar chart form itself, emphasizing counts and comparison over locality and multiplicity, further amplified showing up and becoming visible in the data. As such, Brian and Elena's engagement in the data modeling practices entail dynamic emotional configurations (Vea, 2020), entangling what tallies children report and how publicly they announced and defend their results to the group. Additional analyses are underway to follow other children's' emotional expressions and data sensemaking within this bar chart class session, often of markedly varied emotional expression as they report different numerical tallies (e.g., having zero or low counts) making them less visible in the aggregated data display. We are also analyzing emotional configurations across different data forms that amplify and reduce aspects of the socio-ecological system, including interactive GIS maps and two way tables.

Conclusion

Preliminary findings shed light on how emotion emergent *within* young people's data modeling pursuits can be integral to practices of data construction, visualization and critique. At the same time, findings also point to the importance of attending to the historical relationships that shape children's data modeling pursuits, illuminating how the data forms themselves and children's own histories with the data transformation process are also dynamically configuring and reconfiguring emotion, science sensemaking and disciplinary pursuits.

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Self-Regulated Learning Through Online Formative Assessments: The Effects of Assessment Frequency and Participation on Student Performance

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Abstract: Using online formative assessments, students can monitor their learning and find strategies to attain their self-regulated learning (SRL) goals. However, as formative assessments are often optional and ungraded, some students may not be motivated enough to participate in such assessments. In this study, we argue that the frequency and stakes (i.e., optional vs. required) of formative assessment can influence the interplay between SRL and student performance. Using data from multiple offerings of an undergraduate course, we investigate the role of formative assessment frequency and participation rate in predicting students' course performance. Our findings showed that student performance and participation in the required formative assessments were more predictive of their course outcomes. Furthermore, increasing the frequency of formative assessments did not improve student performance.

Background of the study

With the rise of digital technologies, today's educators (e.g., K-12 teachers and university instructors) use online formative assessment to monitor the students' learning progress and provide them with immediate feedback (Bulut et al., 2022). Online formative assessment can help students develop their capability for self-regulation learning (SRL)—the process of how learners use their meta-cognitive skills together to identify learning goals, monitor their own learning, and regulate their cognitive skills to reach the learning goals (Zimmerman, 2002). Although formative assessments promote student reflection on learning by developing students' self-evaluative capacities (Hawe & Dixon, 2017), within the higher education context, it is still not clear when and how formative assessments can help students improve their SRL skills. In this study, we argue that providing more formative assessments and making them optional (i.e., giving students more freedom in regulating their learning) could influence the interplay between formative assessment and SRL. This study examines the effect of frequency and stakes of formative assessment on students' academic performance as measured by their final course grade. We compare results between two sections of the same asynchronous undergraduate course. These two sections differ in terms of formative assessment frequency (i.e., administered weekly vs. after every lecture) and stakes of formative assessment (i.e., optional vs. ungraded mandatory participation). In this study, we argue that providing more formative assessments (i.e., increasing the amount of formative feedback students can receive to monitor their learning) and making formative assessments optional (i.e., giving students more freedom in regulating their learning) could influence the dynamic relationship among formative assessment, SRL, and student learning.

Literature review

Abney et al. (2017) showed that students' participation in low-stakes formative assessments (i.e. ungraded or optional) could be accounted for by students' approach to learning, such as fear of failure and perceived value of the assessment. Similarly, Jones and Korula (2021) found that student perception of their own assessment preparedness is an important predictor of participation in optional and ungraded formative assessments. In addition, self-directed students who perceive that questions in optional formative assessments are relevant and challenging are more likely to participate in the assessment and achieve better final exam performance as opposed to less motivated students (Brazeal & Couch, 2017). The aforementioned findings support that student participation in formative assessments largely depends on student characteristics.

As a core component of student achievement motivation, goal orientation can also be used to explain students' participation in non-mandatory formative assessments (Chazan et al., 2022). According to Elliot and McGregor's (2001) 2 × 2 achievement goal framework, student achievement goals can be characterized by two dimensions, valence (i.e., approach and avoidance) and goal definition (i.e., mastery and performance). The goal definition dimension focuses on students' learning motivations (increasing personal competence vs.

outperforming peers), while the valence dimension describes students' behaviors driven by either their desire to pursue success (approach motivation) or to avoid negative outcomes (avoidance motivation).In achievement settings, mastery-oriented students tend to seek feedback and thus are more willing to participate in formative assessments because they believe that formative assessments enable them to reflect on their learning and improve their performance (Dijksterhuis et al., 2013). Similarly, Yan (2018) found that mastery goal orientation can positively predict students' feedback-seeking and self-reflection behaviors, while performance goal orientation negatively affects such behaviors. More recently, Kaur et al. (2017) found that formative assessments are more favored to mastery-oriented students than performance-oriented students because, for mastery-oriented students, a formative assessment is perceived as the opportunity to improve their understanding of course content and thereby motivating them to participate in assessments for continuous feedback on their learning. On the other hand, performance-oriented students demonstrated the greatest interest in the grades but the least interest in the received feedback about their learning progress (Kaur et al., 2017).

Research method

Data source

Data for this study came from two sections of an undergraduate course designed for pre-service teachers enrolled in the Elementary and Secondary Education programs at a Canadian university. The first section (n_1 = 123) was taught by Instructor A during the Fall 2021 semester, while the second section (n_2 = 119) was taught by Instructor B during the Winter 2022 semester. Due to the public health restrictions taken during the COVID-19 pandemic, both sections were delivered online and asynchronously. The instructors followed the same curriculum, shared the course materials with students via the same Moodle-based LMS throughout the semester, and used identical course assessments (two midterms and a cumulative final exam). Both instructors also shared online quizzes as formative assessment tools. Multiple-choice items were auto-scored within the LMS, while the answer key for short-answer items was shared with students upon completing each online formative assessment. The LMS recorded all student activities, including assessment results and timestamps for each student activity.

At the beginning of the semester, both instructors explained the main rationale behind formative assessment clearly: these ungraded assessments were designed to help students gain experience and improve their skills to obtain better grades in the midterm and final exams. Students were allowed to complete each formative assessment as many times as they wanted. The accuracy of students' responses to selected-response items and their percent-correct scores were displayed after each quiz attempt to provide students with feedback on their performance. However, the two sections differed based on how online formative assessments were utilized by the instructors. At the beginning of each week, Instructor A posted learning materials for two lectures (e.g., lecture slides, pre-recorded lecture videos, etc.) and an online formative assessment via the LMS. In contrast, Instructor B posted a formative assessment after each lecture. This led to Instructor B having twice as many formative assessments (N = 10) as Instructor A.

Data analysis

We extracted features from the LMS data focusing on formative assessment behavior and course performance. Specifically, we retrieved the first midterm, second midterm, and final exam scores of students for each section. Then, drawing upon previous studies, we extracted features focused on formative assessment behavior, including the average first attempt score (i.e., the mean of formative assessment scores based on students' first attempt), the average score based on all attempts across the available formative assessments, and the frequency of formative assessment attempts for each formative assessment (i.e., how many times students participated in each formative assessment). Since we analyzed the course performance on all three summative assessments (i.e., midterm and final exams), we extracted formative assessment features pertaining to each exam separately. Using the extracted features and students' exam performance, we ran three multiple regression models (i.e., one for each summative assessment) for each section to understand which features predicted the students' performance. This helped us evaluate the unique contribution of each feature to predicting and evaluating student performance. All analyses, including data cleaning procedures, were completed using the R programming language (R Core Team, 2022).

Results

Both instructors completed four weeks of lectures (two lectures per week) before the first midterm. Thus, Instructor A had two formative assessments, whereas Instructor B had four formative assessments before the first midterm exam. In Table 1, The top part presents the multiple regression results for both sections using the formative assessment features extracted from the quizzes before the first midterm. For the class of Instructor A where participation in formative assessments was required, we found that the first attempt score ($b = 0.27$, $p < .05$) and the frequency of attempts for the first formative assessment ($b = 0.85$, $p < .05$) were significant predictors of the first midterm scores. Also, the model showed explained almost 50% of the variability in the first midterm scores. However, the same model for Instructor B only explained about a quarter of variability in the first midterm scores. Similar to Instructor A, first attempt scores ($b = 0.12$, $p < .05$) were a significant predictor of the midterm scores, whereas, unlike for Instructor A, the frequency of attempts to the last two formative assessments ($b = 0.81$, $p < .05$ and $b = -0.84$, $p < .05$) significantly predicted the midterm scores.

Table 1
Regression Analysis Results for Predicting Midterm 1 Scores for Instructors A and B

	Instructor A				Instructor B			
	b	*SE*	*β*	*t*	*b*	*SE*	*β*	*t*
Midterm 1								
Intercept	10.42*	2.55	-	4.09	17.37*	1.97	-	8.84
Avg. First-attempt score	0.27*	0.05	0.60*	5.30	0.12*	0.04	0.44*	2.72
Average score	0.04	0.05	0.10	0.88	0.01	0.04	0.03	0.20
Frequency of attempts (1)	0.85*	0.30	0.31*	2.86	-0.26	0.35	-0.15	-0.74
Frequency of attempts (2)	-0.19	0.47	-0.04	-0.39	0.42	0.38	0.27	1.10
Frequency of attempts (3)	-	-	-	-	0.81*	0.40	0.42*	2.05
Frequency of attempts (4)	-	-	-	-	-0.84*	0.41	-0.46*	-2.06
Adjusted R^2	47%				23%			
Overall Model Fit	$F(4, 118) = 28.04$*				$F(6, 105) = 6.431$*			
Midterm 2								
Intercept	29.36*	1.92	-	15.32	27.00*	1.39	-	19.474
Avg. First attempt score	0.02	0.08	0.09	0.28	0.06	0.04	0.36	1.539
Average score	0.11	0.09	0.38	1.21	0.12	0.04	0.08	0.348
Frequency of attempts (1)	0.59	0.59	0.15	1.01	-0.58	0.38	-0.30	-1.51
Frequency of attempts (2)	-0.38	0.68	-0.08	-0.57	0.27	0.46	0.13	0.58
Frequency of attempts (3)	-	-	-	-	0.24	0.51	0.11	0.46
Frequency of attempts (4)	-	-	-	-	0.05	0.47	0.02	0.11
Adjusted R^2	21%				17%			
Overall Model Fit	$F(4, 115) = 8.671$*				$F(6, 93) = 4.325$*			

Note: *$p < .05$. b and β the unstandardized and standardized regression coefficients, respectively *SE*: Standard error. Frequency of attempts (1) to (4) refers to participation in the first to fourth formative assessments taken before each midterm exam.

Two interesting patterns deserve to be scrutinized in Table 1. First, participation in the first and last formative assessments in Instructor B's class was negatively associated with the midterm scores. This result is likely to be a consequence of the non-mandatory nature of formative assessments in Instructor B's class. Instead of participating in formative assessments regularly and monitoring their performance, some students (especially those with lower midterm scores) took the last formative assessment repeatedly before the first midterm exam to better prepare for the midterm exam. Second, there are differential effects of formative assessments in predicting students' midterm scores. In Instructor A's class, mandatory participation in the first formative assessment seemed to be a significant predictor, whereas in Instructor B's class, optional participation in the third and last formative assessments was significantly related to students' midterm performance. The bottom part of Table 2 shows the regression results for the second midterm exam. None of the formative assessment-related features significantly predicted the second midterm scores for Instructor A and Instructor B. This was primarily because most students performed very well in the second midterm exam, leading to a highly skewed distribution with low variance.

Table 2 presents the regression results for the final exam. For Instructor A, the model explained 25% of the variability in the final exam scores, whereas for Instructor B, the regression model explained only 2% of the variability in the final exams scores and the overall goodness of fit was not significant. For Instructor A, the frequency of attempts to the formative assessment ($b = 3.32$, $p < .05$) was a significant predictor of the final exam scores, even though the scores in the formative assessment were not a significant predictor. This finding suggests that participation in online formative assessments, but not their scores, could be a key factor in explaining which students are preparing better for the final exam. In contrast, the attempts for the first and second formative assessments in Instructor B's class were not significantly related to students' final exam scores.

Table 2

Regression Analysis Results for Predicting Final Exam Scores for Instructors A and B

	Instructor A				Instructor B			
	b	*SE*	β	*t*	*b*	*SE*	β	*t*
Intercept	57.80*	4.54	-	12.72	47.60*	3.18	-	14.99
Avg. First attempt score	0.13	0.12	0.22	1.08	-0.05	0.08	-0.19	-0.66
Average score	0.18	0.13	0.28	1.38	0.14	0.09	0.43	1.51
Frequency of attempts (1)	3.32*	1.51	0.19*	2.20	-0.44	1.20	-0.06	-0.37
Frequency of attempts (2)	-	-	-	-	0.25	1.02	0.04	0.25
Adjusted R^2	25%				2%			
Overall Model Fit	*F*(3, 105) = 13.1*				*F*(4, 76) = 1.486			

Note: *$p < .05$. *b* and β the unstandardized and standardized regression coefficients, respectively *SE*: Standard error. Frequency of attempts (1) to (4) refers to participation in the first to fourth formative assessments.

Discussion

Our results emphasize the predictive utility of online formative assessments in predicting student achievement. This predictive utility seems to increase when online formative assessments are deemed mandatory. Also, increasing the frequency of online formative assessments does not necessarily lead to better student outcomes, suggesting the need for using fewer but more meaningful assessments. Our findings suggest that providing students with feedback through formative assessments can help them regulate their learning and formulate more effective learning strategies to obtain better course grades (Hattie & Temperley, 2007). Also, making the formative assessments required could motivate students to participate in the formative assessments regularly throughout the semester. Although scores from formative assessments may lose their predictive utility over time, students' participation behavior in formative assessments could still inform the instructors about who is likely to be successful in the course.

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Which Way is Up? Orientation and Young Children's Directional Arrow Interpretations in Coding Contexts

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Abstract: Many coding environments for young children involve using navigational arrow codes representing four movements: *forward, backwards, rotate left, and rotate right*. Children interpreting these four, seemingly simple codes encounter a complex interaction of spatial thinking and semantic meaning. In this study of how children interpret directional arrows, we found that they interpret each of the arrows as encoding many meanings and that the orientation of the agent plays a critical role in children's interpretations. Through iterative rounds of qualitative coding and drawing on two examples, we unpack some common interpretations.

Introduction

There has been a push to make computer science education equitable for all students. However, as mentioned in the call for proposals for the ISLS 2023 conference, things that are argued to be more inclusive for many learners have also been shown to disadvantage many others. Sometimes our designs for learning are messy, and as learning scientists, we need to take a step back and try to disentangle the complexity and engage in sensemaking about how learners are interpreting and interacting with our designs for learning and the materials that are meant to support them. Such is the case for the present study. In this paper we explore how young children interpret and interact with the materials we designed to teach and assess their understanding of computational thinking (CT). Like many researchers in early childhood, we use coding as a context to promote CT (Wang et al., 2021). Most coding environments for pre-literate children use navigational codes that are represented through arrows: *forward*, *backward, rotate left,* and *rotate right* (Clarke-Midura et al, 2019). While the idea of using arrows to represent movement may seem simple, it is challenging for young children. The navigational arrow codes are a whole new symbol system they need to make meaning of. It requires understanding what each arrow instructs the agent to do, that one arrow only produces one discreet movement, and that each arrow always produces the same movement but depends on the agent's orientation. In this paper we theorize about the complexity that two codes: *forward* and *rotate left* and how the orientation of an agent affects children's interpretations of the two codes as they engage in tasks designed to assess their understanding of CT. Our inquiry is guided by the following research questions: *How are children interpreting the arrows? How does the orientation of the agent affect children's interpretation of the arrow codes?*

Background and context

The present study has roots in Papert's (1980) Logo Turtle Geometry where the turtle became a virtual computational agent for children to connect with abstract ideas like angles and navigation in a concrete way through "body syntonicity." Reasoning about an agent's orientations, locations, and navigation in space involves spatial thinking. The National Research Council (NRC) defined spatial thinking as comprised of three elements: concepts of space, tools of representation, and processes of reasoning (NRC, 2006). Children first develop spatial orientation concepts in relation to their own position in space and later develop external based reference systems using landmarks outside themselves (Sarama & Clements, 2009). Yet, few studies have systematically investigated the complexity of spatial orientation in children's understanding of CT.

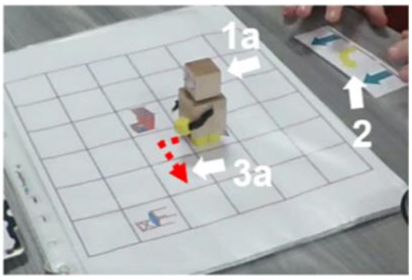
Research design and methods

Task and materials

We designed two tasks that are identical except for the starting orientation of the agent. In both tasks, children were asked to enact a sequence of codes, *forward, rotate left, forward*, that were provided to them in the form of arrows (see Figure 1). Children were instructed to physically move a tangible agent on a 6x6 2D grid. In Task A, the agent shares the same orientation as the child, while in Task B, it is oriented 90 degrees to the left.

Figure 1

Set up for Task A (left) & Task B (right)

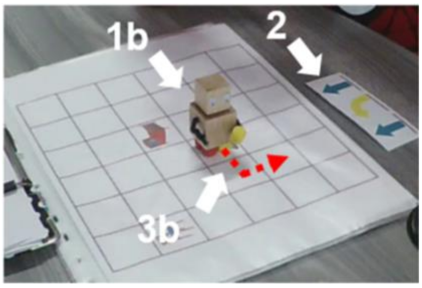


1a: Agent's orientation same as the child's perspective.

1b: Agent's orientation 90 degrees to the left from the child's perspective.

2: Program to enact: FLF

3a & 3b: Expected path the agent will travel if all codes are enacted correctly



Sample and data sources

This research is part of a larger project that is operationalizing CT in early childhood and developing curricular tasks and a performance assessment (Clarke-Midura, et al, 2021a). Data come from video of 146 children aged 5-7, spread across five elementary schools in the western United States, solving the two tasks described above.

Data analysis

This analysis started with *a priori* codes that were developed from a previous analysis where we observed how four groups of children (n=16) interpreted the *rotate left* and *rotate right* arrows during a curriculum enactment with different materials but similar navigational codes (*forward, backward, rotate left, rotate right*). In the present study, as we coded the new video data, we modified and refined the codes as new types of arrow interpretations emerged. The codes were cross-checked with each other and with the data from the previous analysis. We compared codes, identified interpretations that appeared frequently or with more clarity, and could be differentiated from each other. This allowed us to create categories and identify themes. We engaged in selective coding, where we refined, solidified, and clarified codes and categories until we reached saturation.

Results

Various interpretations of forward and rotate left

In our context, a *rotate left* arrow makes the agent stay in the square and rotate 90 degrees to the left and a *forward* arrow makes the agent move one square forward *from the agent's perspective.* However, children interpreted the *forward* and *rotate left* arrows in various ways. We identified four *forward* arrow interpretations and five *rotate left* arrow interpretations. The various interpretations indicate that some of the children did not attach one fixed meaning to an arrow and, as a result, each arrow had the potential to do everything.

Figure 2

Children's Forward Arrow Interpretations

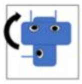
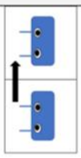
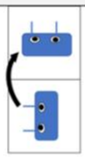
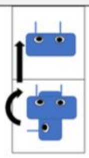
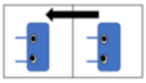
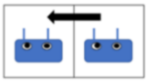
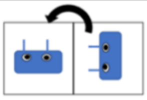
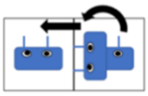
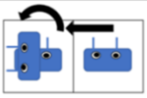
	Spin to face this way	Slide sideways	Curve this way	Rotate and slide this way
Definition	Reorienting the agent to share a child's perspective	Moving the agent one square above without reorienting the agent to face forward	Making the agent curve to the square above	Rotating the agent face forward and then travel to the square above
Visual illustration				

Figure 2 shows that children used *forward* arrows to do things other than moving the agent to an adjacent square. They assigned two distinct movements, rotating the agent while staying in the square and moving one square forward to one *forward* arrow. They enacted both movements either as one fluid movement by making the agent curve one square in the direction of the arrow (*curve this way*) or as two distinct movements (*rotate and slide this way*). Children sometimes enacted the *forward* arrow as *slide sideway* by moving an agent one square forward when the agent's orientation is different from the direction it travels. In this case, children attached the correct movement (sliding one square) to the *forward* arrow; however, they did not take on the agent's viewpoint when moving it.

Figure 3
Children's Rotate Left Arrow Interpretation

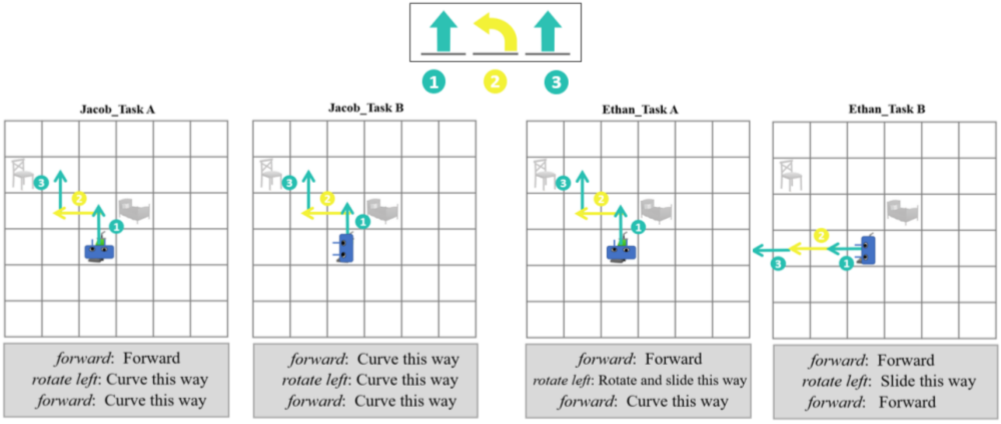
	Slide this way	Slide sideways	Curve this way	Rotate and slide this way	Slide this way and rotation
Definition	Moving the agent one square in the direction of the arrow	Moving the agent one square to the left without reorienting the agent	Making the agent curve to the square on the left	Rotating the agent face to the left and then travel to the next square	Making the agent travel one square and then rotate it to face to the direction of the arrow
Visual illustration					

Children used *rotate left* arrows to make the agent move in ways other than rotate 90 degrees to the left (see Figure 3). Some children interpreted the *rotate left* arrow by enacting two moves: first rotating the agent 90 degrees to the left and then sliding it to the next square (*rotate and slide this way*). Sometimes they combined rotation and sliding by making the agent travel in one fluid movement (*curve this way*). When the agent's orientation was facing left (the same as the arrow's), some children enacted the *rotate left* arrow as if it were a *forward* arrow, by moving the agent to an adjacent square without reorienting it (*slide this way*).

How orientation affects interpretation

Figure 4 presents visual representations of two children's enactment of Task A and B, Jacob and Ethan. The arrow direction represents the direction the agent was facing at the end of each code enactment.

Figure 4
Jacob's and Ethan's Arrow Interpretation



Example 1: Jacob

In task A, where the agent shares Jacob's orientation, he enacted the *forward* arrow correctly. However, the enacted the *rotate left* and last code, *forward*, incorrectly. In Task B Jacob enacts both *forward* arrow codes by making the agent curve to the square above. Even though the agent shared his orientation when he enacted the second code, *rotate left* in both tasks, he enacted it by making the agent curve to the square on the left.

Example 2: Ethan

Ethan enacted the first *forward* arrow correctly in both tasks. In task A, even though the agent shared his orientation when he enacted the second code, *rotate left* he enacted it by rotating the agent to face the left and travel to the next square. In task B, he enacted the left rotation by moving the agent one square in the direction of the arrow (to the left). In Task A, Ethan enacted the second *forward* arrow as *curve this way* yet in Task B, he enacted the second *forward* arrow correctly.

Analytic findings

Using the symbolic system of navigational arrows to sequence and enact codes requires understanding *code-to-movement correspondence*, that each code (arrow) makes the agent do a single discreet movement; and *agent-orientation correspondence*, which means codes always produce the same movement but depend on the agent's orientation. We observed various interpretations that violated these rules; the most common example is using a *rotate left* arrow to do *curve this way*. While the orientation of the agent did affect children's interpretations, their interpretations were not consistent. Some children used the same arrow differently in the same program.

Previous studies have characterized the ways children have difficulty determining spatial orientations other than their own (Sarama & Clements, 2009) including in the context of coding with robot coding toys (Wang et al., 2022; Clarke-Midura et al., 2021b). Our findings align with these studies in that they show how not being able to take on the perspective of the agent is associated with mistakes and incorrect use or enactment of codes. Besides perspective taking, arrow interpretation is influenced by the directional relationship between the agent's orientation and the arrow's. When the agent's orientation is the same as the direction of the arrow code to enact, even if children shift their perspective to the agent's, they may still interpret an arrow's meaning other than it is supposed to be. When the agent is facing an orientation different from the orientation of the arrow code to enact, a child may reorient the agent to the direction of the arrow before any further enactment. In our study, many children look only at the tile and see the *forward* arrow is oriented "up" as depicted in the tile and then move the agent to the direction of the arrow, regardless of its orientation and position on the grid. While using arrows to represent navigation may seem like a simple design idea, our findings illustrate how the arrows caused confusion for children.

Conclusion

In this study, children acted as surrogates by moving a physical agent to solve CT tasks on a two-dimensional grid through arrow-by-arrow enactment. This is a promising context for young children to learn spatial thinking and computational thinking skills. However, the variety of arrow interpretation indicates that tasks situated in this context are also difficult for young children. Children need to coordinate multiple representations and meanings, such as the agent's orientation in relation to the symbolic representation of the arrow's orientation on the code tile, and the position of the arrow tile to the child's orientation. When designing learning and assessment environments for early childhood CT, we need to be aware of how the designs and materials intersect and influence children's spatial thinking skills. This study contributes to our knowledge of the intersection between syntonic learning, spatial thinking, and computational thinking in early childhood.

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the Learning Sciences

How Off-Duty Data Scientists Did Math for Civic and Social Good

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Abstract: This paper presents an ethnographic case study of a team of off-duty data scientists who electively made a new mathematical metric to address a problem with one of their city's key public services. This case study offers an image of an environment that was organized to allow participants to pursue two opportunities by doing math — one was to help potentially improve a public service in the near future and the other was to become better data scientists. The case material offers ideas for designing mathematical learning environments that might similarly offer young people opportunities to learn to do math for social good and to advance their broader interests and concerns (Stevens, 2020).

Introduction

Schools teach students the subject of math, hoping students will carry it into their everyday lives. We need to understand the actual and possible relations between school math and the math that is done outside of school (Stevens et al, 2016). Learning Sciences researchers have shown that people in everyday life are motivated to do math that is fitted to the criteria that they themselves define for success in their daily lives, whether in leisure or work contexts (Lave, 1988; Stevens & Hall, 1998). Recent studies have examined a number of contexts, where the math involved has negative consequences for society, math that is both biased and hidden within an unseen algorithm (O'Neil, 2017; Noble, 2018). A very different genre of study documents examples of math that is done for civic and social good (Esmonde, Curnow & Riviere, 2014; Taylor & Hall, 2013). As we see it, our study contributes to this emerging genre — we tell the story of one team of volunteers who made a new mathematical metric to address a problem with a key public service in their city.

This case study offers an image of an environment that might offer ideas for making math more meaningful for young people in school. Schools find it difficult to motivate children to do math (Boaler, 2000). In contrast, the participants in this case study were motivated to do and learn math in their work; so much so that they did it late at night after long hours working at day jobs in data science. The volunteers organized an environment that offered at least two opportunities — one was to use math to help potentially improve a public service in the near future and the other was to learn skills relevant to their careers as data scientists. The participant's motivating environment might offer, we argue, ideas for reconstructing educational experiences in school (Stevens et al, 2016; Stevens, R., Davey, B, & Nguyen, V., in preparation), to offer children opportunities to do math to advance social good as well as to advance their own interests and concerns (Stevens, 2020).

Research context, data collection, & analytic framework

Civic Technology Volunteers (CTV) is a non-profit organization located in a very large midwestern city. CTV is run by volunteers who come every week after working day jobs as data scientists. The CTV volunteers use publicly available data to build technology applications and present them to a public audience of news media channels and nonprofits. We focused on a project called "Phantom Buses", one of many at the CTV. We conducted ethnographic participant observation (Emerson, 2001) with the Phantom Buses team starting in June of 2022. The first author attended the weekly team meetings held on zoom and face to face, participated in the team's Slack communication platform, read the team's software repository, and conducted semi-structured interviews to understand the project activities outside of the weekly meetings. To date, we have collected approximately 45 hours of video data, 5 hours of interview data, and 30 pages of field notes.

The first author watched the videos after every data collection session, made content logs (cf. Jordan & Henderson, 1995), and generated analytic memos. Our analytic framework falls within the learning sciences and cognitive tradition of problem-solving. In particular, we followed the distributed cognition approach in which an analysis follows how people and tools are coordinated across time and space to solve a problem (Hutchins, 1995). This case study involved a phase of problem solving that is often left out of problem-solving studies — the problem finding phase (Getzels, 1979). The problem-solving in this case study also involved a process called *drawing things together*, whereby disparate data is gathered into one place then transformed into one synoptic representation which is made as strong and complete as possible for an anticipated contestation (Latour, 1987). In the next section, we present the product of our analytic work: an analysis of the chronological set of events from our ethnographic record.

Data and analysis

Lilah finds the problem of Phantom Buses and pulls together a team to address it

Buses are an important part of city transit infrastructure; many bus riders rely on buses every day to get to places of work or to medical care. Since the COVID-19 pandemic, city bus riders have noticed that bus service has seemed especially unreliable. Many bus riders have experienced a situation where the schedule published by the municipal transit association (MTA) claims a bus is coming, but none shows up; that bus is a “phantom bus.”

One of the members of CTV, Lilah, closely followed and read social media stories and online forums where citizens reported their experiences with phantom buses. Lilah heard that some citizens were so frustrated that they had tried to alert the MTA of these phantom buses, but that the MTA dismissed their pleas. Lilah heard that in the upcoming months there would be a public hearing at City Hall where city officials, and citizens would meet to discuss their concerns with the MTA. Lilah began to think of ways to help citizens convince the MTA, in this upcoming encounter, to acknowledge the problem of phantom buses and to fix it. Lilah’s idea was to make a data representation of phantom buses, then give it to citizens who could present it at the upcoming public hearing. Lilah searched around and found two relevant datasets. One dataset consisted of the set of locations and times at which all buses operated by the MTA were scheduled to arrive at their stops, called the “schedule dataset”. The second dataset consisted of real-time live data from the Global Positioning System tracker hardware that is on every MTA bus, called the “real-time dataset”. Lilah’s idea was to characterize the phantom bus phenomenon by quantifying the discrepancies between scheduled and actual service levels. Lilah had found a problem, which Getzels (1979) aptly described as a critical but overlooked part of problem-solving.

Lilah brought the problem of phantom buses to the CTV and pulled together a team to address it. Lilah hoped that other CTV members might share enough of her concerns about this key city transit system, and also share interest in expanding their data science repertoires, that they might want to join the team. Three other CTV members joined. The team divided their labor (Hutchins, 1995; Stevens, 2000) according to each member’s distinctive competencies and interests in learning new data science skills. Then the project work began in earnest.

The team draws together data and transforms it into a strong synoptic math metric

To convince the MTA at the upcoming public hearing to fix the problem of phantom buses, the team would have to *draw together* the disparate data into one compelling synoptic representation of the problem (Latour, 1987). To start, the team had to gather raw data from both the public “real-time” and “schedule” datasets and store it in one place. Storing the data in one place would require Lilah to find a data storage service and to write a kind of computer program that she had never written before (FN, 6/02). Lilah took this opportunity to learn. She selected a data storage service that she was curious about but had never used in her day job as a data scientist. She wrote the new computer program and revised it until it reliably aggregated the two datasets (FN, 6/14). Having gathered the data into one place, the team was ready for the next step — deciding on a way to quantify phantom buses.

The team set out to find a way to quantify the phantom buses phenomenon that would expose two aspects of the problem at once — its pervasiveness and its distribution across the city. The team insisted on seeing the distribution because they suspected that phantom buses were most concentrated in neighborhoods in the South and West, which historical records showed were chronically neglected by the city. The team wanted to be ready to argue, at the upcoming public hearing, that the MTA should focus its resources on fixing phantom buses in those neighborhoods, if indeed their analysis showed that they were most affected by the problem. With this in mind, the team decided to quantitatively represent the phantom buses phenomenon as a metric consisting of the ratio of actual to scheduled trips. Then, the team had to decide between two ways of aggregating the data — by stop or by route. The team decided on the latter, because it offered a practical advantage for the upcoming contestation. The MTA had control over the staffing by route but not by stop. Therefore, in the upcoming hearing at City Hall, it would be easier for the team to ask city officials to compel the MTA to increase its staffing on specific routes than at particular stops. The team had found a way to quantify the phantom buses phenomenon. But the team was still not yet ready for the anticipated contestation.

If the team was going to present their metric at the upcoming public hearing, they still had yet to do the work of calculating it. The two datasets contained so much data that the team had to write separate computer programs to calculate the numerator and denominator (i.e., actual vs. scheduled). This was no easy task, but the team persisted out of their desire to both use the metric for the upcoming contestation and to learn to write new kinds of programs. To calculate the numerators, the team taught themselves to work with a number of libraries in the Python programming language in order to transform a metaphoric mountain of geo-spatial latitude and longitude data of the real-time locations of the buses. Calculating the denominators was not easy either, because it required the team to convert the schedule dataset, which was encoded in an idiosyncratic data format that only the MTA used, into a more standard one to match the format that the numerator dataset was expressed in. Then, having separately calculated the numerators and denominators, the team wrote a third computer program to combine the two. This computer program contained a line of code which read g = trip_count_rt / trip_count_sched, which is equivalently expressed in shortened form as g = r / s, where for a given route, g stands for the ratio of phantom buses for that route, r stands for the number of actual real-time bus trips, and s stands for the number of scheduled bus trips. From this computer program, the team created a data table showing the metric computed for all of the buses in the city (FN, 7/18). A few rows are depicted in Figure 1(a). The leftmost column, highlighted in yellow, showed that phantom buses were concentrated in the South and West of the city. The team had represented the pervasiveness and inequitable distribution of phantom buses.

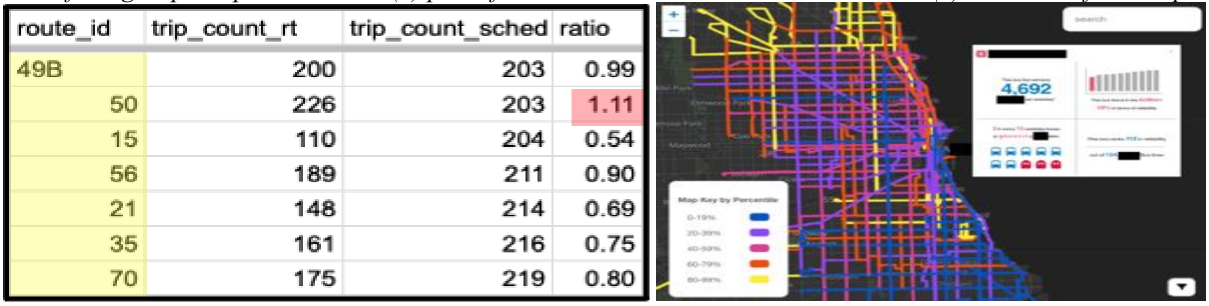
The team needed the metric to be strong for the anticipated contestation with the MTA at a City Hall Transit Hearing. But team member Diego noticed a potential problem that called the metric's strength into question. The problem was that some of the routes had ratio metrics with values greater than one. One of these ratios is highlighted in red in the rightmost column of Figure 1(a). For any such route, this would mean that there were more actual trips than scheduled trips; this would indicate *surplus* buses, rather than phantom buses. The team worried that the MTA might challenge the ratios above one as faulty, if they did not represent a *fact* of reality but rather were an *artefact* of a poor algorithm (Latour & Woolgar, 2005). The team members went to great lengths to figure out whether their computations were indeed incorrect. Lilah inspected her prior code and noticed that it was "double-counting" numbers, and that this was ultimately rooted in a tricky data architecture problem involving what the team called "non-unique identifiers" (FN, 10/4). The metric was not yet strong enough for an anticipated contestation with the MTA at City Hall.

Diego then proposed an idea for revising the metric so it could not be dismissed so easily by the MTA. Diego's idea was to calculate the ratio metric in a coarser time window than it had been calculated before (daily rather than hourly). Diego then wrote new code, which generated data tables based on his newly calculated metrics. The team then double-checked the new code to ensure that its architecture addressed the issues that had plagued the old code, and that the resulting new ratios were plausible when considered together as a whole distribution. After these revisions, most of the numbers were lower than they were before, indicating even more phantom buses than the prior round of calculations had identified. The team had now eliminated a problematic artefact in their metric and had enhanced the quality of the evidence about the phantom buses problem, aligning nicely with Latour's description of making a representation stronger for its uses in future anticipated contestations.

The final step in the team's process involved the team transforming Diego's data table to produce a final synoptic map visualization of the metric, pictured below in Figure 1(b). As of this writing, the team has shared the map of the metric with citizens via social media, along with a supplementary written report detailing the methodology the team used to make the metric and the team's software repository of computer programs. Citizens can now testify before City Hall to get city officials to persuade the MTA to fix the problem of phantom buses, especially in neighborhoods most affected. To summarize, the team had listened to citizens' experiences with phantom buses, found a problem (Getzels, 1979), quantified the pervasiveness and inequitable distribution of that problem, then drew together and transformed data into a synoptic representation — they had turned the question of Phantom Buses into a fact (Latour, 1987). As of this writing, we don't know if the team, or the citizens with whom they shared their metric, will succeed in the upcoming contestation with the MTA at City Hall. But if Latour's conceptual model is as apt as we have found it in this case, they were as prepared as they could be.

Figure 1

Two of the group's representations, (a) part of a data table with the initial metric, and (b) the team's final map



route_id	trip_count_rt	trip_count_sched	ratio
49B	200	203	0.99
50	226	203	1.11
15	110	204	0.54
56	189	211	0.90
21	148	214	0.69
35	161	216	0.75
70	175	219	0.80

(a) (b)

Discussion

This case study is one of a small but growing number of examples of a new genre of math that is done for civic and social good (Esmonde, Curnow, & Riviere, 2014; Taylor & Hall, 2013). Our community can make use of more such examples, to show learners that math is not just a tool of the powerful (Noble, 2018; O'Neil, 2016).

This case study speaks to learning issues at both the collective and the individual levels. At the collective level (Hutchins, 1995; Stevens, 2000), the team learned how to take a *question* about a potential civic problem and turn it into a *fact* that documented that problem. The team learned something that was not known before and now could be 'taught' to others. At the individual level, each project member took opportunities to become better data scientists. For example, Lilah identified a mistake in her code and revised it with Diego's help.

In addition to the value of this case study as basic research on mathematics and data use in the wild, it also might suggest ideas for motivating young people to learn math. In school that motivation is hard to find and when it is found it is often better characterized as what psychologists call extrinsic rather than intrinsic. Students often do math for the benefits that high grades in math courses bring (Boaler, 2000). In contrast, the Phantom Buses members did math for free and without 'credit', volunteering after working all day in math-heavy data science jobs. A constant refrain math teachers everywhere hear is "when are we ever going to use this". This case suggests that learning environments that provide analogously consequential problems as those found and solved by the Phantom Buses team could mean a real answer to that question, with the added benefit that young people might not see only see that math has a meaningful use, but one that can make the world a better place.

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Situating Antiracist Professional Development in Cultural-Historical Context

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Abstract: In this paper, we report a systematic review of the literature on teacher professional development (PD) focused on antiracism and ask the following questions: *(1) what are the assumptions about race and racisms embedded within PD designs? and (2) what is the relationship between PD design features and outcomes for teachers (e.g., development of antiracist dispositions and practices)?* We reviewed research that is explicit about the design of PD for teachers' development of antiracist praxis with particular attention to how PD designs are conceptualized, and how they facilitate changes in teacher practices. We found that many PD interventions did not connect their designs to cultural-historical conceptualizations of race, and even fewer made empirical claims about changes in teacher practice as a result of PD.

Introduction

In the wake of George Floyd's murder (E. Hill et al., 2020), a national reckoning about systemic racism awakened school leaders and policymakers across the U.S. to the fact that racism is real, alive, and thriving (Madkins & Nazar, 2022). The recognition that there was a need to create professional learning opportunities for teachers that were serving a growing population of minoritized learners, intensified *professional development* (PD) efforts – defined as bounded, organized activity for teacher learning – in public schools to confront racism and learn, now colloquially termed, *how to become an antiracist* (Kendi, 2019).

While the energy for anti-bias and antiracist teacher PD has somewhat dwindled after the U.S. protests of 2020, the urgency for a radical transformation of *teacher learning*–the developmental learning process bounded within and outwith PD–has never been more necessary. The cumulative impact of historical inequities on opportunities to learn, along with existential threats that disproportionately impact communities of color (e.g., Covid-19 and climate change), means that status-quo public education does not simply reproduce racial structures, but can exacerbate inequalities in realms beyond education.

Schools have simply been too effective at reproducing inequitable educational outcomes for black, indigenous, and other children of color (BIPoC) in the U.S. These patterns are a byproduct of the everyday ways in which structures of domination on the basis of race (Omi & Winant, 2014) shape inequitable opportunities to learn, and are by no means a reflection of minoritized students' inherent ability to learn. Teachers, embedded within these systems, invariably participate in maintaining a racially unjust status quo, regardless of whether they are cognizant of the ways in which they do (Milner, 2017). Teachers *could*, however, be marshaled as critical players in the process of reimagining schooling–reconfiguring the educational processes that create meaningful outcomes for children of color, in the near term (i.e., opportunities to learn), as well as far (i.e., possible futures).

In this paper, we focus on envisioning what it takes for teachers to learn how to reimagine and refigure educational processes they orchestrate through teaching practice in service of the growth of BIPoC youth. We seek to surface how PD designs for antiracism help teachers grow in ways that, generatively, lend themselves to the creation of healthful learning spaces for minoritized children to grow and thrive in the near term (and have the potential for longer-term impacts on children's possible futures). We report a systematic review of the literature on teacher PD and ask the following questions: *(1) what are the assumptions about race and racisms embedded within PD designs? and (2) what is the relationship between PD design features and outcomes for teachers (e.g., development of antiracist dispositions and practices)?* We review research that is explicit about the design of PD for teachers' development of antiracist, equitable, and culturally relevant praxis. In this review, we consolidate PD design features that yield teachers' expansive learning about equity, justice, and antiracist praxis. Our goal is to 1) synthesize the current state-of-the-art on PD for antiracism, 2) identify design features of PD that lend themselves to teachers' expansive learning around antiracism, and 3) to identify the gaps in the literature on supporting deep and sustained conceptual transformation around race/racisms that could be embodied in teaching practices that work towards fundamentally antiracist ends for BIPoC students.

Methodology

Situating antiracist professional development in cultural-historical contexts

We conducted a synthetic review of literature on teacher PD focused on *antiracism*. We define *race* as social-cultural construction of *racial meanings* (real or imagined attributes used to classify people) (Omi & Winant, 2014). These signifiers "inform practices, and shape institutions and communities, demarcate social boundaries, and organize the distribution of resources" (Omi & Winant, 2014, p. 125). *Racism*, then, is the production or reproduction of "structures of domination based on racial significations and identifiers" (Omi & Winant, 2014 p. 128). In schools, this process of production/reproduction can occur at the macro-level through structures such as school funding (explicit systems of unequal and inequitable distribution of resources to public schools that serve particular communities), at the meso-level through systems such as tracking (a system of sorting children by perceived ability levels in schools, which in the U.S. disproportionately places BIPoC youth in low and remedial tracks); and the micro-level instructional decisions (e.g., how teachers teach children in low and remedial tracks, such as lowering the cognitive demand of instruction). In other words, the consequences of racism in schools and teaching are inequitable opportunities to learn, which in the U.S. have materially and disproportionately harmed BIPoC children and youth.

Therefore, we understand antiracist teacher PD as designs for teacher learning that seek to develop teachers' conceptual understandings about race/racisms, as well as pedagogical practices that fundamentally resist the reproduction of the racial meanings that shape education equities for BIPoC youth. More specifically, we view antiracist teacher professional learning in terms of human development as situated within cultural historical activity systems (Engeström et al., 1999). In this sense, we attend to several features of designs for PD: 1) mediational tools for sensemaking around race/racisms and antiracism, 2) implicit and explicit articulations of the nature of race/racisms with particular attention to its cultural-historical formation, systems of power, and hierarchical systems; 3) implicit/explicit theories about how teachers learn. Next, we examined the relationship between these design features on the outcomes of PD interventions. Our goal is to consolidate the evidence, in terms of designs for teacher learning that support teachers' generative growth in dispositions and practices that yield healthful learning spaces for BIPoC youth.

Review methods

We conducted a database search in ERIC that focused on three broad components: 1) teachers, 2) antiracism, and 3) professional development. After removing duplicates, a total of 1470 articles were identified. We used excluded articles that did not meet the following criteria, 1) description of K-12 PD design centered around antiracism, 2) was an empirical study, and 3) BIPoC students were identified as beneficiaries of growth in teacher learning. Studies were excluded if they were evaluation studies or doctoral dissertations. This resulted in 31 articles that were decomposed to analyze features of the interventions (e.g., mediational tools, conceptualization of race/racism, duration, frequency, iteration, situativity, roles of teachers/PD providers, intended outcomes, reported outcomes, and evidence of outcomes). In this paper, we focus on the 14 studies that documented evidence that teachers' shifted in dispositions or practices.

Findings

Gaps in cultural-historical articulations of antiracism

From the cultural-historical perspective on antiracism and learning we utilized to conduct this review, we observed gaps and variations in the ways they conceptually framed antiracism. We found that almost half of the studies, which all explicitly articulated goals to change teachers' practices towards antiracist ends, did not define or frame antiracism in ways that acknowledged how racism shapes power in the learning environments, is systemic, or historical in its formation. In other words, many of the studies were striving to advance teachers' antiracist practice but did not fully acknowledge the cultural-historical nature of racism. Not fully conceptualizing the nature of the phenomena raises questions for whether an intervention could be fully efficacious.

Six out of the 14 manuscripts that shared a goal for change in classroom practices did not offer any cultural-historical framings of antiracism. Many of the studies (K. D. Hill, 2012) conceptualized antiracism from a perspective of culturally-relevant pedagogy (e.g. Ladson-Billings, 1995), which in its original formulation, includes calls for educators to support the development of "critical consciousness" in teachers. However, a common theme in the studies within this category was that they focused on supporting teachers' development of pedagogical practices but did not link these practices to broader, sociocultural practices and structures of racism. Other articles in this category (e.g. Katz et al., 2010) limited the scope of teacher learning to derivative models of culturally relevant pedagogy, such as multicultural education, focusing on increasing representation in the classroom in which cultural markers of particular groups (e.g. historical figures) were integrated into classroom teaching.

Of the eight studies that did frame antiracism in terms of systems, power, and history, only two conceptualized antiracism in terms of all three of these aspects of a cultural-historical framing of racism/antiracism (Seglem & Garcia, 2015; Shah & Coles, 2020). These studies were explicit about how learning environments were shaped by racialized power dynamics and the nature of systemic racism as a historical process. These studies connected all three aspects of this frame to the PDs they designed and implemented. The remaining six articles touched on one or two dimensions of racism/antiracism and made explicit design connections (e.g., engaging teachers in discussions of Critical Race Theory as a mediational tool for sensemaking about systemic racism). For the purposes of this paper, we examined these eight articles further to investigate the evidentiary base for how PDs constructed through these framings of antiracism accomplished their stated goals for changes in teacher practice.

Deepening the connection between antiracist frames and empirical outcomes

Based on the articles reviewed, there is a need for more research to provide strong evidence on how PD designs focused on antiracism can promote changes in teacher practice. Of the eight articles that explicitly framed antiracism from a cultural-historical perspective, we found that half had made evidentiary claims about changes in teacher practices resulting from their participation in formal teacher learning (Brown & Weber, 2016; Irby, 2018; Johnson, 2011; Villavicencio et al., 2020). One study examined the effects of the pre-service teacher professional learning design on “racial noticing” in the classroom and found that while teachers developed anticipated conceptual understandings in pre-service methods classes, such conceptual learning did not translate to classroom practices during student teaching in the classroom (Shah & Coles, 2020). The other three manuscripts did not examine how their professional learning designs impacted classroom practice.

The small number of articles that connected cultural-historical perspectives on race to their PD designs and observed changes in teacher practice suggested designs were successful in changing teacher practices. However, we view a need to expand the evidentiary basis of the studies that connect features of PD designs for antiracism with teacher practices. One article examined teachers’ use of school disciplinary data through ethnographic methods and observed changes in the ways teachers collaboratively engaged in sensemaking on school disciplinary data (Irby, 2018). Brown and Weber (2016), through a case study of two pre-K and kindergarten teachers who participated in PD designed to incorporate culturally-relevant pedagogy into classroom activities, found that lessons designed in this PD context were implemented in the two teachers’ classrooms. Similarly, through a case study of two middle school science teachers, Johnson (2011) found that the two teachers who participated in a PD to incorporate aspects of culturally-relevant pedagogy into their classroom practice did in fact implement classroom practices intended to better serve Hispanic students in their classes. Villavicencio and colleagues (2020), reporting on a PD organized by the Center for Racial Justice in Education to, “provide opportunities for educators to examine how racism manifests in their schools and develop policies and practices that are grounded in racial justice”(P.2), found through a case study of two school sites that while staff in both schools developed shared language regarding racial justice and implemented them into organizational change plans, only staff in one school implemented those plans.

Discussion and implications

Designs for learning inherently make conjectures about how people learn, and a robust conjecture attends, intentionally, to these processes by designing features (tools, tasks, discursive practices, participant structures) that help to mediate learning processes towards an intended outcome (Sandoval, 2014). In this review, we found that few PD designs interrogated the nature of racism/racisms as historical and cultural practices, in order to support teachers’ learning about how to embody antiracism. The findings also highlight that designs that engaged teachers in sensemaking around the cultural-historical dimensions of race and racisms, reported outcomes of transformation in teachers’ practices towards antiracism.

The implications of these findings highlight the need for research and PD practices focused on supporting teachers in using their agency to resist normative forms of activity that ignore the historicity of race and racism while serving to uphold extant hierarchies and systems of oppression and power, as it is precisely these norms that over time have material consequences for BIPoC children and youth. Thus, we conclude that designs for teacher learning around antiracism must attend to the nature of race/racisms–social processes that are tacit yet ubiquitous– and attend to how to develop teachers’ critical consciousness, and how to develop teachers’ agency to utilize emergent conceptual change around the phenomena of race/racism to transform praxis. The nature of racism as a wicked problem means that there is a need for design logics that can help to make visible to teachers the ways in which hidden and socialized ideologies shape teaching and learning, and its consequences (Lee et al., 2022). In addition, there is a need for design logics that can see themselves as sowers of seeds of resistance to ubiquitous and normative, activities, tools, and ideologies that reproduce racism.

Endnotes

(1) Full list of reviewed articles and search terms https://tinyurl.com/antiracismPD

(2) This work was supported by the National Science Foundation, Award #2143993

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Spatial Reasoning and Debugging With Lego Structures

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Abstract: Our study builds upon K-2 students' early block building experiences and the increased importance of fostering computational thinking skills, especially debugging. We had 12 K-2 students debug a Lego structure by finding and fixing differences between a given and target structure. Half of the students worked with red Lego bricks only while the other half worked with various colors of bricks. We analyzed the type and order of errors they fixed and their process for debugging. Misplaced Lego bricks on the plate were the most difficult for students to find and fix.

Introduction

With the increased focus on computational thinking, considering how students use computational thinking skills (e.g., debugging) across non-programming domains such as block building is important (Barr & Stephenson, 2011). In block building, debugging can involve identifying and fixing differences between two structures (Kocabas et al., 2022), a type of change detection task (Rensink et al., 1997; Shore et al., 2016). In recent research, K-2 students built a vertical Lego structure. They were then told to find and fix differences between their completed structure and a modified one using a building manual (Kocabas et al., 2022). The students successfully engaged in debugging using strategies similar to those in programming. However, students who used a grayscale manual (as opposed to color) identified fewer differences, and the symmetrical features of the vertical structure played a role in their debugging (Kocabas et al., 2022). Students' efforts to build the original structure may have aided their efforts to debug it. In this study, we expand on prior findings by investigating students' spatial thinking as they debug a combination horizontal-and-vertical structure when they did not build the original structure. Our research questions include the following: How do students debug a multi-colored versus a red Lego structure when referring to pictures of the target structure and a video of the structure being composed? (a) Which bugs do students fix and in what order? (b) What debugging strategies do students use?

Spatial reasoning and change-detection framework

Spatial visualization skill is "…generating and manipulating mental images of two- and three-dimensional objects, including moving, matching, and combining them" (Clements & Sarama, 2009, p.110; see also intrinsic spatial skills, Newcombe & Shipley, 2015). Children ages 5-8 (similar to our participants) develop from being able to slide, flip, and turn shapes (sometimes in the wrong direction) to being able to use mental images to predict the results of moving shapes (Clements & Sarama, 2009). Further, they develop from *local framework users* that can interpret "objects' positions relative to landmarks" (p. 118) to being able to interpret locations based on coordinates (Clements & Sarama, 2009; see also extrinsic spatial skills, Newcombe & Shipley, 2015). If the landmarks are not obvious, K-2 students might struggle to place blocks along the forward and backward dimension in relation to those landmarks (e.g, Kocabas et al., 2022). Block building activities support these spatial reasoning abilities (e.g., Brosnan, 1998; Casey et al., 2008), part-whole reasoning (Casey et al., 2008), and visual-difference recognition.

Two types of visual change-detection tasks include identifying differences after sequentially seeing two versions of a scene (e.g., Shore et al., 2006; Stieff et al., 2020) or seeing two versions of the scene side-by-side (see "Hidden Pictures" tasks, https://www.highlightskids.com/games). Fewer elements in the scene or central errors make differences easier to spot (Rensink et al., 1997; Shore et al., 2006). Additionally, while deleted objects are the hardest to detect, changes in object position and orientation are easier to spot than changes in color (Rensink et al., 1997; Shore et al., 2006). In contrast, visual changes such as color on digital molecular representations were easier to detect than other changes such as spatial grouping for undergraduate students (Stieff et al., 2020). Debugging is a critical process in programming and non-programming activities such as puzzles or block building (Bofferding & Kocabas, 2021; Ahn, et al., 2021; Caeli & Yadav, 2020). However, in change detection debugging tasks with a Lego structure, students were most likely to find errors at the top and bottom of a vertical structure, along with differences in orientation and placement. Errors in the middle of the structure were hardest to find (Kocabas et al., 2022). They also used spatial thinking techniques like visualization and rotation and similar debugging strategies as in programming (Kocabas et al., 2022; Murphy et al., 2008, see Table 1).

Methods

Participants and setting

In this exploratory study, we recruited four kindergarteners, four first graders, and four second graders from an afterschool program at a Montessori school in the midwestern United States. During each session, students met with one of the researchers one-on-one in a classroom. As students worked with the Lego bricks, we used two cameras to record their work from the front and back of the structures.

Design

The data comes from the third out of three sessions of a larger project. During this session, we gave students an already-built Lego structure (randomly assigned to using multicolored or red bricks) and asked them whether they would like to use the pictures or video to debug the six bugs in the Lego structure (see Figure 1A & 1B). They could switch between these media whenever they wanted. As they debugged, we asked students questions about where they were looking in the picture or video, how they identified erroneous bricks, and how they knew how to fix errors. We also gave some hints (e.g., “A structure was placed in the wrong spot on this green plate.”) if the students were stuck or feeling frustrated. We analyzed how students debugged the six bugs on the Lego structure in the third session of the project. We first identified which bugs each student debugged and explored the sequence of debugging among the bugs. We also identified if they introduced a new bug when debugging. Then, we coded the students’ debugging process based on programming and block debugging strategies (see Table 1; Kocabas et al., 2022; Murphy et al., 2008, see also Bofferding et al., 2022).

Table 1
Description of Program Debugging Strategies and Potential Application to Block Debugging Strategies

Debugging strategy	Programming description	Finding bugs in block structures
Tinkering	Students randomly making changes; multiple changes at one time.	Students play with the blocks, randomly adding or removing pieces to see the result.
Tracing (top-to-bottom or bottom-to-top)	Students follow each line of code and match it with the result, reasoning forward or backward.	Students start at the top or bottom of the structure and match it sequentially with the steps in building the structure.
Pattern matching	Students just know what is wrong or recognize the problem based on past experience.	Students notice a difference by looking at the overall structures. They may move their eyes back and forth to similar parts of the structure and picture to notice what has changed.
Rebuilding	Students scrap the code and reprogram from the beginning.	Students take apart the structure and rebuild it using the target structure by using the manual.
Understanding the Structure	Students reason about how the code works and the problem.	Students turn the physical structure or take apart parts to see how they are put together.

Results

Bugs and order

Overall, students who debugged the multicolor structure found roughly one more bug on average (M=5.25, Mdn=5.75) than students in the red structure group (M=4.17, Mdn=5). All students found and fixed Bug5, which involved rotating the eye, making it the easiest bug. In fact, three students in the multicolor group and four students in the red group found it first. Students were less successful at fixing the rotation issue with Bug4 with only nine students doing so (and it was often the fifth bug they found). Therefore, although students could rotate bricks (Clements & Sarama, 2009), identifying the differences in orientation was easier when the brick had a distinct feature. Students who did not find rotation Bug5 first often found the missing piece instead (Bug2) or fixed the piece with an incorrect thickness (Bug1). Eleven students (six multicolor, five red group) found Bug2, followed by nine students (five multicolor, four red group) who fixed Bug1. The difference between groups increased for correcting Bug3 on the staircase; five students from the multicolor group fixed it, while three students from the red group did so. Students in the multicolor group not only had to fix the block from a 2x3 to a 2x4, but they also had to change the color. While these students noticed both parts of the bug (if they found the bug), one student noticed the change in color later.

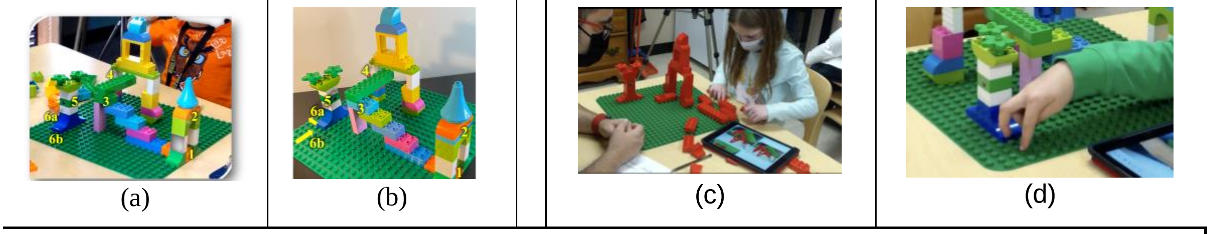
Even though the video showed Bug6a and Bug6b first, most students fixed these errors last (if at all), and most students needed the hint that one of the structures was put in the wrong place. Once they figured out that the tree was in the wrong place, five students from the multicolor group and four students from the red group fixed Bug6a, which involved adjusting the tree structure outward (from three to two studs from the edge), farther away from the staircase structure. Four students from the multicolor group and only two students from the red group also fixed 6B by adjusting the structure inward (from four to six studs from the edge).

Debugging strategies

Groups used similar debugging strategies and referred to the video and pictures of the final structures to varying extents. Two students only relied on the pictures to debug, six students started with the pictures and then switched to the video to help them as needed, and four students started with the video and then switched to the pictures as needed. No students only used the video to find the differences, but all of them turned the structure at some point to understand the structure and check for differences. Only one first grader used a rebuilding strategy (see Figure 1C) when trying to correct differences in a chunk. She fixed Bug2 and Bug3, but then later removed the front arch with tower and the staircase that led from it. She re-placed Bug1 (placing the thin piece back) but put it back in the wrong place as she attempted to recreate the staircase. Further, she did not space the stairs correctly as she rebuilt, so the placement of her fixed Bug3 ended up in the wrong place. She did not replace the front arch and tower (including the fixed Bug2) before deciding to be done. All other students fixed bugs by removing the pieces directly around the bug and placing them back immediately. As the students corrected the Lego structure, they employed pattern matching and tracing strategies while moving between the pictures and the video. Additionally, each student utilized the understanding of structure strategy by turning the structure to identify any differences. Nonetheless, in some cases, specific students chose to look at the structure from different viewpoints instead of turning it. When fixing Bug6a and Bug6b, students usually counted the studs on the base (Figure 1D), and only one second grader counted the studs on blocks in her process to fix Bug3.

Figure 1

(A) Given Structure and Target Structure, *(C) Rebuilding the structure, (D) Counting the studs on the base*



(a) (b) (c) (d)

Incorrect pieces: Bugs 1 and 3, **Missing pieces:** Bug 2, **Incorrect orientation:** Bugs 4 and 5,
Incorrect placement: Bugs 6a and 6b

Discussion and significance

Unlike in previous change detection tasks with Lego structures, we organized the structures horizontally. Although Bug5 was shown third, students were most likely to fix it first, easily turning the eye. This result suggests they could anticipate the rotation and that pictures on the bricks made them central to the Lego scene. It took longer for students to notice orientation Bug4 compared to Bug5, further suggesting that students might easily notice spatial bugs involving orientation when some visual feature makes it stand out more (Stieff et al., 2020). Contrary to traditional change detection tasks where identifying missing elements are hardest (Rensink et al., 1997), identifying the missing brick (Bug2) was one of the first two bugs students noticed, similar to prior Lego debugging results (Kocabas et al., 2022), even for five students who were only looking at the images. Changes in block size (Bug3 on the stairs) were harder for students in the red group to notice; students in the color group might have found this bug easier to find because it was also in a different color. Future explorations should determine if pairing bugs could make them more salient to students.

Interestingly, changes in placement (Bug6a and Bug6b) took the longest for students to find and were hardest (with many needing hints). Therefore, placement bugs on the Lego plate appear to be more difficult to detect than placement bugs on a structure (Kocabas et al., 2022). Students had an easier time detecting differences in placement when the tree structure needed to be shifted away from another structure as opposed to shifted to the right in relation to a structure, suggesting the saliency of proximity to landmarks (Clements & Sarama, 2009; Newcombe & Shipley, 2015). In addition, students counted the studs on the base to identify and fix the placement errors. Having more parts of the block design placed horizontally (as opposed to vertically), may have encouraged some students to use mathematical concepts such as counting and helped move them toward seeing the Lego plate as a form of a coordinate system made up of the studs. Future work could further explore factors that encourage students' use of the Lego plate as a coordinate system versus proximity to other landmarks when placing pieces.

For debugging, the findings were consistent with previous studies that block play can engage children in debugging in early years of education. Compared to our previous analysis where students debugged *after* building a structure (Kocabas et al., 2022), none of the students completely started over building from the beginning and followed along with the video to build the corrected structure. In fact, only one student completely removed a chunk, and that student had difficulty putting it all back together. Building a structure first may help students' rebuilding; whereas fixing one structure at a time may have been easier given the several parts of this design.

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Culturally Responsive Computing for Black Boys Through Sports Technology

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Abstract: Identity and intersectionality must be foregrounded in design interventions for computing and STEM education. In this paper, our research team presents findings from a sports and technology intervention we developed with the culturally responsive computing framework. We implemented the intervention in a local summer program for young Black boys entering grades 3-8. Data were collected and analyzed from caregiver interviews. Findings suggest that youth recognized relationships between digital technologies and sports, and conceptualized more expansive ways for technology to mediate their sports interest. The interviews also revealed the need for greater intentionality in facilitating family engagement.

Introduction

Learning Sciences literature on the relationship between sports and technology highlights approaches to engaging minoritized youth in CS-STEM (STEM and computer science) learning experiences by situating them in athletics (Drazan et al., 2017; Jones et al., 2020). Efforts for disciplinary learning that introduce or expose the CS-STEM practices and knowledge within non-traditional learning contexts – while reinforcing youths' cultural practices and knowledges – can enable minoritized youth to recognize CS-STEM within their interests. We present findings for an intervention on sports and wearable technologies at Brothas Camp, a summer program for Black boys in elementary and middle school. We engage the following research question in this study: What do conversations at home reveal about CS-STEM interest development for youth that are exposed to sports technology through a sports camp?

Positionality statement

Responding to the charge that Vakil et al. (2016) gave academic researchers to "critically examine the role that race, racialization, and power play across the arc of DBR [design-based research] projects" (p. 205), we acknowledge here our diverse positionalities. All the authors of this paper are People of Color. The fourth author is a Black male engineer who plays sports to this day and who facilitated our sports technology curriculum. Our first and third authors facilitated several of the sessions and played sports in their youth. They were able to provide context where necessary, expanded on the youths' ideas, and teased with them. One of the authors is also a former teacher who leveraged her blackness when interacting with youth and camp staff. Although our second author did not interact with the camp, she was integral to the data analysis and writing the findings. We also acknowledge our outsider relation to Brothas Camp. None of us grew up in the city where Brothas Camp took place, and our intervention pushed into the camp, which kept us relatively separate from the camp community.

Literature review

Disciplinarity (in learning, practice, and identity) can function as a means for excluding and othering. Research on CS-STEM interest development (Wang et al., 2017; Dou et al., 2020) and the "identity turn" in CS-STEM education (Shaw & Kafai, 2020) has noted how existing identities should be foregrounded in interventions for broadening participation. Many of these research efforts address stereotypes, such as the notion of CS-STEM as acultural, apolitical, and decontextualized, and CS-STEM identity as "singularly-focused," "asocial," "competitive," and "male" (Lewis et al. 2016). However, exposure to computing content that engages participants in larger critiques about a technology's purpose, potential, and impact tends to be more interesting to minoritized youth (Margolis et al., 2015; Webb et al., 2012; Vakil & Ayers, 2019). Research on "practice-linked identities" (Nasir & Hand, 2008; Nasir & Cooks, 2009), "practice-linked learning and environments" (Jones et al., 2020), and "everyday learning" (Philip & Azevedo, 2017) demonstrates the need for broadened access to disciplinary resources for diverse learners.

Culturally responsive computing (CRC; Eglash et al., 2013; Scott et al., 2013) is a pedagogical framework for computing education that uses culturally-responsive values to validate learner interests, identities, and cultures. The framework includes several important tenets. Tenet 1 sets the expectation for youth use existing tools innovatively and construct artifacts that represent big ideas, irrespective of prior knowledge or exposure;

Tenet 2 supports unique learning contexts where youth explore a technology's capabilities, consider their limitations, and transform them; and Tenet 3 attends to learners' identities and the importance of intersectionality in helping youth understand the multiple dimensions of self. By engaging in critique and interacting with tools, youth in CRC learning environments realize their identities in relation to power and become empowered to actively resist these dynamics. Tenet 4 describes the role of digital technology in equipping youth to reflect on and reimagine their identities through counternarratives and counternormative images. Tenet 5 invites youth to reappropriate disciplinary and research practices to dismantle systems and empowers their communities. Importantly, CRC affirms the critical role that caring adults such as parents and community members have in guiding and advocating for youth.

Design of intervention

Brothas Camp (renamed for anonymity) was a summer program that offered Black boys in grades 3 through 8. Camp sessions for elementary students occurred separately from the middle school students, and youth within each session were organized by their grade levels. The Brothas Camp designers incorporated several communal aspects to instill pride and promote camaraderie. Staff members and college mentors – all Black men – were affectionately referred to as "brothas," and the group became "my family". Our work with Brothas Camp provided youth the opportunity to explore, de-settle, and reconcile their relationship with athletics and CS-STEM.

Contextualized learning opportunities for CS-STEM provide alternative conceptions of what computer science is to youth who do not selectively engage in CS-STEM activities (Drazan et al., 2017; DiSalvo et al., 2014) or who do not benefit from "preparatory privilege" (Margolis et. al, 2015; Isaac & Gardner-McCune, 2021). Such activities can essentialize dominant epistemologies, which for our American context meant (whether intentionally or unintentionally) requiring participants to forsake their identities to develop CS-STEM identities and practices. Our intervention exposed youth to sports wearables while attending to both their heritage culture (blackness) and vernacular culture (sports) (Eglash et al. 2013). Similar to other sports technology interventions, learning was situated on the court and field to connect these sites of sports practice and activity to CS-STEM experiences involving wearable physical computing kits. We conducted three 45-minute sessions with middle school youth and four with elementary school youth. Middle school youth completed activities for track and field with pedometers and smart watches, soccer activities with micro:bit microcontrollers, and basketball drills with sensor-enabled basketballs. Elementary school youth engaged with the same activities for track and basketball, and also drew their dream sports technology.

Methods

Some qualitative and quantitative data – including youth drawings – were published in the Wallace et al. (2023) study. For this paper, we focus on qualitative jottings and interviews with youth's caregivers. Members of the research team engaged in participant observation, recording jottings about the implementations and youth insights. These data helped support our sensemaking around youth experiences with the design intervention. We include data from three semi-structured interviews conducted with caregivers after Brothas Camp. The interview protocol focused on: what the child shared with family members regarding their camp experience; the child's interests in sports and how they engage with or build digital technologies; impressions of the child's relationship with school and extracurricular activities; and suggestions for program improvements. The Brothas Camp director recruited caregivers to participate in the interviews. Caregivers completed an intake process form and consented to participating in the study. Interviews were audio-recorded and machine-transcribed with a web conferencing platform. Transcripts were then corrected by the authors and reformatted for analysis.

The first and second authors coded short passages within the transcript to identify speech related to how caregivers described youth interactions with the sports-technology intervention and their perceptions of the technologies. These codes referenced parent wording. The second iteration of coding looked for instances of youth's connections between sports and technology. We used Braun and Strauss' thematic analysis (Vaismoradi et al., 2013), to find thematic codes within the data by identifying, analyzing, and presenting those themes. These more detailed codes were grouped into categories: at-home connections to technology and sports, building community, and academic and athletic identities.

Findings and discussion

In all three interviews, at-home connections between technology and sports emerged from interactions around smartwatch technology. The interviews revealed how conversations from the camp made it home, and how the families structured communication around the day's events. Youth brought up ways that this technology could track heart rate, step counts, and sleep. Parents immediately recognized their youths' excitement with these technologies and mentioned nuances around their talkativeness. One youth used the tech to regulate their physical movement with the hourly reminders. Another one enthusiastically compared the features of their smartwatch with the features of their parent's smartwatch, and they explored the system in a way that the parents had not done themselves. A third child was passionate about sound engineering and wanted to explore ways to connect to this technology. Even so, there was difficulty in remembering events when not explicitly prompted to recount them. One caregiver remarked, "He mentions some of these things, but because I didn't have a reference point for them, you know, when I'm like, 'How is camp? What was your favorite thing?' I don't think he used these exact words." Caregivers recommended that discussion prompts and general information be shared in future implementations to reinforce learning at home.

The interviews were an opportunity for caregivers to address the scholar-athlete identity. They wanted to expose their Black boys to opportunities beyond being "just an athlete" so they see themselves as knowers and practitioners at the intersection of technology and sports. They also noted identities outside the scholar-athlete that connect sports to technology: "...my son loves sports, right? But I want him to be both an athlete and a scholar. And so, there are so many jobs that are within sports that kids don't see outside of the athlete. Somebody who tracks all this stuff as a statistician…Because he's really interested in that. So if I can keep him engaged in this way, he'll see different avenues". Involvement also meant helping their youth navigate the difficulties of discrimination and intersectional spaces. As one parent called out: "He's just not really into sports like that…and you know that's something that all Black boys are supposed to do." This parent stated that they manage the societal expectation for Black boys by validating their child's desire to do whatever activities they enjoy. There are stereotypes around athletic identity and academic acumen, which they referred to as, "this challenge of being able to bring that athletic identity to the academic space without being stigmatized." The families relayed the importance of having affirming spaces that promote possibilities and choice for Black boys when raising them in environments that can be unwelcoming. All three praised the Brothas Camp's emphasis on fostering brotherhood. One caregiver stated, "I'm super excited for him to be in this space of Black joy…everybody looks like me".

Our intervention for Brothas Camp introduced the youth to CS-STEM and to the technology community within sports. Yet, identities are not developed from exposure alone. For youth to conceptualize a CS-STEM identity will require multiple and sustained opportunities for practice and collaboration with caregivers and communities. We designed the intervention with CRC in mind, but connected learning presents an additional framework for facilitating these family engagements in more intentional ways. According to Ito et al. (2013), "Connected learning is realized when a young person pursues a personal interest or passion with the support of friends and caring adults, and is in turn able to link this learning and interest to academic achievement, career possibilities, or civic engagement." Caregivers' desires for deeper discussions with youth reinforced to us the importance of family engagement in sustaining culturally-responsive learning.

Limitations

Relationship dynamics between researchers and those involved in the research are fragile due to race and power (Vakil et al., 2016). For this study, we interviewed caregivers instead of the learners themselves. We wanted to preserve the sanctity of the Brothas Camp community since the activities of Black boys are already heavily surveilled and critiqued in society. Though well-intentioned, this did make data analysis challenging. For instance, our data collection methods prevented us from making claims about the youth participants' CS-STEM identity development. We also do not present the "authentic voice of Black boys" (Coleman, 2016). Nevertheless, caregiver interviews provided us with insights into their thinking and suggestions for extending learning at home.

Conclusion

As an endeavor in culturally-responsive computing (CRC), our sports technology intervention expanded the Brothas Camp youth participants' conceptualizations of CS-STEM. Exposure to various technologies within the sports context created new opportunities for youth to reflect on technology through conversations at Brothas Camp and at home. Several youth also got the chance to ideate future innovations in sports technologies. While we were able to note changes in youths' perceptions of sports and technology, it is unknown what effects the intervention had on their identities, and to what degree. Consequently, future directions for this project include: designing interventions that shift CS-STEM interest in middle school students, communicating our programming to families to extend its effects to home, and considering thoughtful data collection methods that attend to researcher and educator goals while also attending to the interests and concerns of minoritized youth. Our recent research (Wallace et al., 2023) found that CS-STEM interest increased for the elementary school students, which aligns with the current literature. Facilitating family engagement could support CS-STEM identity development, in addition to providing more data on the ways in which caregivers guide youth to connect sports and technology. We envision environments where youth learn to code on the court and on the field, allowing their passion for sports to support the development of new interests and identities. These explorations will certainly require envisioning more creative data collection methods.

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Ideologies of Place and Reasoning About Space With Maps

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Abstract: Contemporary research in the learning sciences has illuminated the central role that ideologies play in reasoning. I extend this research by investigating how ideologies of *place* mediate reasoning about *space* when people use maps. Using map-reading frameworks and critical discourse analysis, I traced how one student, Aaron, drew on ideologies about various neighborhoods to read and interpret patterns within maps of Austin.

Introduction

Mapping is a form of spatial thinking which involves defining, orienting, and representing objects in space (NRC, 2006). Research about how people reason with maps has taken a variety of perspectives. From the cognitive perspective, psychologists have identified a foundational set of spatial thinking skills which all people develop to reason with maps (e. g. Uttal, 2000). From the cultural perspective, anthropologists have described the complexity of practices that different human groups have developed for reasoning with maps (e.g. Hutchins, 1995).

However, maps are not objective representations of space and reasoning with maps is not solely a cognitive or cultural phenomenon. Rather, reasoning with maps is intimately entangled with broader issues of power and dominance (Scott, 2008). Using maps to reason about space also involves thinking also about *place*. Place is a geographical construct which describes the socially shared meanings about who or what activity is natural within a particular space (Cresswell, 1996). Place is where “geography and ideology intersect” (Cresswell, 1996, p.1) and supports people in “seeing, knowing, and understanding the world” (p.16). Therefore, reasoning with maps is simultaneously a cognitive, cultural, *and* political achievement.

This paper investigates the entanglement of ideologies of place and reasoning about space with maps. I examined a group of preservice teachers as they used maps to learn about the geographic and political causes of urban heat island effect in their local city. The primary research question guiding this project was: *how do ideologies of place mediate reasoning about space with maps?*

Conceptual framework

To theoretically guide this work, I drew on three bodies of literature: First, I drew on Rubel et al. (2017) to conceptualize how people reason with maps. Reasoning with maps involves five related practices: (a) reading a map (interpreting the symbolic components of the map); (b) reading within the map (comparing places within a map); (c) reading beyond the map (identifying spatial patterns); (d) reading behind a map (interpreting causes of a spatial pattern); and (e) entering a map (collecting new data for a map). I used this framework to trace how preservice teachers reasoned with maps of their local city to learn about urban heat island effect.

Second, I drew on Hall (1996) and Philip (2011) to conceptualize ideologies. Ideologies are the “mental frameworks – the languages, the concepts, the categories, imagery of thought, and the systems of representations – which different classes and social groups deploy in other to make sense of, define, figure out and render intelligible the way society works” (1996, p. 26). I used Hall and Philip’s conception of ideology to identify ideological talk that occurred alongside reasoning with maps.

Third, I drew on Cresswell (1996) to conceptualize ideologies of place. Ideologies of place are collections of social meanings which are attached to spaces. Cresswell specifies four axiomatic elements of a place ideology: (a) classifying place – naming a place and defining its spatial extent; (b) differentiating place – describing how one place is distinct from others; (c) naturalizing place – specifying what people, objects, or organisms are ‘normal’ in a place; and (d) place as practice – specifying what actions are or ‘normal’ in a place. I used Cresswell’s four elements to describe instances where people drew on ideologies of place to reason with maps.

Context, participant, and data sources

This research was conducted in a secondary STEM teacher education course. I investigated a 6-lesson series where the course instructor and six preservice teachers used maps to investigate the causes of urban heat island effect in their local city, Austin, Texas. This study focused on one student from the class: Aaron (a psuedonomy). Aaron is a White, cis-gender, male STEM preservice teacher. He had lived in Austin for over 20 years and had many things to say about places in Austin. Many of Aaron’s remarks regarded the nature of certain neighborhoods in the city, the types of people who lived there, and his perceived history of each place. To examine how Aaron’s ideologies of place mediated reasoning with maps, I collected video recordings of all classroom activity, artifacts that students used or created, and wrote field notes for each day.

Data analysis

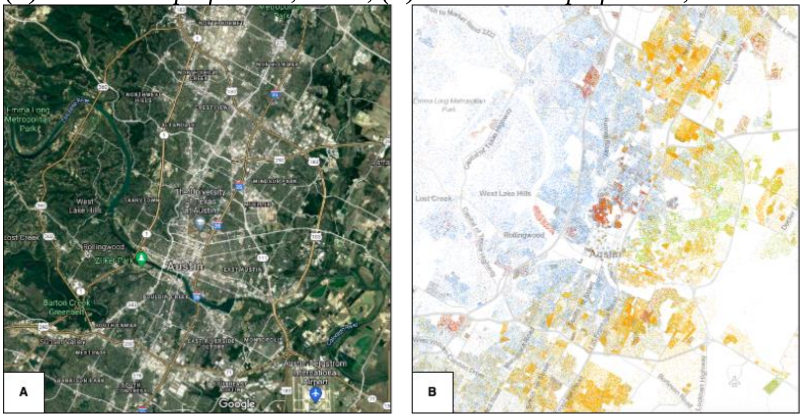
In a forthcoming manuscript, I detail my analysis of the entire 6-day lesson series. In this manuscript, I focused on the first day when Aaron and his classmates used two maps to learn about urban heat islands in Austin, Texas: a satellite reference map a race-dot thematic map. I began by extracting and transcribing any instance when Aaron reasoned out loud using one of the three maps. To understand how Aaron's ideologies of place mediated his ability to reason with maps, I proceeded through three analytical passes with the data:

First, I used Rubel et al.'s map reading framework to analyze how Aaron reasoned with each map. I read the transcripts, viewed the video footage, and tagged moments when Aaron engaged in one of the five map-reading practices. This allowed me to see the coarse practices Aaron used to read maps of Austin. Second, working with Hall's conception of ideology and Cresswell's four elements of place ideology, I searched each instance for ideological remarks made by Aaron. I read the transcripts and tagged any remarks which classified places, differentiated places, naturalized places, or associated places with certain practices (Cresswell, 1996). This allowed me to render initial understandings of the various place ideologies which Aaron drew upon to reason with each map. Third, I used tools from sociosemantic analysis (van Leeuwen, 1993) to probe these instances further to see how Aaron represented the people, materials, and actions associated with urban heat island effect. This allowed me to further clarify the various ideologies of place which Aaron dew upon to make sense of maps of Austin.

Results

I present two episodes to illustrate how Aaron drew on ideologies of place to reason with maps. In the first episode, I examined how Aaron interpreted patterns in a satellite map of Austin (Figure 1, A). In the second episode, I examined how Aaron interpreted patterns in a thematic map showing the racial make-up of Austin (Figure 1, B).

Figure 1
(A) Satellite Map of Austin, Texas; (B) Race-Dot Map of Austin, Texas



Episode 1: Satellite map of Austin

The first episode occurred while students were discussing a satellite map depicting the center of Austin (Figure 1, A). The course instructor (KB, a pseudonym) began *reading the map* for students: identifying points of interest (the university, a major shopping mall), identifying major boundaries (the river and two highways), and clarifying the color schemes ('lighter areas' on the map were concrete and the 'darker areas' as on the map were nature). Finally, she asked students to reflect on differences they saw on either side of I-35, one of the two major highways that bisects the city into East Austin and West Austin. Aaron was the second student to respond, and said:

1.1	Aaron	Honestly it's what we would consider the slums = Or you know when I first came here that
1.2		area was kind of the slums of Austin = You hate to put it that way but it was (.) .hhh Yeah
1.3		that = Yeah that is where you had built up areas = but it's where it's where the poorest =
1.4		those were the poorest neighborhoods right in the area you are pointing to right now (.) .hhh
1.5		east of 35 right ne- right east of downtown

In this response, Aaron *read within the map* a variety of important spatial patterns. He named East Austin as 'the slums', located poor neighborhoods within East Austin, and described it as 'built up.' Immediately after, KB and a student (Elias, a psuedonym) responded to Aaron's classification of East Austin as 'the slums':

2.1	KB	Historically these are (*tracing cursor, more slowly, over the East Austin area*) (.) uhh (.) yes
2.2		like a lower:: uhh (1.0)
2.3	Elias	SES
2.4	KB	Ye:ah (.) .hhh Um all along the east side of 35 (traces cursor up and down on East side of
2.5		map) (.) and now- I mean now what you seeing = and this isn't really part of the
2.6		conversation of our unit = but what you are seeing (traces cursor over East 7th street, West
2.7		to East, then draws circle within East Austin) is around here now is a lot of gentrification
2.8		going on (.) in Austin (.) taking advantage of those low property (.) um (.) values (.) Uh but
2.9		(.) yes (.) historically we've got lower (cursor moving randomly, on East side of Map) (.)
2.10		people who are in a lower SES class living east of 35 and more expensive property on the
2.11		west (cursor moving randomly, on West side of Map) (.) and particularly as you get closer
2.12		and closer to Mopac (traces cursor on Mopac, back and forth, North to South) (.) your prices
2.13		are going way up(.)

The course instructor responded first by tracing her cursor over the East Austin neighborhood while pondering a different word to describe the area. She began to *read within the map* by saying that East Austin is a "like a lower::" but trailed off. Elias completed her effort to *read within the map* by saying "SES" (socioeconomic status). The course instructor followed up, *read behind the map,* and said three new ideas: First, she explained that East Austin is presently undergoing a process of gentrification. Second, she indicated that 'historically' East Austin had been the primary place of residence for 'lower SES class.' And finally, she continued to explain that 'historically' there was a pattern where property cost increased as you moved from east to west across the city, "particularly as you get closer and closer to Mopac" (2.13-2.14).

I interpreted this interaction as ideological because it involved negotiating various *classifications* and *differentiations* of East Austin. Aaron began by classifying East Austin as 'the slums' and justified this based on his personal experience having lived in the city for many years. He differentiated it from other parts of the city by explaining that East Austin had 'built up areas' and is the part of the city where the 'the poorest neighborhoods' were present. This can be contrasted by imagining areas of the city with less 'built up areas' or 'richer neighborhoods.' He closed his remarks by re-affirming the location of 'the slums' as being "east of 35" and "right east of downtown." In response to Aaron, KB and Elias provided an alternate ideological framing of East Austin. Together, they re-classified East Austin as 'lower SES' rather than 'the slums.'

Using tools from sociosemantic analysis, we can see important ideological differences in how Aaron represents two groups of spaces/people: East Austin and 'the public consensus.' East Austin is referenced by Aaron's use of two pronouns (it and that) (1.1, 1.3) and a definite article and noun (that area) (1.4). By using these words, Aaron circumscribes East Austin into a single entity which can be classified and differentiated. This is what van Leeuwen (1993) refers to as the *spatialization*. Spatialization is a representational strategy where a group of people is represented by the place/space they live in. By spatializing a group of people, a speaker can attribute qualities or actions to a space rather than to the people who live in the space.

The public consensus is referenced by Aaron's use of the pronouns 'we' and 'you' (1.1). Aaron began by saying 'it's what *we* would consider the slums' (1.1). Shortly after, he says '*you* hate to put it that way but it was' (1.3). Both 'we' and 'you' are what van Leeuwen refers to as *generalization*. Generalization is when a speaker does not refer to specific people in the real world, but instead refer to abstract or hypothetical groups. I interpret these generalized 'we' and 'you' to represent some form of 'public consensus.' Eliciting a public consensus to justify classifying East Austin as 'the slums' is an ideological strategy which made Aaron's remarks seem natural. This is a hallmark indicator that ideological geographies are being established through talk.

Episode 2: Racial map of Austin

The second episode occurred while students viewed and discussed the race-dot map (Cable, 2013) Austin (Figure 1, B). The Race-Dot Map is a thematic map which uses data from the 2010 census to visualize one dot per individual within the census block group they live in. The course instructor began again by *reading the map* for students (explaining the symbols). The course instructor then asked for students to make connections between the satellite map and the race-dot map. Drew responded first, followed by the course instructor and Aaron.

3.1	Drew	There's like (.) you can clearly see I-35 (.) um and to the left um it's all White or Asian
3.2		American and to the right its all Black or Latinx so [like] and that very clearly like (.) that
3.3		racial divide happens to also be like the divide between the left side of I-35 on this map is
3.4		way more green than the right side.

3.5	KB	[Yeah]
3.6	KB	Indeed ((knowing and formal tone))
3.7	Aaron	There is a strong correlation between uh identification and SES sorry but that's how I see it

Drew began by *reading the map* (identifying I-35), *reading within the map* (explaining patterns from the race-dot map), and *reading beyond the map* (making connections to the previous Satellite Map). Using the categories from the map, Drew explained that west of I-35 the dots were primarily representing White and Asian American people, and East of I-35 the dots were primarily representing Black and Latinx people. Drew then connected this to the previously established pattern that west of I-35 has more trees or is "way more green" (3.5). The course instructor agrees briefly by saying "indeed" (3.6) in what I interpreted to be a formal and 'knowing' tone, as if Drew explained the pattern KB was hoping to see. Aaron followed Drew's remarks by *reading beyond the map*, to explain a correlation between identification and SES. He closed his remarks by apologizing for this idea.

In this short sequence, a variety of ideological moves were made. Drew began by drawing upon the I-35 boundary to classify the city into two regions, East and West. Then, Drew used the dot colors to differentiate East and West by describing the general composition of racial groups in each area. Despite there being many boundaries between racial groups on this map, the boundary of I-35 was repeated as an important line to differentiate the city. Finally, Drew made a connection between the racial compositions and the previously differentiated pattern of West Austin having more greenery than East Austin. Aaron's response layered new ideological meanings onto the pattern which Drew established. Aaron explained that there was a correlation between identification and income level. Although Drew didn't mention income, it seemed Aaron was referring to the conversation moments before where the course instructor and Elias re-classified East Austin as 'lower SES'. Aaron then drew a connection between the racial divide along I-35, and the perception that East Austin is lower SES and West Austin is higher SES. With this remark, Aaron further differentiated East Austin as lower SES, with primarily Black and Latinx residents, and having less greenery than West Austin.

By drawing on sociosemantic analysis, we can further see the ideological nature of Aaron's portrayal of East Austin. Aaron began his remark with the verb phrase "there is." Sociosemantic anlaysis refers to this as an *existential* process, where the speaker is bringing something into existence that needs no further justification. The use of the phrase "there is", naturalizes the statement that follows: racial identification and SES are correlated. Aaron goes on to complete his sentence by saying "sorry but that's how I see it" (3.9). I interpreted the use of apology here to indicate that Aaron believed this fact to be true, although potentially uncomfortable or even controversial for the class to hear.

Discussion

In summary - through interactions with his classmates, two maps of Austin, and the course instructor – Aaron read the map, read within the map, and read beyond the map while drawing on an ideological geography of Austin. This ideological geography classified East Austin as 'the slums', differentiated it as being a low SES area, with less tree cover, and primarily Black and Latinx residents. He naturalized these statements by evoking public consensus with generalized phrases such as "It's (East Austin is) what *we* would consider the slums." This research demonstrates the necessity for examining the relationship between ideologies of place and reasoning with maps.

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Examining High School Students' Self-Efficacy in Machine Learning Practices

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Abstract: Artificial Intelligence (AI) has increasingly become a ubiquitous face in our daily lives. Following this trend, many organizations and educational researchers started fostering AI education at the K-12 level. Yet, there is less knowledge about the impact of curriculum interventions on students' self-efficacy. In order to understand K-12 students' AI learning and interests, it is critical to examine their self-efficacy. This paper examines high school students' self-efficacy in machine learning practices before and after participating in a technology-enhanced AI curriculum intervention for three weeks. We analyzed students' pre- and post-questionnaire responses to investigate the impact of the AI curriculum intervention on students' self-efficacy. Our analysis revealed that students' self-efficacy toward text classification tasks significantly increased after they completed the AI curriculum activities. Additionally, we found that students' characteristics in terms of their interests and engagement in the activities played a critical role in their self-efficacy.

Introduction

Artificial Intelligence (AI) literacy has become a necessity for a data-savvy workforce. Therefore, introducing AI literacy at an early age is significant to prepare youths in AI-related fields. Particularly, K-12 is a critical stage for young people to develop foundational knowledge and interest in AI-related careers. Currently, much has been known about AI education at K-12 is related to how to support students' understanding of the AI implications from social, technical, cultural, and ethical perspectives (Ali et al., 2019). However, only a few studies emphasized the impacts of AI education on high school students' confidence. As an illustration, Chua et al., (2019) organized a pilot program to support high school students' data science knowledge. In this pilot study, students worked on five different curriculum modules and explored Data Science concepts such as data visualization, probability in ML, and Webscraping with Python. This study showed that students developed an understanding of basic concepts and became more confident in explaining these concepts. Yet, these kinds of studies are limited to explaining K-12 students' confidence in specific domains, especially in ML, since the training mostly focuses on a broader conceptual understanding of Data Science.

While efforts to integrate AI into K-12 classrooms have been ongoing, less is known about the impacts of AI curriculum interventions on students' self-efficacy in ML practices. Examining K-12 students' self-efficacy is critical to understand their achievements, motivation, and interests in learning AI concepts. Therefore, there is still a need for empirical studies on how AI curriculum activities help students to gain confidence in ML practices. Thus, the purpose of this study is to examine high school students' self-efficacy in ML practices before and after they experienced technology-enhanced AI curriculum activities. Specifically, this study aims to address the following research questions: (1) How does students' self-efficacy change after participation in technology-enhanced AI curriculum activities? and (2) With regard to changes in self-efficacy in machine learning, which type of students can be identified, and what are their individual characteristics?

Theoretical framework

Influenced by behavior, cognition, and the environment, self-efficacy is the belief in one's capabilities to perform a task. "Self-efficacy beliefs determine how people feel, think, motivate themselves, and behave" (Bandura, 1994, p.1). At the core of Bandura's (1986) Social Cognitive theory (SCT), self-efficacy engages in a "triadic reciprocal causation model in which the behavior of a person, the characteristics of that person, and the environment within which the behavior is performed are constantly interacting," (Van der Bijl & Shortridge-Bagge, p.9, 2002). Bandura (1994) asserts high self-efficacy with a greater interest in various careers and believes those use self-improvement to master the skills to achieve career pursuit. The tasks and activities that improve self-efficacy rely heavily on educators to create learning environments conducive to developing cognitive skills (Bandura, 1994). Studies showing improved self-efficacy used specific tasks like extensive teacher-supported scaffolding (Jin et al., 2021), collaborative pairs of the same gender (Wei et al., 2021), and explicit instruction of concept mapping (Boroumand et al., 2021). For example, Konak (2018) evaluates High School students' self-efficacy after participating in a K-12 cybersecurity program that combined hands-on experiences with collaborative and inquiry-based strategies through a pre-and post-survey. This week-long program included heavy skill-based scaffolding before the problem-solving activity. In this study, they found that active experimentation components of the hands-on activities helped improve self-efficacy in problem-solving. Over the last two decades, there has been considerable research on K12 teachers' self-efficacy. However, the literature is sparse for studies on self-efficacy in K12 students in the STEM fields but even less for AI Education. Most studies focus on high school and college students in Science and Math. Hence, in this study, we address the critical gap in the literature by examining self-efficacy in K12 AI Education for students after completing technology-enhanced curriculum activities.

Methods

This study was conducted in the context of a high school Journalism classroom in a public school in the Northeastern United States. The class included twenty-eight students; however, eight students did not complete the data collection process. Therefore, in this research, we only included the data from twenty students; nine Black/African, four Hispanic, five White/Caucasian, one other, and one prefer not to answer. Fourteen of the students were female and six were male. At the beginning of each class, the teacher introduced key concepts in the StoryQ AI curriculum (Chao et al., 2022) and asked students about their thinking of these concepts. Multiple sources of data analysis, including pre-and-post surveys, pre-and-post knowledge assessments, video recordings, interviews, and activity-specific questions were collected. In this particular study, we only used students' data from pre-and-post surveys and activity-specific questions. The pre-and-post surveys were identical and had sixty-four questions that included five constructs: thoughts about AI, current understanding of the roles and responsibilities of AI developers and users, understanding of knowledge and skills required to develop AI, interests in AI, and self-efficacy. Since this research aims to investigate students' self-efficacy before and after they completed the AI curriculum activities, we mainly focused on the self-efficacy construct in the survey. While developing self-efficacy items, we examined the validated surveys around the STEM self-efficacy literature like the STEM career motivation scale (Shin et al., 2016). Two researchers examined these surveys and developed thirteen self-efficacy items on a 5-point Likert scale (1- strongly disagree; 5- strongly agreed) related to the curriculum content. After the self-efficacy items were created, the research team was invited to test these items and give feedback. After several iterations, the items were finalized. While interpreting the reliability, DeVellis (2021) suggested that if a coefficient is between 0.70-0.80, it is "respectable", and if it is above 0.80, it is accepted as "very good" for an instrument. We checked the reliability of the items in the pre-survey ($\alpha = 0.94$) and post-survey ($\alpha = 0.93$). To address the first research question, paired t-tests were performed to analyze differences between pre-and post-survey responses. We used SPSS to analyze all the data. To address the second research, we identified three students with regard to the changes in their self-efficacies and presented their characteristics as cases. We specifically investigated three types of students; (1) started with low self-efficacy and ended with high self- efficacy, (2) started with high self-efficacy and ended with low self-efficacy, and (3) did not have a change in their self-efficacy. After we identified these students, we explored their activity-specific responses. In each curriculum activity, students answered open-ended and multiple-choice questions. We followed exploratory analysis to gain a deep understanding of their characteristics and learning progress throughout the activities. We analyzed the open-ended questions by following open-coding strategies (Williams &Moser, 2019). After the first round of analysis, the research team discussed the sub-themes related to each case and finalized the findings. We used pseudonyms for the participants while presenting the findings.

Findings

A paired-sample t-test was conducted to compare the high school students' self-efficacy in ML practices before and after students experienced the AI curriculum activities. Mean values for the 13 self-efficacy statements varied between 2.29 and 3.35 in the pre-surveys and between 3.39 and 4.06 in the post-surveys on the five points Likert scales (1Strongly Disagree to 5 Strongly Agree) (see Figure 2). Overall, we found a significant improvement in students' self-efficacy from pre-survey (M=2.66, SD=0.85) to post-survey (M=3.70, SD=0.54), (t (18) =4.82, $p < 0.001$). Suggesting that completing the AI curriculum was related to an increase meaning scores of students perceived/reported self-efficacy. When we closely examined each self-efficacy item, we saw that the largest increase was observed in an item that asked about students' confidence in training a computer model to classify text. On the pre-survey, 58% of the students (n=11) indicated less confidence or neutral (selected "disagree" or "neutral" to the statement), whereas, on the post-survey, 74% of the students (n=14) demonstrated high confidence in the statement (selected “agree” or “strongly agree”). This shows that the curriculum implementation helped students to become more confident in ML practices, in particularly developing ML models for text classification tasks. On the other hand, the least increase was observed in an item that asked about students’ confidence in completing a new course unit related to AI and ML. In the pre-survey, students were mostly neutral or slightly disagree with this statement. When we examined their post-survey, we found that they kept the same attitude in the post-survey. This demonstrates that students might not see the similarities between text-classification tasks and other ML topics like image recognition or speech recognition. Therefore, they might not feel confident in completing a new ML course.

After we explored the changes in the students’ self-efficacy, we explored students’ characteristics to gain more understanding of similarities and differences. We investigated their responses to the activity-specific questions as well as their survey responses. We followed the thematic exploratory analysis to identify patterns between the students’ self-efficacy levels and their activity progress. Firstly, we identified students who started the curriculum activities with a low self-efficacy level and ended with a high self-efficacy level. Lindsey was a 12th-grade, female, White/Caucasian student who had generally moderate positive attitudes towards AI but was also suspicious about the impacts of AI on jobs in the United States. She was familiar with AI technologies around her. When we investigated her responses to the activity questions, we found that her completion rate was 88%. In according with her completion rate, her interest in ML tasks might be increased and this might also lead to an increase in her self-efficacy. Additionally, when she was working on Activity 6, she indicated that working as a group was the most effective strategy to understand ML concepts. The peer interaction while completing the ML tasks might also be another factor that affects her self-efficacy. Put differently, she might feel more comfortable asking questions and/or sharing her ideas while working with her classmates and this might help her self-efficacy. Secondly, we also investigated students who had higher self-efficacy before the curriculum activities but ended with lower self-efficacy after completing the activities. We saw that only two students out of twenty were applied to this situation. In regard to their completion rate and the changes from pre-to-post-survey, we decided to examine one of the students closely. Diego was a 12th-grade, Male, Hispanic student who heard of the term AI through online magazines and TV shows. Even though he stated a slightly positive attitude toward AI, he mentioned no interest in AI when it came to sharing his emotions and feelings about this term. His overall completion rate was 70% but when we closely examined his responses to the activities, we saw that his completion rate in the ML activities (e.g., Activity 6) was quite low. For example, he only responded to fourteen questions out of thirty-eight in Activity 6. He might have some challenges to continue answering the questions. Finally, to gain a deeper understanding of students’ self-efficacy and their learning progress, we investigated students who did not show more than a 10% difference from pre-survey to post-survey. We identified two students who had a 0.08 difference between the mean of the post-survey self-efficacy items and the mean of the pre-survey self-efficacy items. One of the students stayed neutral in both the pre-survey and post-survey while another student felt strongly confident in her ML practices in both surveys. Thus, we mainly focused on the student who generally stayed neutral on the self-efficacy items. Destiny was an 11th-grade, Female, Black/African student who heard the term AI through movies, TV shows, and social media. Before the curriculum activities, she was slightly positive toward the impacts of AI on people’s lives and neutral in terms of her emotions and feelings related to AI. Her completion rate of the activities was 78.3%. When she was working on the ML activities, she indicated her enjoyment in working with others. She completed the majority of the work in the ML activities and demonstrated an understanding of ML concepts, including building ML models, identifying useful features, and explaining why a feature has a large influence on a model’s performance. Yet, her mean score of self-efficacies did not show a significant difference from the pre-survey to the post-survey. When we closely examined her response to each self-efficacy item, we saw that her self-efficacy showed an increase in three items that were related to explaining the text-classification concept. On the other side, she was less confident in completing a new course unit on a type of classification model (e.g., image recognition or speech recognition). She might find those new concepts more complex than text classification, therefore, she might not feel confident about that.

Conclusion

With the developments in AI technologies, there have been numerous calls to engage K-12 students in AI education. In spite of ongoing efforts to integrate AI into K-12 classrooms, little is known about the impacts of AI curriculum interventions on students' self-efficacy. This study aims to fill this gap by exploring high school students’ self-efficacy in ML practices before and after they completed technology-enhanced AI curriculum activities for three weeks in the context of a Journalism classroom. Additionally, this study also investigates high school students’ characteristics while completing the activities regarding to the changes in their self-efficacy levels. The results of this study demonstrated that students’ self-efficacy in ML practices increased significantly after they completed the AI curriculum activities. In particular, after the curriculum intervention, students became more confident in feature engineering tasks related to ML practices. On the other side, this study showed that students needed further training and reinforcement to feel confident in completing a new ML course, including new ML concepts like image or speech recognition. In accordance with the literature, our approach to teaching AI and ML concepts through hands-on learning practices was promising to support high school students' self-efficacy in ML practices. Drawing on the SCT perspective, these hands-on experiences provided mastery-level experiences in ML practices. Students were able to practice ML concepts through three different curriculum lessons. These might help them gradually develop a high level of self-efficacy throughout the curriculum activities. Additionally, when we closely examined students' characteristics, we found that students' completion rate in the activities, peer interactions among them, and initial interests in ML practices can be predictors for their self-efficacy in ML practices. In line with other studies, our findings demonstrated the importance of students' active participation and initial interests in completing learning activities. Many studies showed the significance of understanding self-efficacy in designing scaffolding learning tasks and activities. The findings of this research can inform AI curriculum developers and researchers in designing and developing AI curriculum intervention in high school classroom settings. Our work contributes to the AI education field by demonstrating a way to integrate an AI curriculum into non-STEM classrooms to foster K-12 students' self-efficacy in ML.

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Authentic Invitations: Offering Girls of Color Voluntary, Contextual, and Responsive Opportunities to Develop Computing Identities

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Abstract: Broadening participation in computing requires a deeper understanding of how to support girls of color in developing computing identities, or views of themselves as active participants within computing. We propose the concept of *authentic invitations* as a promising avenue for supporting girls of color in developing computing identities. To illustrate the three proposed dimensions of an authentic invitation, we highlight the experiences of Deandra, a 16-year-old Black girl who participated in an informal computing program for girls of color hosted in public libraries. Our findings show how offering voluntary, contextual, and responsive invitations to participate in computing can support girls of color in authoring computing identities that integrate their social and personal experiences.

Introduction

Opportunities for girls of color to meaningfully participate in computing continue to be inequitably distributed in K-12 education (Garcia, et al., 2020). When girls of color do have access to computing education, they often face racialized and gendered stereotypes that position them as lacking motivation and unable to master challenging course content (Allen & Eisenhart, 2017). In this paper, we examined how informal computing programs can design nurturing learning spaces that proactively dispel stereotypes and foster positive computing identities, or views of oneself as an active participant who can contribute and belong within computing (Mahadeo et al., 2020). We propose the concept of *authentic invitations* as a promising avenue for supporting girls of color in developing computing identities that are grounded in their lived experiences. We conceptualize an *authentic invitation* as an offer to participate in learning that is 1) voluntary and not mandated; 2) contextual and not conditional; and 3) responsive and not dismissive of girls' past, present, and future selves. To illustrate the three proposed dimensions of an *authentic invitation*, we highlight the experiences of Deandra, a 16-year-old Black girl who, while pregnant and working a part-time job, participated in an informal computing program for girls of color hosted in public libraries. Ultimately, we argue that providing meaningful connections between girls' lived experiences and computing identities can result in broader and more inclusive conceptions of what it means to participate in computing, especially in ways that extend beyond academic performance and career goals.

Conceptual framing: Authentic invitations to author a computing identity

Our work draws on disciplinary identity models that explain how learners develop feelings of recognition, interest, and capability within disciplines (Mahadeo, et al., 2020). The process of "authoring" a disciplinary identity involves performing behaviors, actions, and speech that are valued and recognized by peers and educators (Johnson et al., 2011). Students can be positioned by educators and peers in specific ways based on their race, gender, class, and the context (Allen & Eisenhart, 2017). These positionings can influence how they author their identities and come to imagine their future as active experts in science fields. We examine how girls of color develop computing identities, which describes the extent to which a learner identifies as a "computing person," within the context of an informal computing education program (Rodriguez & Lehman, 2017). Prior conceptualizations of a computing identity typically involve performing behaviors that are recognized as related to the discipline of computer science, such as learning to program (Harrington et al., 2019). Instead of developing a performance-based computing identity model, our work examines how *authentic invitations* to participate in a learning environment that equally values personal meaning making and computing skills impacts the development of computing identities among girls of color. Our conceptualization of an authentic invitation is informed by community-based practices that acknowledge that "transformation occurs through choice, not mandate," that community building supports "people to participate and own the relationships, tasks, and process that lead to success," and that invitations are "the call to create an alternative future" (Block, 2008). Based on these community-based practices, we describe an authentic invitation as one that is 1) voluntary and not mandated; 2) contextual and not conditional; 3) responsive and not dismissive of girls' past, present, and future selves. Thus, invitations to learn should support student agency (voluntary), consider obstacles to participation (contextual), and provide opportunities for girls of color to thrive on their own terms (responsive).

Research design

The study context is an informal computing program hosted at a library in an urban city in Southeast Michigan, USA. The curriculum consisted of twenty hours of activities that introduced girls to computer programming using an Arduino, an opensource microcontroller. While we evaluated the curriculum effectiveness, we do not present those results in this paper. The program enrollment was capped at 10 girls per implementation. Recruitment was conducted by librarians who hosted “open houses” and focused on recruiting girls, ages of 13-16, who identify as Black, Latina, and Native American. Two researchers attended each program session and collected field notes and audiovisual recordings of participant artifacts such as group projects and expressive artwork. Three members of the research team analyzed the data using an inductive coding process and collaboratively conducted thematic analysis. The analysis process included cross-checking interpretative claims using data triangulation that converged information gathered across the textual, audio, and visual forms of data.

Findings

Rather than report a summary of whole group experiences, we focus on the experiences of one participant to present a unified account of how authentic invitations can influence the development of a computing identity. Deandra was chosen as the exemplary narrative because her experiences exemplify the construct of interest in a particularly interesting manner given her initial reluctance to participate in the program, her decision to complete the program twice, and her life circumstances. While her experiences may not be “typical,” exemplary narratives can still be used to understand a wide range of developmental processes because they represent the upper ends of development and allow for the inclusion of detail, context, voice, and emotion (Bronk, King, & Matsuba, 2013).

An introduction to Deandra

At the time of the program, Deandra was a 16-year-old Black girl who worked at a local doughnut shop and attended the program in her work uniform since she started her work shift shortly after each session. She participated in two full implementations of the program (40 hours total); first in the summer of 2019 and again in the fall of the same year. While Deandra demonstrated her interest in the program by adjusting her work schedule, she also positioned herself as someone who was “too cool” for the program. During her first experience participating in the program, Deandra positioned herself as someone who was mainly interested in the program because of the “snacks” and was not afraid to announce “I ain’t doing that” when asked to participate in an activity. Although Deandra publicly dismissed most of the program activities, she attended while pregnant, chose to return for a second implementation, and ultimately accepted invitations to participate in computing.

Authentic invitations as voluntary: Deandra becomes “good at this type of thing”

Deandra arrived late during a session when the girls were learning to use an Arduino because she had been experiencing morning sickness. The librarians invited her to participate in the session but did not mandate her participation. When she realized how far along the other girls were on the project, she used humor to deflect from her nervousness. She peered over girls’ shoulders to look at their projects and when she saw fumes rising from the soldering iron one of the girls was using she exclaimed, “Oh no! I’m not doing that!” Deandra chose not to participate and spent the remainder of the session sitting at a table with her head down. She was never asked to leave, and she was never chastised because the invitation to participate was always voluntary and not mandated. At the end of the session, the librarian, Sarah, encouraged her to return, “I hope you feel better. See you tomorrow!” Deandra did return the next day. She boisterously grabbed an Arduino and began joking again when Sarah invited her to learn how to integrate a photoresistor with the Arduino. “Oh no no no,” she said as she proceeded to grab all the materials she needed to complete the project. Sarah laughed at her feigned trepidation as she helped Deandra get settled. By the end of the session, Deandra had learned to use variables to store the resistance value of a photoresistor (int sensorValue = 0) in the Arduino Integrated Development Environment. After successfully getting an LED to respond to changes in light using the photoresistor, Deandra proclaimed, “I’m good at this type of thing!” While it may seem counterproductive to accept Deandra’s refusal to participate, respecting her decision underscored the voluntary nature of the authentic invitation to learn new computing skills and highlighted her ability to have control over how and when she wanted to learn.

Authentic invitations as contextual: Deandra becomes a “veteran”

When Deandra enrolled in the program, she arrived with her grandmother, sister, and cousins. Before Deandra’s grandmother signed her up, she asked Sarah, “Is it okay if one of them is pregnant?” Although we had not planned for meeting the needs of a pregnant participant, the invitation we offered to participate in computing was contextual and not conditional. We worked with the librarians to consider the context of Deandra’s specific life circumstances and agreed to find ways to support her participation by accommodating her doctors' appointments, the physical demands of pregnancy, and her evolving familial relationships. As previously described, Deandra did not always feel well enough to participate. She struggled with morning sickness, swollen feet, and headaches. She also balanced her work and doctors' appointments with her program participation. While participating in computing was a valued program outcome, the librarians accepted that Deandra could not always participate and continued to communicate their investment in her success through persistent and consistent academic and emotional support. After several sessions, it became clear that the program served as a refuge for Deandra. During an activity that introduced girls to the concept of an algorithm using dance steps, Deandra shared that she "loved coming here because at home everyone is focused on the baby." She also later shared that learning new things helped her stop worrying about "drama" with her family. The program offered Deandra a safe space to learn new computing skills and a refuge from the evolving context of her life and family relationships. When the next program implementation began in the fall, Michelle, one of Deandra's cousins enrolled but Deandra did not show up. Sarah asked Michelle to encourage Deandra to return, "Next time you see Deandra, let her know we miss her, and we hope she comes with her baby." Michelle responded, "Is that allowed? Can she bring her baby?" Deandra did show up during the next program session and she lovingly showed off her baby, "His stomach is so big but then he has these little chicken legs." The librarians and researchers took turns holding the baby while Deandra participated in the program activities. As she participated, Sarah positioned Deandra as a leader with prior experience. Deandra also positioned herself as a "computing person" by offering to help "newbies." When a new participant struggled, Sarah said, "Well it's a good thing Deandra is here. She is a veteran. She can help you." By describing Deandra as a "veteran," Sarah positioned her as knowledgeable and skilled and acknowledged her as someone capable of continued participation in computing.

Authentic invitations as responsive: Deandra becomes a member of the group

Deandra struggled to form relationships with other girls in the program and tended to stay near her cousins. After Deandra refused to participate in an icebreaker designed to build trust between participants, Sarah shared her frustration, "Deandra refused to get up for the icebreaker. She just did not want to engage at all. It made it awkward and weird for the other girls. Everyone felt it." Deandra and her cousins also giggled when other girls showed excitement over completing computing activities, which caused the other girls to feel self-conscious. Deandra's behavior was a clear violation of the shared norms the girls had collaboratively created, which included "Be kind and respectful to others." Part of being responsive and not dismissive of girls' sense of self involves having them honestly examine their attitudes and beliefs about themselves and reflect on how those attitudes and beliefs influence their intrapersonal relationships. Sarah reminded Deandra that it was important to "build each other up" and asked her why she was behaving "outside of the boundaries" the group had agreed upon. After reflecting on her behavior, Deandra explained that she was just "messing around" and agreed to be more mindful about how her behaviors affected others and asked to be held accountable if she lost her "filter." Deandra's commitment to change was tested during the next program session when she told a member of the research team, "You're big." The researcher replied, "Oh, you mean like fat?" Deandra tried to play the comment off as a joke, but the researcher held her accountable, "If in the next few hours you feel like you want to apologize to me for that, I'm here to hear you. Just anytime, I do expect it though." Within a couple of minutes, Deandra apologized, "I have no filter. Yeah, I'm sorry." Over time Deandra began to interact with the other girls, entering the space within the agreed community norms. Sarah described the change she saw in Deandra, "She started feeling more trusting and she started making more positive comments to the other girls by the end of the week. She was receptive because I think she felt safe and felt accepted by us." By supporting personal reflection on past and future behaviors, Sarah's invitation to continue participating was responsive to Deandra's sense of self. She left the possibility open for Deandra to change her behaviors in the future.

Discussion

By allowing program participation to be voluntary and not mandatory, Deandra was free to refuse our invitation to learn new computing skills. Accepting Deandra's refusals required reframing how non-participation was viewed in the program and it pushed us to consider how an invitation to participate could be authentically voluntary and still supportive of girls' personal and academic growth. Deandra taught us that an authentic invitation must support and not suppress opportunities for decision-making and agency throughout the learning process, even if the decisions do not always align with the goals of the program. An approach that treats the invitation to participate in computing as a voluntary decision may help support the development of more agentic computing identities that allow girls to see themselves as having choice and control over how they use computing skills in their lives. In our program, an authentic invitation also meant encouraging girls to bring their whole selves to the learning environment. The invitation to participate in the program was not conditional and did not require the girls to leave their multiple identities, prior experiences, and personal lives at the door. Deandra and her cousins openly talked about their families, crushes, and worries - all while participating in computing. Respecting the context of Deandra's life circumstances and inviting her to bring her home life into the learning environment, such as welcoming her baby, resulted in her continuing to show up to the program. She participated in the program on her own terms and authored a computing identity that aligned with her life circumstances. Finally, by making space for girls to reflect on their academic and self-growth, we were responsive and not dismissive of girls' past, present, and future selves. For Deandra, the process of authoring a computing identity involved using humor to persist through computing activities that made her feel nervous. The librarians were responsive to Deandra's mode of identity work and invited her to participate in computing in ways that felt comfortable for her. The librarians were also responsive to Deandra's future self and worked with her to author a computing identity that could include her baby. Yet, an authentic invitation also included challenging Deandra to change behaviors that were comfortable but detrimental to forming positive relationships with other girls. The librarians supported Deandra in developing a computing identity that included views of herself as "good" at computing, integrated her life as a mother, and laid the foundation for positive peer relationships.

Conclusion

In this paper, we present the concept of *authentic invitations* as a promising avenue for supporting girls of color in developing computing identities. We acknowledge that analytically focusing on one participant limits the extent to which readers can understand the variety of experiences that girls could have in these programs. However, we posit that Deandra's exemplary narrative helps illustrate the upper ends of identity development and demonstrates the potential of using authentic invitations to foster computing identities among girls of color. Future work will focus on developing more formalized roles for returning participants and examine how serving as a near-peer mentor influences their development of a computing identity. By illustrating how authentic invitations can be used within an informal computing program, we contribute a greater theoretical and empirical understanding of how girls of color author computing identities and offer our approach as an avenue for expanding narrow performance-based computing identity models in ways that account for girls' lived experiences.

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Community Cultural Wealth in Latinofuturism: Leveraging Speculative Fiction for STEM + Arts Asset-Based Pedagogies

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Abstract: In this conceptual paper, we present our work in progress towards the theorization and operationalization of an asset-based pedagogy for STEM + Arts content infused with the aesthetic and speculative fiction movement of Latinofuturism. As Latine scholars, we aim to contribute to the education field with an alternative approach to support the Latine population who is still disproportionately underrepresented in the STEM fields. Through our review of the literature and media, we use the theoretical framework of Community Cultural Wealth, specifically its six forms of capital, to examine Latinofuturism as a genre that can connect STEM + Arts themes with Latine culture through speculative practices. We propose that asset-based pedagogies situated in Latinofuturism aesthetics provide emancipatory opportunities for Latine to dream and think beyond the current barriers of access to STEM + Arts and create a new STEM culture *for* and *with* Latine.

Introduction and background

Our pluralistic world is more connected than ever, and so is the opportunity to exchange ideas and to collaboratively work to address, solve, or even improve the situation of complex challenges that affect us all. Such unprecedented and complex "wicked problems" (Rittel & Webber, 1973) include global pandemics, severe issues to our food systems due to climate change, systemic racism, wars, and their humanitarian and economic ripples, among many other issues. As education practitioners and researchers of increasingly pluralistic and interconnected societies, we need to reflect on our pedagogical practices and ensure we adequately support learners within our spaces. In this conceptual paper, we present our initial work towards the theorization and operationalization of an asset-based pedagogy for STEM + Arts (1) content infused with the aesthetic and speculative fiction movement of Latinofuturism. Through the theoretical lens of Community Cultural Wealth (Yosso, 2005), we examine Latinofuturism and show its leveraging potential to encourage Latine learners to participate, expand their cultural practices, and enrich the STEM + Arts disciplines while contributing to the solutions and improvement efforts of our 21st-century complex challenges.

The underrepresentation of Latine in STEM education

The increase in the racial and ethnic composition of the population in our countries and classrooms is evidence of the expansion of pluralism of ideas, and it is an opportunity for education researchers and practitioners to embrace and nourish marginalized Students of Color (2) with unique cultural practices and strengths. For instance, from the latest data collection in 2019, more than half (52%) of all public elementary and secondary school students in the U.S. attended schools where Students of Color made up 50% or more of the total enrollment (NCES, 2022). Also, the most recent census data in the United States showed that the Latine population (i.e., Hispanic and Latina/o) comprises 19% of the total population in the United States, becoming the largest minority (U.S. Census Bureau, 2020).

However, some minorities are excluded and underrepresented in the Science, Engineering, Technology, and Math (STEM) fields. The Latine population is one of them who are still disproportionately underrepresented in STEM classrooms and workplaces. In fact, Latine youth face numerous barriers to entering and participating in the STEM fields. Several explanations of these barriers point to the nature of school curricula and structural and cultural factors, such as curriculum not culturally relevant but designed for the majority white middle-class; lack of funding to pursue a college education; difficulty in adapting to the culture of STEM college classrooms; and unnecessary rigor within competitive, exclusionary, and elitist environments (González et al., 2005; Chapa & De La Rosa, 2006; Flores, 2011; McGee, 2020). Therefore, new curricula, pedagogies, and educational environments that invite, embrace, and nourish Latine culture are more paramount every day.

The asset-based framework of Community Cultural Wealth

Some educational institutions have operated under the deficit view model towards minorities, treating these marginalized populations as lacking abilities and possessing deficits that need to be addressed by pouring knowledge into their empty minds. We can resist and eradicate this damaging worldview by changing our mindset to embrace the cultural practices and strengths these populations already possess and incorporate them into our learning environments. This has been the aim of the strength-based and *asset-based pedagogies* tradition. This tradition has been advanced by many scholars, such as the work of Funds of Knowledge by Luis Moll and Norma González; the Third Space by Kris Gutiérrez; Culturally Relevant Pedagogy by Gloria Ladson-Billings; Community Cultural Wealth by Tara J. Yosso; and Culturally Sustaining Pedagogies by Django Paris and H. Samy Alim. We specifically inform our conceptual work with the theoretical framework of Community Cultural Wealth (CCW; Yosso, 2005).

The asset-based framework of CCW is a critical race theory approach to recognize and acknowledge the strengths of Communities of Color toward social and racial justice. CCW focuses on *wealth*, defined as the historical accumulation of resources and assets to resist forms of oppression (Yosso, 2005). In her work, Yosso (2005) challenges the assumption that Students of Color come to school with cultural deficiencies, but she calls to value and embrace their prior experiential knowledge and cultural practices from their home and their communities. In order to accurately inform our conceptual paper, we include here the definitions of each of the six not mutually exclusive or static forms of capital that nurture this community cultural wealth (Yosso, 2005): **(1)** *Aspirational capital***,** defined as the "ability to maintain hopes and dreams for the future even in the face of real and perceived barriers" (p. 77). **(2)** *Linguistic capital* refers to "intellectual and social skills attained through communication experiences in more than one language and/or style" (p. 78). This capital also includes communication abilities via music, visual art, and poetry. **(3)** *Familial capital*, the "cultural knowledge nurtured among *familia* that carry a sense of community, history, memory, and cultural intuition" (p. 79). **(4)** *Social capital* alludes to "networks of people and community resources for instrumental and emotional support" (p. 79). **(5)** *Navigational capital, "*skills of maneuvering through social institutions" not created with minorities in mind (p. 80). And **(6)** *Resistant capital*, which is 'knowledge and skills fostered through oppositional behavior that challenges inequality'(p. 80).

From our literature reviews and other studies in progress, we have found that the particular aesthetic movement called *Latinofuturism* (Merla-Watson, 2019) employs speculative fiction to imagine new possibilities and futures while displaying evidence of all of the six capitals of CCW. In the following sections, we refer to each of the above definitions to show how CCW is present in Latinofuturism and why it can be leveraged to center Peoples of Color in their own learning and teaching. This theoretical move has the potential to empower Peoples of Color to reimagine the irrelevant pedagogical standards designed for the dominant population.

Latinofuturism

Speculative practices, dreaming and thinking beyond the present social and technological realities and future-oriented, is a powerful form of resistance and agency against inequity. Speculative fiction, an umbrella term that includes the genres of science fiction, fantasy, and horror, has been used by critical pedagogues to reimagine our present, or as Thomas (2013) put it, for "reading and rereading, writing and rewriting the world" (p. 4). Thomas & Stornaiuolo (2016) describe this practice, *restorying*, as using new media tools to reimagine the world and retell popular stories by changing to an alternate identity, time, place, mode, perspective, or metanarrative. Learning scientists have used speculative practices and their potential to empower youth, especially from minoritized communities, to engage in constructing and thinking on meaningful and more equitable futures (Holbert et al., 2020; Mirra & Garcia, 2020).

Latinofuturism, describes a broad range of Latine speculative aesthetics produced by creators of Latine origin (Merla-Watson, 2019). This speculative form of fiction denotes Latine aesthetics of various media, drawing inspiration from Afrofuturism and focusing on topics such as *indigenismo* (indigenous cultures), *mestizaje* (interracial mixing), and *coloniality* (dominant/dominated), which question narratives of progress and technological advancement (Merla-Watson, 2019). However, it is still a matter of discussion if Latinofuturism should include indigenous-futurism from the Indigenous Peoples of Mesoamerica and Latin America. Latinofuturism sees Latine people not as passive consumers of the speculative but as creators that repurpose speculation towards emancipatory ends (Merla-Watson, 2019). The work of Sedas et al. (forthcoming) on everyday ingenuity as a culturally-relevant practice of engineering of some Latine participants provides a concrete example of how we envision Latinofuturism to be integrated into a STEM + Arts asset-based pedagogy.

Community Cultural Wealth in Latinofuturism

To evidence how each of the six forms of capital that nurture CCW are displayed in Latinofuturistic media, we present evidence from comics, art installations, and video games (Figure 1). **(1)** *Aspirational capital***.** In Latinofuturistic speculation, creators imagine futures, materialities, and possibilities for themselves to generate new worlds (i.e., worldmaking). For example, in *"Puerto Roboto"* (Santiago & Reyes Rico, 2021), the author dreams and creates a futuristic world where Puerto Rico is the "global center of robotics, engineering, and new technology." **(2)** *Linguistic capital.* In *"Children of the sea"* (Pueyo & Luis, 2021), a character finds a prayer to the goddess Lemanjá which is written in Portuguese, as well as many signs and writings as part of the comic. Students could use their own linguistic resources and mother tongue to restory STEM + Arts practices and include multilingual elements in their artifacts, also to access artistic references in many languages. **(3)** *Familial capital* connects with Latinofuturism as it includes inquiry on the past, heritage, and history. In Latinofuturism, family history, knowledge, and practices are brought to dialogue with STEM + Arts practices. For example, in "*Día de la vida*" (Pérez & de la Torre, 2021), memories and stories of the past come alive through holograms that emulate dead family members. **(4)** *Social capital.* As Latinofuturism centers Latino communities as protagonists, students could cultivate and foster their relationships. In *'Aztech: Forgotten Gods'* (2022), an indigenous-futuristic video game, the character is seen supported by other members of the community. Many of the challenges in the game are solved through the community's wisdom and resources. **(5)** *Navigational capital* appears in Latinofuturistic stories and aesthetics, as they often include narratives of challenging and reimagining social institutions. In "Espiral" (Manzano, 2021), the main character learns to navigate a complicated diplomatic negotiation and succeeds due to his kindness and through promoting intercultural exchange between future Latin America and space. Lastly, **(6)** *Resistant Capital* is broadly depicted in Latinofuturistic artifacts as its main themes are migration and coloniality. Engaging with and producing Latinofuturistic media includes reflecting on historical inequalities that the Latine diaspora has faced and also how Latine people have continued to resist. For example, in *"Walk on Water"* (Guadalupe Maravilla, 2019), futuristic *coyotes* (people smugglers) resignify immigrant labor; they use futuristic vacuum cleaners and sounds to "clean" the space of New Yorkers Political phobias and blockages (Ramirez, 2021).

Figure 1
Community cultural wealth in Latinofuturistic media (see endnote 3).

Aspirational capital in 'Puerto Roboto'

Linguistic capital in 'Children of the sea'.

Familial capital in 'Dia de la familia'

Social capital in 'Aztech: Forgotten Gods.'

Navigational capital in 'Espiral'

Resistant Capital in 'Walk on Water' .

Towards an asset-based pedagogy situated in Latinofuturism

We have shared our theoretical considerations on how situating STEM + Arts pedagogies within the aesthetics of *Latinofuturistic* movement may provide a nourishing learning environment since these aesthetics display the six forms of capital denoted in CCW already present in Latine populations. Providing latine youth with these opportunities may constitute an example of much needed culturally relevant STEM curricula that invite Latine to participate while embracing and celebrating their cultural backgrounds. Asset-based pedagogies infused with Latinofuturism may present opportunities for Latine to engage with STEM + Arts practices while *restorying* their past, present, and future narratives in these fields. Our present and future work includes a systematic literature review of empirical studies that describe the use of Latinofuturism in such asset-based pedagogies and also concrete examples of how Latine youth bring their community cultural wealth to reimagine STEM education that is relevant to them and their own communities and cultures.

Endnotes

(1) We use the term “STEM + Arts” instead of the “STEAM” to symbolically give the Arts its place as equal to the other disciplines and signal the implicit trouble of the STEAM construct, as explained by Mejias and colleagues (2021).

(2) The National Center for Education Statistics uses the designation of “Students of Color” to those who are Black, Hispanic, Asian, Pacific Islander, American Indian/Alaska Native, and of Two or more races.

(3) Power and Magic Press, Publisher of “MAÑANA: Latinx comics from the 25th Century,” granted written permission to use figures in this educational publication.

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"I'm Not Typically the Type of Person Who Takes the Lead": Using Physical Computing to Support Identity Development

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Abstract: Within computer science (CS) education, physical computing has emerged as a tool for designing learning environments where children can learn computer science and increase their identification with and interest in computer science. Here, we report findings from our examination of students' identity work based on their participation in an 18-week after-school club in a Korean elementary school focused on physical computing with four sixth-grade students. In analyzing multiple observational data sources (e.g., video recordings, interviews), we highlight how a focal student authored himself as an expert and a club leader. Our findings show the importance of an interest-based learning environment for identity development.

Introduction

Science, Technology, Engineering and Mathematics (STEM) education and learning sciences scholars have demonstrated the importance of examining identity processes that occur across K-12 learning environments (Bell et al., 2017). Azevedo and Mann (2022, p. 179) define identity work as "the interactionally achieved, historically and contextually situated process" of "actively authoring him/her/theirself as a particular kind of individual" and others' positioning of that person. This work occurs over time and across settings as individuals engage more deeply in communities of practice (Lave & Wenger, 1991). Informal STEM settings may offer fewer limitations than traditional schooling contexts for designing student-led learning environments centering on children's interests—important instructional design principles that can foster interest-based engagement and identity development. Here, interest-based engagement in practice refers to "self-motivated, often self-guided, short- and long-term participation in the fabric of activities that make up the practice" (Azevedo, 2013, p. 464). Individual interests are linked to cognitive, social, cultural, and material dimensions, and establishing environments where interests can take root and grow is key to instructional design (Azevedo, 2013).

Physical computing (Blikstein, 2013; Kalelioglu & Sentance, 2020) emerged as a tool to support children's engagement in CS learning and increase their identification with and interest in CS while helping us understand humans' interactions with digital environments. Physical computing can 1) promote creativity and engagement, 2) deepen students' understanding of and interest in CS, and 3) enhance their computational thinking skills (Blikstein, 2013; Kalelioglu & Sentance, 2020; Przybylla, 2015). The physical computing device is a "programmable tangible that would bring programming to the physical world" (Blikstein, 2013, p. 173). An example of using physical computing in practice is the BBC micro:bit, a microcontroller with many features (e.g., LED lights, programmable buttons, sensors), used in this study as a tool to support students' interest-based engagement and elaborate on the role that tools, artifacts, and materials play in learning (e.g., Saxe, 1992).

We examine how four sixth-grade students' identities developed through an interest-driven physical computing project over 18 weeks, given that human behavior is best understood by tracing its change over time (e.g., Saxe, 1992). Drawing upon sociocultural theories of learning (Lave & Wenger, 1991), we unpack students' identity work by situating physical computing in a student-centered interest-driven learning environment. We view learning as a contextual and social phenomenon acquired by engagement in a community of practice (Lave & Wenger, 1991) and examine how a focal student, Song, became a leader of a collaborative project and authored himself a CS expert. We ask, how did interest-driven physical computing influence Song's identity work over time? Using observational data sources, we discuss how the design of the learning environment supported his increased interest in and identification with CS. We also highlight Song's identity work related to being a club leader and CS expert, including his deepened participation in CS learning activities, and personal growth, contributing to the literature related to CS identity development.

Methodology

Study context and data collection

The study context was the Bright Computing After-School Club at J Elementary School, located in a low-middle income school district in Seoul, South Korea. In the club, students typically learned how a small media station is operated and how to utilize digital tools (e.g., computer, camera, streaming equipment). The study participants were four 12-year-old sixth-graders (one female, three male students) and the club teacher, Ms. Han, a Korean woman in her late twenties who taught the students science during the school day and worked with them in the club. Students voluntarily participated in the club and shared an interest in learning technology and a desire to experience digital devices. Most students had less than six months of learning experience with introductory-level CS elementary education, while Song had more than 2.5 years of experience; none had prior experience with physical computing. All students had experience using a block-based programming language (e.g., Entry, Scratch), but stopped other CS activities because they did not enjoy teachers' unidirectional instructions.

We desired to foster a learning environment where students could pursue their own interests without fear of being assessed for correctness. Author 1 came up with the idea for redesigning the club, the research plan, and met weekly with the teacher to assist. Students were given space to work on their projects and resources, including smart tablets, BBC micro:bit boards, computers, and crafting materials (e.g., paper, scissors, glue). Ms. Han had limited familiarity and expertise in CS, so there was little teacher intervention; students primarily used resources (e.g., YouTube videos) to teach themselves and support their learning. Researchers examined student learning activities over 18 weeks and collected five data sources: video recordings of students participating in the club; the teacher's reflective diary documenting both science classes and the after-school club; student artifacts; student and teacher interviews; and notes from weekly meetings with the teacher. We video-recorded each session and documented the specifics of individual students' activities in and beyond the club. Ms. Han kept a reflective diary with rich records of daily teaching reflections from each science class and after-school club session. We collected any artifacts students produced as part of their physical computing projects (e.g., micro:bit electric guitar, micro:bit digital pet). After 18 weeks, when the project was complete, Authors 1 and 3 conducted semi-structured interviews with each student in Korean (30 minutes each) and translated transcripts into English. Interview questions were designed to elicit information about students' activities at the club, classroom work, family life, and other learning environments. We also asked follow-up questions to gain clarity about their artifacts, perceptions, and visible and salient behaviors in video recordings.

Data analysis

This study is part of a larger, ongoing design-based research project (Barab & Squire, 2004) combining case study methodologies (Yin, 2012). This approach includes ethnographic mapping of themes and description via participant observation, collection of artifacts, production of a detailed reflective diary (Geertz, 1973), and video-based interaction analysis (Jordan & Henderson, 1995), enabling a focus on the macro-, meso-, and micro- systems shaping student activity and learning. To understand students' identity processes over time, the first author open-coded transcripts from video recordings, interviews, teacher's reflective diary and examined student artifacts (Miles et al., 2018). We segmented instances of video recordings and performed interaction analysis to identify and describe occurrences of identity work in the classroom (Jordan & Henderson, 1995). The data was holistically analyzed through the lens of sociocultural theories of learning (Lave & Wenger, 1991), examining how they were positioned to engage in specific kinds of activities over time, the types of persons associated with that work, and the self-reflection and social recognition work that developed over time (Jordan & Henderson, 1995). We layered this analysis with analytic memo writing (Emerson et al., 2011). From these analyses, we selected Song as a focal student. His identity work was most prominent in the data sources (e.g., video recordings, teacher's reflective diary), providing detailed evidence to develop an account for his identity work. We selected instances of the focal student's identity work related to authoring himself as a particular kind of individual, relating these to the instances of recognition by the teacher and peers.

Results

Song's identity work toward becoming a club leader

We present results from Song's identity-building efforts. Before initiating the club, data sources (interviews with Song and Ms. Han, teacher's reflective diary) revealed Song was generally quiet and disengaged in overall school activities. In his interview, Song mentioned his parents' divorce and implied that it had an impact on his life. Initially, Song's position relative to the other three club members was clearly peripheral, as he hardly spoke or communicated with them. Although none of the students had prior experience with micro:bit, over the course of 18 weeks, Song developed a reputation as an expert on digital devices and coding among the club members, identifying him as the member most skilled with computers and occasionally asking him for help.

Considering Song's identity work relative to the club's internal group structure and functioning, it was evident that Song had become the club's leader. In asserting his position, he would "teach [peers to] do something" (Excerpt from Song's interview) and enthusiastically seek resources for what his peers would appreciate and find easy to try out together. He said, “We are friends. We’re the same age. It’s not about teaching from the teacher. It’s about playing together. I wanted the kids to look at this side, the computer, with more interest. I looked for things they might like.” There was a virtual group chat space where club members and teachers interacted. The children asked questions when they had difficulties with physical computing tasks outside of the actual club space, and Song responded to those questions. Even his daily displays of closeness and affection for computing (based on video recordings) seemed to reaffirm his standing. We interpret these actions as Song’s work to maintain his identity and position as the club’s leader and author himself as an expert in computers.

Song’s identity work as the club’s leader was accompanied by his demonstrations of knowledge that hinted at his familiarity with and expertise in the field of computing. Although Ms. Han’s role was primarily as a supervisor, she also publicly asked Song a few times to help others who were struggling, such as when students were having problems connecting micro:bit to the computer or when the codes would not work, thus reaffirming his primary authority over the club activities. His power and authority appeared to stem from club members’ and Ms. Han’s recognition of Song’s prior experience with computers and digital devices.

Song gaining confidence and strengthening relationships with family and peers

Song’s gained power and authority also had influences on his daily school life. Clearly, there has been a change. Whereas he had been very quiet and disengaged in class prior to the club, Song became attentive, enthusiastic, and very talkative by the end of the after-school club. The following excerpt from the individual interview demonstrates who he is becoming: “Well, you know, I taught them [peers] do something. I was looking for what they would like, and I tried to find things that they would like and that would be easy for them. You know, I’m not typically the type of person who takes the lead. [Interviewer: But aren’t you the class president right now?] That's right. Ha ha! That’s because [when we were working on the micro:bit project], I realized I could help them and guide and lead them. So, I got that bit of leadership and learned about being a leader, and this time I ran for class president. [Interviewer: The confidence started with the micro:bit?] Ha ha! [nodding and acknowledging]

Song had developed such specific forms of participating in and contributing to the club. Song developed close personal relationships with peers through club activities. Over the course of 18 weeks, four club members collaboratively created their own digital pets and electric guitars using micro:bits through a series of trial and error and struggling moments. When they succeeded in creating a working micro:bit guitar, for instance, they were all full of enthusiasm and stated that they now want to try building other things using the physical computing device. For example, Song was particularly interested in designing and building a face recognition device that opens the door as the next step in applying his knowledge. He wanted to improve the security of the club’s physical space by installing the device in the club room entrance, which would prevent non-affiliated individuals from entering the after-school program classroom. He reported gaining confidence through club activities, and as a result, he even ran for and was elected class president. Song reported that his personal relationship with his dad had also gotten better. He said that, with coding as a mediator, he was better able to comprehend his father’s work. He mentioned that his desire to learn about computers was influenced by his father, who is a computer engineer. Song said, “I felt interested to see my father do it [coding]. I started to learn coding on my own because I thought it would be fun for me as well.”

Song authoring himself as a CS expert

Song claimed that he began coding at an early age and began learning block-based programming language independently in first grade. For third grade, he attended an after-school computer program. He added, “I joined [the program] a bit late. But they [friends] were already pretty good. [Interviewer: Coding?] Yes. That made me want to win them. Since then, I've been learning on my own after school... Then, when I was in 4th grade, the program disappeared because of COVID, so I went to it for about a year or two.” Song said that he hopes to be a video creator and keep engaging in technology-related work in the future. He recalled that he had edited videos as a hobby since kindergarten: “I filmed a video of me playing with a toy with my friend and uploaded it on YouTube. I edited it with my phone.” His identity-building efforts were strongly tied to his own views on digital devices and technologies. The following interview excerpt displays one portion of Song authoring himself as a CS expert: “It’s [computer] my life… Before my dad bought me a computer, my father and I used to share one. I was only four years old when I first used a computer… But then I did some pilot things. Since then, I've been more interested. But now I'm also very interested in hardware, not just computer software. Assembling and stuff like this… My computer broke down once before. It won’t boot. But I saw on YouTube that you could take out some kind of RAM and put it back in. So, I took out the RAM and put it back in. From then on, I was more curious. [Interviewer: What grade were you in?] I was in 4th or 5th grade, so from then on, I became more fully immersed in it and I did it all night long. 48 hours really... I studied Python for 48 hours.

Discussion

As researchers in the learning sciences, we are interested in advancing the field's understanding of how learning environments can shape identity work, especially in CS educational settings. Identity work happens across settings and time and in relationships with others as individuals engage more deeply in communities of practice. This work can be supported when students have interest-based engagement and their learning is supported by material infrastructure (Azevedo, 2013; Saxe, 1992). To this end, we analyzed data from sixth-graders' participation in the Bright Computing After-School Club for 18 weeks. This learning environment was designed to foster students' interest and identification with CS using a physical computing tool (i.e., micro:bit). We highlighted how Song authored himself as a CS expert and club leader and how others positioned him as such within and across learning environments. Since club activities centered around physical computing, students' identity work was often accompanied by displays of knowing and learning of computing concepts. We discovered that Song's identity work is inextricably intertwined with the knowledge he acquired independently, out of his own curiosity and for his own amusement (Azevedo & Mann, 2022). Song continuously took action to maintain his identity and position as the club's leader. His identity work was also related to others' recognition which, as a result, helped increase his confidence and strengthened his relationships with family and peers. Song "being a leader of the club" stretched across settings and contexts and was expanded to "being a class president" and "having a more intimate father-son relationship" as he engaged more deeply in the club. Song's position in relation to the other three club members was peripheral at first, but his participation grew into forms that were more central to the functioning of the club and even outside the club. Our findings build upon and extend prior research in CS educational settings that suggests physical computing can promote creativity and interest in CS (Blikstein, 2013; Kalelioglu & Sentence, 2020; Przybylla, 2015). Further, our work demonstrates the value of an interest-based physical computing learning environment for promoting students' interest in CS and deepening engagement, which supports their identity work. Such an environment and the tangible tool provided students with the opportunities to better imagine what they wanted to create, and to design and produce artifacts in the actual world that reflected their own interests and identities. Students' interests in CS increased as they connected it to their specific interests and the computing project they desired to undertake. Students' identity work was influenced by the design of the club, which provides opportunities to pursue their interests, interact with others, overcome struggles, reaffirm their own standings, and maintain their identities and positions. Moreover, interactions within and beyond the club revealed social group dynamics rich in identity work from all club participants; thus, we will further investigate all students' identity work in our future study.

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Live Zoom Room: Understanding How Young People Build Joy and Connection Online

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Abstract: In online learning through Zoom, focusing on joy has been a useful strategy to resist deficit narratives about youth of color during the Covid-19 pandemic. To better understand designing and facilitating joyful STEM learning, we explore unique interactional phenomena in "Live Zoom Room," an online, out-of-school cooking program, World through Food. We performed interaction analysis on video data to identify semiotic resources and themes that contributed to joyful moments. Findings revealed that participants drew from common sets of tools and resources to cook and communicate through Zoom and improvised while doing so. These resources allowed participants to be themselves online, and to build on each other's actions, forming a foundation of joyful STEM learning experience.

Introduction

The COVID-19 pandemic and closure of educational spaces forced youth and educators to reconsider the ways we learn together in space and time. As a result, educators in schools and out-of-school-time (OST) programs redesigned their curricula to deliver content via various video-assisted online learning platforms like Zoom. Adapting to Zoom posed unique challenges to project-based, STEM OST learning programs because the activities and projects often required special tools and materials provided by the program on site. Learning on Zoom posed other challenges, too, due to digital fatigue and emotional distance for learners and facilitators (Toney, Light & Urbaczewski, 2020). However, moments of great joy and happiness also occurred on Zoom that sustained participants through the pandemic. Joy and happiness have been framed as responsive actions to unpleasant situations to change perspectives (Adams, 2022; Lu & Steele, 2019). These responsive actions are useful as resistance strategies against a dominant white narrative that positions youth of color as lesser than, lacking cognitive and emotional abilities.

To understand how we can better design and facilitate moments of joyful learning over live Zoom sessions, we need to identify such moments and understand what makes them joyful for young people. We identify and analyze interactions using a "Live Zoom Room" (LZR) practice in which analysts collaboratively view video of learning over Zoom, over Zoom. LZR allows us to understand the unique semiotic resources involved in understanding joyful STEM learning online. We identify *substrates* (Goodwin, 2018) of joyful STEM learning--the semiotic fields of resources that Zoom offers (e.g. video, audio) for participants to operate on, to build from, and to modify actions. We ask: how do young people (and adult facilitators) draw from resources in Zoom, and build on each other's embodied interactions through Zoom to create a shared meaning of joy in STEM learning?

Conceptual framework

A substrate is a symbolic or semiotic resource that serves as a "point of departure for transformative operations that create new action" (Goodwin, 2018, p. 32). We position Zoom as a set of semiotic resources that organizes and transforms participants' interactions and sense-making processes. Zoom interactions are unique in that they occur in real time, but at a spatial distance. In our study, participants were often observed interacting with the technology in semiotically transformative ways where the resources of Zoom became points of departure for new actions to unfold. Zoom's ability to support the real-time unfolding of semiotic actions contributes to the joyful "liveness" of the Zoom learning environment.

Liveness is made possible through a sense of immediacy which occurs through moment-to-moment interactions. Immediacy results in a sense of presence, made possible when the distance between embodied experience and live experience is diminished to the point where mediation becomes invisible (Davis, 2012). We look to Zoom as the mediating technology that enables participants to engage in co-operative embodied interactions that accumulate and transform at a distance, and in real time. It is important to note that these in-the-moment interactions at a distance are made possible by the technology of Zoom, which is not neutral nor evenly distributed across hardware and connection (Eubanks, 2018).

When we use technologies, they reshape how we experience the environment, thus reorganizing the relationships between people and the environment (Verbeek, 2005). In our study, this meant how participants created and experienced joy was shaped by the kinds of relationships they had with Zoom technology. To better see this unfolding relationship, we draw upon Ihde's theory of human-technology relations as an analytical lens through which to understand the *substrates* that are produced. Ihde's human-technology relations are highly context dependent; we adopt and adapt two relations in this study: 1. *alterity relation* and 2. *embodied relation* (as cited in Verbeek, 2005, p.127).

First, *alterity relation* concerns how humans are "related to or with a technology" (Verbeek, 2005, p.127). It often refers to the ways in which humans use or interact with a technology to do a certain task. *Embodied relation* is the mediation of those technologies which transform a user's actional and perceptual engagement with the world (Verbeek, 2005). In the context of Zoom-human relations, *alterity* and *embodied* relations are not always clearly demarcated, and they are always in motion together. This is because we use Zoom to communicate and relate to other people; we usually do not connect directly, and only to Zoom. For example, if a youth prefers using audio, they are relating to a part of Zoom technology to communicate in a specific mode. Thus, when we describe participants' propensity to draw from particular resources in Zoom (e.g. using chat), we refer to this as *embodied alterity relation*. We reserve *embodied relations* for instances where participants' field of perception, or bodily actions are mediated via Zoom. We use *alterity* and *embodied relations* as helpful lenses to examine how people use Zoom resources and build their own *substrates.*

Study context

STUDIO is a research practice-partnership between the University of Washington (UW), and a community-based organization (CBO) located in a mixed-income, public housing community in a city in the Pacific North West region. STUDIO is a collaborative effort to create and facilitate STEM, project-based curricula that serves middle and high school youth of color from local immigrant and refugee families through a learning community (Herrenkohl et al., 2019). Researchers, CBO staff collaborate with youth and work with undergraduates who serve as mentors to youth by participating in 2-2.5 hours of weekly program activities. STUDIO considers youth, families, and undergraduate students as co-designers and facilitators of OST curriculum that we describe and analyze below. During the early months of the COVID-19 pandemic, STUDIO responded by designing an online STEM-based cooking program called *World through Food*. The curriculum took place between September and December of 2020 and aimed to bring participants together to cook, explore STEM concepts embedded in cooking, and support one another. The CBO staff and researchers purchased and delivered ingredients to youth's homes weekly before each Zoom session. All activities took place over Zoom once a week for two hours synchronously. Video recordings of these Zoom sessions were then collected and analyzed (Jordan & Henderson, 1995). The first author identified segments of videos that indicated joyful learning, and these were then co-viewed by a team of researchers to identify key semiotic resources, themes, and substrates (Goodwin, 2018).

The vignettes below were from the first day of *World through Food* when youth and facilitators made Dalgona coffee, a drink trending on Instagram in 2020. We observed that youth and facilitators had different ways of engaging with resources in Zoom. Although youth talked more over time, their preferences toward using distinct Zoom resources largely stayed the same. This prompted the authors to analyze the Zoom video data from the beginning more closely, and thus use the vignettes from the first day.

Findings

Although facilitators and youth have a similar range of resources, we observed that each individual participant had specific preferences toward certain sensory modalities such as audio and chat. These specific *embodied alterity relations* that individual participants formed with Zoom affected how participants embodied themselves online, and built upon each other's actions to create *substrates* of joyful STEM learning. Youth had control of turning on and off different Zoom functions (e.g., muting themselves, turning off their camera) with the exception of recording, setting up breakout rooms, and muting the audio of other participants; only the host had control over these functions. The authors chose to focus on audio and video in this study because these were the most often exhibited communication preferences. We describe how these preferences were used in Zoom by youth to joyfully connect and communicate using vignettes below.

1. Max's embodied alterity relation: Creating moments of joy through video and audio

In the short exchange between Lucy, Max and Jiyoung, youth created moments of laughter and joy as they built on each other's actions using video and audio to compare foam to prepare for drink making. Max was making his drink using cocoa powder because he had made Dalgona coffee in a previous session and he was wondering whether cocoa powder and milk were easier to foam up than the coffee blend.

01 Max: Lucy, is it supposed to be not that hard to do?
02 Lucy:*[[she smiles]]* It's already thick in consistency so, it depends on what you want.
03 Max: Mine is just, *[[Max shows his bowl upside down in front of the camera]]* hahaha
04 Lucy: Same. *[[Lucy shows her bowl upside down as well]]*

05 Jiyoung: Magic hands! Coco team.
06 *[[Max puts the bowl upside down over his head]]*
07 Jiyoung: Mine looks like this *[[putting her whisk up on the screen, and a blob of coffee mixture falls down]]*
08 Max: You have to whisk it more.
09 Jiyoung: I guess *[[She speaks with a playful inflection and facial expression]]*
10 Max: Arm strength, Jiyoung! This is your workout.
11 Jiyoung: hahahaha

In line 03, Max enacted stickiness of the mixture by putting his bowl upside down and holding it in front of the camera, showing that the mixture was thick enough to stick to the bowl. Then, he started laughing out loud as if the mixture's stickiness was intriguing and amusing. His preference of using audio and video together, his particular *embodied alterity relation* with Zoom, supported him to embody his sense of humor by creating a moment of levity and joy in the group as well as to communicate the status of his cocoa drink. Max's actions became a *substrate* when Lucy mimicked his motion by showing her bowl in an upside down position and smiling (04) (See Figure 1). Jiyoung followed this chain of *substrates*, and modified it by showing her own mixture and adding a lighthearted comment, "magic hands"(05). Although they were making their drinks from different ingredients, they all were using the same tools, whisks and bowls that allowed them to enact similar actions. Max encouraged Jiyoung to keep whisking and made an joke about exercising (10). Max's joke was a response to her comment, "I guess" with a facial expression that expresses a bit of protest (12). When Max noticed that she, a facilitator, was complaining about whisking, he encouraged and made fun of her at the same time; he transformed whisking into a visible arm workout. This short interaction ended with Jiyoung laughing out loud; Max, Lucy and other participants smiling together. In this sense, this *substrate* is an example of how Max embodied his sense of humor through audio and video, and how moments of joy can be shared in Zoom rooms.

Figure 1
Lucy puts her bowl upside down like Max did with his bowl.

Although Max was apt to use his microphone and camera to communicate, he rarely did so by adjusting his body positions to show what he was doing to other people. He would sometimes disappear from the video frame to help his brother Alan with cooking. The lack of bodily reconfiguration contrasted with how facilitators adjusted their body to maximize visibility will be addressed in vignette 2. This pattern of video use showed us that Max was less concerned with how he appeared on Zoom screen, rather he cared more about communicating that he was participating along with other people in the Zoom room.

2. How facilitators support youth and how youth reciprocate with joy

This vignette illustrates how facilitators use different kinds of bodily configurations to effectively teach, over Zoom, a new practice. Below, we describe how facilitators built on each other's actions to support youth in whisking, an important step in creating foam in Dalgona coffee by mixing instant coffee powder and water. When the participants started the activity, two facilitators, Lucy and Jiyoung took the lead in instructing what and how much of each ingredient were needed. To make sure their voices were picked up by the microphone, and their hands were visible by the camera, facilitators centered their bodies in front of their laptops. Jiyoung further demonstrates this intentional bodily positioning to effectively communicate within the Zoom room.

Figure 2
Lucy, Jiyoung, and Cathy model whisking for youth in the live Zoom room.

Jiyoung showed how to whisk by moving her hands and arm left and right, and explained verbally, "There are different ways to whisk, I usually go left and right like this, that puts a lot of air into it. Go left and right really fast." Further, when she noticed that her hands were not visible on the camera, she raised her bowl, angled toward the camera and whisked in the air, a quite awkward body position for the whisker (see Figure 2). If she did not have to show the youth how to whisk through the camera, Jiyoung would have put the bowls down on the countertop for more stability. This kind of intentional use of camera and reconfiguration of body position is what we mean by Zoom mediating our *embodied relation* with the technology.

Jiyoung's whisking motion was quickly adopted by Lucy and Cathy right after Jiyoung lifted her bowl. Like Jiyoung, Lucy raised her bowl in front of the camera. Cathy modified her action by lowering her camera lens so that viewers would be able to see her bowl and whisk on the table (see Figure 2). While they are building on each other's actions in close succession, other participants started changing their whisking motion from swirling to quick left and right turns. One youth, Moshin, gave us a verbal response, "That's actually a good idea! I am seeing some bubbles." In Zoom, where facilitators' bodily sensations are limited for checking on youth, Moshin's comments provided facilitators a sense of relief and joy as their effort to support youth was reciprocated. The joy is apparent in Jiyoung when she smiled and replied to Moshin with encouragement, "Yes, go Moshin!" The *substrate* that Jiyoung presented by reconfiguring her body in front of the camera was modified by Lucy and Cathy to teach youth how to whisk more effectively. When Moshin took up this *substrate* with his joyful approval, the facilitators' *substrate* became not only a resource to teach but also to express joy in striving to reach a shared goal of making a delicious coffee.

Conclusion

Across two vignettes, we presented how youth and facilitators drew from resources in Zoom to build on each other's actions to create shared joyful moments. There are three critical aspects of *substrates* of joy that we attend to: 1. Similar sets of resources involved in cooking and communicating, 2. Synchronicity of participation, and 3. Immediacy of actions. As participants tried to learn and teach how to use whisks, they paid attention to each other's ways of using Zoom's resources; they created a series of visual and auditory substrates to communicate. Because participants had a similar set of tools and materials, and engaged in the same activity at the same time, they could inhabit similar actions, and thus be able to build on each other. Further, substrates were available for a short period of time, pushing participants to react immediately and improvise. While doing so, they added their own sense of humor, and they responded with appreciation and approval, making moments of joyful STEM learning possible. Educators interested in creating joyful online STEM learning environments should design common activities that engage similar sets of tools and materials for each participant, and ensure access to the resources available on Zoom that creates a foundation for building actions together.

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Expansive Framing for Citizen Science: Use of a Facilitated Online Platform to Connect Current and Future Teacher Practices in STEM

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Abstract: Engaging pre-college students as consequential contributors to socioscientific endeavors requires teachers to shift their pedagogical approaches to encompass more expansive views of community, learning goals, and student roles. Drawing on ecological perspectives, teacher professional development can support expansive shifts by fostering connections across contexts, including links between current and envisioned practices. In a summer PD program designed to promote adoption of pedagogies for citizen science, we used a facilitated online learning platform to support teachers in enlisting resources across contexts to expand their perspectives of what is possible for their practice. This design-based research project used qualitative methods to explore whether and how teachers' projective posts more expansively framed their practices relative to practices they initially described.

Introduction

In a world increasingly affected by climate change and the misconceptions surrounding it and scientific fields in general, it is vital to equip teachers to prepare students with skills and dispositions to become active and ethical participants in STEM fields. There is a need for teachers to enact innovative pedagogies that support consequential and connected learning in STEM instruction (Jordan et al., 2021). Such approaches require K-12 teachers to take complex approaches to disciplinary content and pedagogical practices. Example approaches include place-based citizen science and community-centered engineering, each oriented towards students being recognized as rightfully present members of their classrooms and broader communities (Calabrese Barton & Tan, 2019). Effective professional development (PD) experiences for such pedagogies necessitate intensive commitments of time and collaborative energy, often among teachers and facilitators who are dispersed across physical distance. Online learning platforms can facilitate continuing PD in distributed learning communities across temporal, geographical, and institutional space (MaKinster et al., 2006).

We report on a hybrid PD program designed to support classroom enactments of innovative STEM instruction through school-based citizen science (CitSci) focused on testing a novel solar energy innovation. Through an ongoing program, teachers participate in the cocreation of a network of researchers, community experts, and K-12 students contributing to sustainable and equitable community-centered energy transitions. Here, we report on STEM teachers' participation in the online connected growth platform designed to support the development of a networked community of teachers distributed across schools, districts, and cities. The facilitated platform aims to engage teachers in learning and contributing to the pedagogies envisioned for K-12 STEM students in the CitSci program. The purpose of this study is to explore ways the platform supports teachers in expanding their pedagogical practices to include new perspectives on community, educational goals, and student roles that are vital to consequential and connected learning in STEM (Jordan et al., 2021).

Literature

Shifts in pedagogies and content knowledge are harder for teachers to make than are changes to discrete classroom behaviors (Desimone & Garet, 2015) and yet these types of deep changes are necessary to engage students in consequential STEM learning. Adopting new approaches requires reflecting on and shifting "habitual and socially reinforced ways of thinking about schooling" (Priestley et al., 2015). We see teacher learning through an ecological perspective that suggests PD opportunities should enable teachers to agentively connect new concepts with past, present, and future visions of their practice, across multiple settings, and with a diversity of resources including other teachers' wisdom and support. Learning is thus conceptualized as stretching across multiple scales of social influence and time, enlisting interconnected relationships, experiences, and tools as resources for sensemaking (Ehrenfeld, 2022).

When teachers have the opportunity to connect multiple resources from across their lives, in essence, to "expansively frame" (Engle et al., 2012) their learning in terms of its relationship to their current practices, past PD, lived experiences, and imagined future practices, they can better make decisions for agentive action in practice (Priestley et al., 2015). Teachers who learn in community are more likely to incorporate pedagogies presented in PD programs into their practices (Penuel et al., 2007). Benichou et al. (2022) and Stephens et al. (2022) reported on researcher-practitioner collaborations in which participation in PD fostered teachers' expansive framing of their own and their students' learning. This expansive framing led to enhancement of practice through greater understanding of and engagement with the PD concepts and aims.

Online platforms show promise for facilitating teachers' expansive framing and professional growth in community even when not co-located (MaKinster, 2006; Andrews et al., 2019). The platform used in this study, Journey.do, brings together expansive framing and ecological perspectives motivated by the idea that growth occurs when learners see their context-of-use as consequentially connected to the content and context of learning (Barab et al., 2019). On Journey.do,, teachers can share stories that recruit their experiences, beliefs, values, goals, and expertise as resources for making sense of new concepts (Jongewaard et al., 2021).

Method

This design-based research (DBR) study addressed the question: *How and to what extent do teachers' projective story posts more expansively frame their future practices relative to posts that describe their current practices?*

Participants and context

Participants in this first design cycle of a multi-year DBR study (Barab & Squire, 2004) included 9 STEM teachers (experience ranged from 1 to 10+ years) in a 6-week (~100 hour) PD program co-designed by researchers located in a southwestern US desert. Three teachers taught high school (earth systems, chemistry, botany), two middle school (STEAM, science), and four elementary (3rd-5th).

The PD context of this study was a summer program that engaged teachers in co-developing and instantiating Agrivoltaic (agri-PV) CitSci as an innovative pedagogy. School-based CitSci provides opportunities for students to engage with professional researchers and other community members through authentic science practices (Bautista-Puig et al., 2019). *Citizen science* is a viable instructional strategy for engaging students in scientific argumentation and investigations, (Phillips et al., 2019). Nonetheless, we join others in calling for CitSci pedagogies to go beyond data collection to include students in all phases of knowledge generation (Morales-Doyle & Frausto, 2021), and taking action on data they and others collect (Harris et al., 2020). *Agrivoltaics* is a relatively new area of research that couples agriculture with solar energy production in order to grow food across more of the year, generate multi-uses of land to decrease social conflict, and conserve water. Early results suggest that agri-PV shows particular promise for desert climates, like the study setting. Thus, the agri-PV CitSci PD sought to prepare teachers to engage their students in investigative research at campus-based agri-PV sites through collecting, analyzing, interpreting, and sharing data with university researchers, and also with K-12 co-lab members across campus sites. With this long-term agenda in mind, teachers came together to learn about agri-PV, work in teams to design and test agri-PV CitSci tools and protocols, and co-develop CitSci curriculum. Through our PD design, the co-designers sought to promote teachers expansively framing their pedagogical practices in order to expansively frame youths' science engagement (Benichou, 2022). Specifically, we focused on fostering teachers' expansive framing of (a) community (b) learning goals, and (c) student roles, because these elements are required for successful enactment of the agri-PV CitSci program.

This study's design intervention built on Journey.do's ecological design to create online modules to structure individual and collective growth and support teachers' expansive framing of their practices relative to agri-PV CitSci. Each Journey.do module has a 4-phase engagement cycle: 1) Connect, 2) Grow, 3) Apply, and 4) Inspire. When teachers begin a module, they view the rationale and learning goals for the module, set by the program designers. In the Connect phase, teachers read stories by members who have already completed the module, written in response to a prompt that asks them to reflect on their current practice or to envision enactment of the module concepts in their future practices. The member just starting the module responds (i.e. "connects") to stories with emojis or comments. Responses to stories give participants a chance to support each other and use each other as resources when envisioning their own practices. In the Grow phase, members encounter the module's informational content that invites them to become authorities on the module concepts, expanding and deepening their disciplinary and pedagogical content knowledge. Subsequently, participants move to the Apply phase where they write their own story posts. Through storytelling, participants enlist their experiences, beliefs, and hopes as resources to develop expanded visions of what their practice might become. The prompts promote links between (a) past, current, and future practice, (b) partnerships in and out of classrooms, and (c) goals for students as learners and as contributors. In the final phase, Inspire, participants submit their story for publication; others can create a thread of responses.

Data collection and analysis

Teachers were asked to complete 8 1-to-2-hour Journey.do modules in total, 4 before and 4 during the six-week PD. Altogether, the teachers shared 44 story posts averaging 230 words each and generated 144 responses.

Analysis for this study was limited to the story posts. Qualitative analysis entailed iterative rounds of deductive and inductive processes. Grounded in our belief that consequential and connected learning requires expansive views of *community*, *learning goals*, and *student roles* (Jordan et al., 2021), three researchers first worked independently to deductively pre-coded the stories for description of these concepts (Ravitch & Carl, 2019), followed by collective negotiation. We then honed our understanding of these three concepts within the context by inductively identifying sub-themes within the data (e.g., community within school, community beyond school, student contributions), looking across the coded data within and across posts, to collectively characterize distinct orientations toward community, goals, and roles. Viewing each teacher's collection of coded data through the lens of expansive framing (Engle et al., 2012), and comparing across teachers, we determined that there was a spectrum of framing along which some teachers viewed their practice more expansively than others. We clustered the teachers in 2 groups: 5 initially viewed their practices related to community, goals, and roles more narrowly, 4 viewed their practice more expansively, with an understanding of community extending beyond the classroom, goals for learning expanding past content mastery, and vision of student roles as agentive contributors. We then compared each teacher's stories of current practices with their stories of projected practices to interpret shifts in how they expansively framed. We limit reporting of findings to 6 focal teachers who contributed the highest number of posts: 3 from the "narrow" and 3 from the "expansive" clusters.

Findings

In each of the 6 focal teachers' posts, we saw more expansive framing of at least one aspect of their practice. Teachers varied in the extent to which the practices were expanded as well as in which of the 3 areas were expanded. In the cluster of those who initially expansively framed their practices, teachers continued to expand and deepen their visions of what could be, with concrete ideas for steps they would take. Those whose initial practices were more narrowly framed connected new concepts with their current practices, but also expanded in ways that suggested qualitatively different orientations to community, learning goals, and student roles.

Among the three teachers whose practices were initially less expansive, one teacher's shift was especially noteworthy. Sam began the program confident in their pedagogical approaches, which they described as "innovative, research-based instructional methods." However, their view of community was limited to students in the classroom as they participated in the "collaborative spirit of science." Sam's during-summer stories maintained a value on collaboration, but also expanded to propose partnerships with community members outside of their school. For instance, they wrote about a potential partner at an organic farm, saying, "we can enter into a reciprocal relationship" leading to the "creation of a generation of young people who can, through their own work, proliferate the core principles upon which [the owner] herself operates." Building on their current idea of students working toward common goals, Sam envisioned a community expanded by the inclusion of experts where learning and contributing are reciprocal, and relationships over time push shared goals towards fruition not just for a school year, but across generations.

Another teacher, Penny, whose view of community, goals, and roles were relatively narrow in earlier entries, showed expansion of student roles. In describing her prior work with the school garden, Penny described her students as "helpers." After learning about citizen science on the platform, Penny showed a view of students as contributors to scientific endeavors: "We are *all* researchers and can benefit science." Penny wrote that she was inspired by student-created art in one of the other teachers' gardens to solicit student art for her school's garden. While the shift is subtle, we see that through interactions with other teachers and new concepts encountered on the platform, she began to expand roles for students beyond helpers to partners with their own voices. In her existing practice, a third teacher, Liz, positioned students as contributors to the class's learning through conversations about phenomena she chose for the class to study. Her prospection of the garden expanded on agency in student roles, envisioning art students collaborating with physics students to design a fountain and describing students as having "options for what is grown and what questions are asked."

In the cluster of teachers whose practices already expansively framed community, goals, and roles, two teachers envisioned even more community connections and listed concrete ways their students could become more consequentially connected with community members and scientific projects. Val already had 2 years of experience working with agri-PV geared toward consequential and connected learning. Her projective stories intermingled plans for changes to the school gardens, with ideas for a year of garden-based community interactions in which students led tours, shared produce, and forged relationships with other organizations. Like Val, Mark's practice already positioned students as agentive contributors to a community beyond the classroom. His current stories focused on student belonging and identity as science caretakers of the school's gardens. His projective stories envisioned possibilities for his students to go beyond being science learners to being citizen scientists doing "real research", starting with the agri-PV beds and then to "scale up" to a project benefiting butterfly migration. A third teacher in the more expansive cluster expanded her view of what it meant for students to be climate action advocates. Bella told current stories of students creating ways to raise their schools' awareness about endangered species. After a PD module about justice in STEM, her prospection expanded student influence to the surrounding community and to complex issues of inequitable access to green technologies. For these 3 teachers, expansive framing of practice in relation to community, learning goals, and student roles was not new, but their stories revealed a strengthening and further expansion of pedagogies.

Discussion

By designing invitations to connect current practices with envisioned ones, online modules can support teachers in framing their practice more expansively whether they are strengthening already expansive views on community, goals, and roles or moving from narrow perspectives. Future research will explore if and how enactment of innovative pedagogies is supported through continued opportunities to share reflective and projective stories of practice as teachers attempt to enact their envisioned agri-PV CitSci pedagogies. Ongoing study of the agri-PV CitSci network and Journey.do will look at future cohorts as well as follow teachers and their online interactions into their school year implementation to learn more about the ways networked communities on learning platforms can support connected and consequential STEM pedagogies.

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Preparing Students for a "Post-Truth" World: The Epistemic Unfriendliness of Science Curricula

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Abstract: The contemporary information society is "epistemically unfriendly"—that is, it is rife with often confusing, conflicting information that varies dramatically in quality. To prepare students for the epistemic unfriendliness of the contemporary world, it is vital that students be exposed to some of this unfriendliness in school so that they can learn to cope with it. But to what extent do existing curricula expose students to epistemic unfriendliness (e.g., various kinds of poor evidence, various kinds of trustworthy sources, etc.)? Using the Grasp of Evidence framework to guide our analysis, we provide a preliminary analysis of the extent to which five selected researcher-developed science curricula expose students to epistemic unfriendliness. Our results to date indicate that students may get relatively few opportunities to engage with poor evidence and sources on the dimensions of evaluation, integration, and lay use of evidence.

Introduction

In the contemporary information society, people find themselves in an "unfriendly epistemic environment" (Chinn et al., 2021). By this, we mean that the information world is rife with confusing, conflicting information that varies dramatically in quality, yet it is difficult to determine which sources and information are trustworthy and which are not. In this world people often encounter evidence, but the evidence is frequently of low quality or cherry picked. To find out what is accurate, citizens need to become adept at negotiating this unfriendly epistemic environment. In contrast, schools typically present students with epistemically friendly, even sanitized environments (Chinn et al., 2021; Duncan et al., 2018). Evidence is typically simple and straightforward. Exposure to biased or inexpert sources can be rare, and controversies are often avoided (Hess, 2009). In such environments, students will have little chance to learn how to deal with poor evidence, weak arguments, misleading sources, and other unfriendly features of the so-called "post-truth" world. An overly friendly epistemic environment will not prepare students to distinguish between accurate information and misinformation, good and poor evidence, sufficient and insufficient evidence, and trustworthy and untrustworthy sources. It is vital for students to be exposed to some of these unfriendly elements in school so that they can learn to cope with them.

Goals and theoretical framework

This project appraises the extent to which selected science curricula incorporate features of epistemic unfriendliness. We have chosen to focus on science curricula because many of the issues that citizens encounter in the digital world (e.g., COVID-19, the safety and efficacy of vaccines, climate change) are scientific issues and require that people come to grips with scientific evidence and scientific sources of information. Accordingly, the eventual goals of this overall project are to examine a wide range of science curricula to see how well they prepare students to grapple with the epistemic unfriendliness of the digital world related to scientific issues—that is, to what extent these curricula incorporate elements of poor scientific evidence and trustworthy scientific sources so that students learn to deal with them. Which forms of unfriendliness are and are not incorporated?

How can we conceptualize curricula in order to analyze how "epistemically unfriendly" they are? The Grasp of Evidence (GoE) framework developed by Duncan et al. (2018) provides a useful tool for this analysis. In this section, we provide a brief overview of the GoE framework, noting how it can be applied to analyze the degree to which learning environments incorporate various dimensions of unfriendliness. In the remainder of the paper, we will report on our work to date to apply this framework to analyze science curricula.

The GoE framework is grounded in Ford's (2008) notion of *grasp of practice*, which conceives scientific practice as encompassing both construction and critique of scientific knowledge. A grasp of practice involves both the ability to engage in the practice and to reflect on it metacognitively. The GoE Framework (Duncan et al., 2018) applies these notions to practices of evidential reasoning. They posit that there are five dimensions involved in reasoning about evidence. We use four of their dimensions as most relevant to our analysis:

- *Evidence evaluation* involves examining the methodological qualities of the procedures used to generate scientific evidence. This can involve identifying methodological strengths and weaknesses related to (a) what kind of comparisons are made (if any) and the extent to which these comparisons could be confounded, (b) issues of sampling such as sample size and representativeness, (c) appropriateness of data collection procedures, (d) the validity and reliability of measures, and (e) the appropriateness of the generalizations made. A curriculum that prepares students for features of epistemic unfriendliness encountered out of school will expose students to evidence that is poor (as well as good) along these various dimensions.

- *Evidence interpretation* involves appraising the strength of evidence in supporting and contradicting various alternative explanations. Evidence interpretation includes consideration of issues such as (a) the relevance of the evidence, (b) how comprehensively the evidence supports the model, (c) the directness of the support, and (d) whether evidence can be used to confidently rule out certain explanations. In epistemically unfriendly environments, students should encounter evidence that is strong and weak along these various sub-dimensions.
- *Evidence integration* moves beyond one or a few pieces of evidence and considers the role of larger bodies of evidence. In many situations, scientists make judgments based on large bodies of evidence, not just one or a few studies only. Yet students may seldom be exposed to syntheses of research (reviews, meta-analyses, etc.) as opposed to single studies. Larger bodies of evidence can vary from highly consistent (e.g., evidence on climate change) to highly unsettled (e.g., evidence on many issues in the early days of the COVID-19 pandemic). Scientists consider whether discrepancies can be resolved through identifying critical differences among studies (e.g., differences in procedures, study quality, etc.). It may be valuable to weigh whether there are different lines of evidence available. Science curricula should expose students to the challenges of reasoning about these larger bodies of evidence, not just one or a few pieces of evidence.
- *Lay use of evidence* takes account of the fact that proper appraisal of scientific evidence often requires a great deal of disciplinary expertise. Laypeople cannot be expected to have the rich disciplinary knowledge of experts (Osborne & Pimentel, in press). With bounded disciplinary knowledge, people must often defer to experts who have the detailed technical knowledge to make sense of evidence in a field (Bromme & Goldman, 2014). This means that science students need to learn to consider which sources to trust, and how to identify good and bad sources like those in the real world. In order to appreciate a wide range of criteria for determining source trustworthiness (e.g., expertise, bias, benevolence, integrity, track record), they need to be exposed to sources that violate these criteria as well as sources that meet them (Chinn et al., 2021). Students should consider how certain practices of venues such as editing, fact checking, and peer review can influence trustworthiness. They should grapple with challenges of identifying and weighing the degree of expert consensus on topics of interest.

This brief overview highlights the various ways in which the GoE framework can serve as a guide to examining dimensions of epistemic unfriendliness. Next, we describe our method for analyzing curricula, and we present our first efforts to apply this framework in an analysis of five inquiry curricula in science.

Method

Guided by the GoE framework, we developed a coding scheme to code curricula according to whether they had students consider unfriendly facets of evidence. Coded facets within each of the four dimensions captured the facets summarized in the previous section, along with additional facets laid out in the full GoE framework (Duncan et al., 2018). Table 1 presents a selection of these categories. (We have chosen a subset of all categories to present in this paper due to space limitations. Our full analysis contains additional categories, most of which encoded facets of unfriendliness that did not appear in any of the analyzed curricula.)

As a first step in assaying our coding scheme, we selected five researcher-developed curricula to analyze. We chose to analyze influential contemporary science curricula developed by researchers because these seemed to be the curricula most likely to present a wide range of complex challenges to students. The analyzed curricula were substantive lessons/units spanning at least multiple weeks. Our plan in the full project is code over 30 curricula; the choice of these five to begin with was arbitrary. In this preliminary analysis, we analyzed these curricula: (1) BioGraph (Yoon, 2022). We examined 5 lessons on biological systems for high school students. (2) IQWST (Investigating and Questioning Our World Through Science and Technology). We chose 11 lessons on heredity and natural selection (Krajcik et al., 2013). (3) PRACCIS (Promoting Conceptual Change and Reasoning in Science) (Rinehart et al., 2016). We chose a unit on cell organelles to analyze from this model-based inquiry curricula for middle-school students. (4) PUM (Physics Union Mathematics), an ISLE (Investigative Science Learning Environmental) based physics curriculum for high school (Etkina et al., 2021). We selected the Physics II dynamics unit. (5) WISE (Web-based Integrated Science Environment) (e.g., Linn & Eylon, 2011). Current online WISE curricula include many units across all grade levels; we focused on a set of chemistry units for middle school.

For each curriculum, we obtained online or published materials detailing the analyzed units. We used these as the basis for coding the curricula, augmented by reading published articles and chapters describing the units and their use. We acknowledge that coding other units might yield different results, and in ongoing work, we will analyze additional units for each selected curriculum. We developed codes through extended discussions among the authors, achieving concordant objectivity through iterative cycles of joint deliberation (Douglas, 2009).

Table 1

Percent of the five selected curricula (for selected lessons) that incorporated each category of unfriendliness for students to consider when making judgments (cognitive engagement) and reflecting (metacognitive engagement)

GoE Dimension	Category	Brief explanation	Cognitive	Metacognitive
Evidence Evaluation	Comparisons and confounds	Students weigh possible confounds between conditions that could impact conclusions or consider the presence or absence of comparisons when drawing conclusions.	20%	0%
	Sampling	Students weigh challenges of considering smaller or larger samples and/or the representativeness of samples when making judgments.	20%	0%
	Measures	Students consider the validity and/or reliability of lower as well as higher quality measures.	20%	0%
	Generali-zation	Students consider whether over- or under-generalizations to findings have been made when developing models or explanations.	0%	0%
Evidence Interpretation	Contrary evidence	Contrary or anomalous evidence are considered to rule out an explanation or drive revision of an inadequate explanation.	80%	60%
	Strength of evidence	Students weigh stronger or weaker evidence along subdimensions such as the degree to which evidence is diagnostic, direct, and/or comprehensive.	20%	20%
	Effect sizes or degree of fit	Students weigh evidence that varies in effect sizes (e.g., considering how to interpret studies with small effect sizes versus large effect sizes)	0%	0%
Evidence Integration	Quantity of evidence	Full bodies of evidence are considered (not just one or a few selected studies) to reach conclusions.	0%	0%
	Reconciling discrepant evidence	Students reconcile conflicting bodies of evidence along dimensions such as evidence quality, evidence strength, and evidence details.	20%	0%
	Synthesis reports	Students weigh reviews of evidence (e.g., meta-analyses and other reviews), not one or a few individual studies.	0%	0%
	Lines of evidence	Students consider how more versus fewer lines of evidence bear on conclusions.	20%	0%
Lay use of evidence	Source trustworthiness	Students consider source trustworthiness when making decisions and grapple with sources that vary in quality.	20%	0%
	Source criteria	Students use criteria such as expertise, bias, integrity, etc., to evaluate poor as well as good sources.	20%	0%
	Consensus	Students encounter variation in the extent of expert consensus on issues and must weigh this in their conclusions.	0%	0%

When coding the curricula, we assigned two codes for each category (i.e., two codes for each row in Table 1). To begin the process, we perused the set of lessons for each curriculum to scrutinize the range of evidence and sources that students worked with across all the student tasks. We next scored the level of cognitive engagement with each category. This referred to whether students needed to consider better and worse evidence or better and worse sources (as relevant to the category) and to use this information to reach conclusions at least one time within the analyzed set of lessons. If so, the unit received a score of 1; if not, a score of 0. For example, in the category *sampling* within the evidence evaluation dimension, we scored a 1 if students encountered too-small as well as good sample sizes, or unrepresentative as well as representative samples, and needed to consider these issues when developing models or reaching conclusions. Second, we coded at the *metacognitive* level. Curricula were assigned a 1 if students reflected metacognitively on the corresponding feature of unfriendliness at least one time in the analyzed set of lessons. Otherwise, curricula were assigned a 0. For example, in the sampling category, curricula were assigned a 1 if students were prompted to explicitly reflect on and discuss sample size or sample representativeness and the problems posed by too-small or unrepresentative samples. If there was no explicit discussion or reflection on sample size or representativeness, curricula were assigned a 0.

Results

Table 1 summarizes results for selected coding categories with a brief description of the meaning of each category. We report the proportion of curricula that scored positively for each category. The main findings are: (1) Cognitive engagement with epistemic unfriendliness in the analyzed categories was, overall, rare in these units. (2) Evidence interpretation was the dimension that most often incorporated epistemically unfriendly features, but only in presenting students with contrary or anomalous evidence that students needed to use to revise explanations or to rule them out. (3) There were fewer opportunities for students to grapple with the integration and lay dimensions. Students seldom needed to consider more than a few pieces of evidence, and they seldom considered sources at all, let alone poor sources. (4) Most evidence presented was to be considered as methodologically good by students; discussions of evidence quality were not common. (5) Even when cognitive engagement with epistemically unfriendly features was present, metacognitive engagement was usually absent.

Percentages indicate the number of curricula that scored a 1 for the analyzed sequence of lessons, divided by 5 (the number of curricula scored).

Discussion

This paper has reported on the first steps of a project to analyze researcher-developed science curricula according to how effectively they expose students to the various categories of epistemic unfriendliness found in the contemporary information society. We have demonstrated the viability of using the GoE framework to perform these analyses. This report is, of course, only an initial foray into affordances of research-based science curricula. Further analyses will enrich our findings and, no doubt, identify additional curricula that take interesting approaches to introducing various categories of epistemic unfriendliness to curricula.

Our preliminary findings suggest that curricula should do more to introduce various categories of epistemic unfriendliness to science classrooms. In the units analyzed, students had few opportunities to engage with the kinds of epistemic unfriendliness that they encounter in the digital world out of school, particularly with respect to evidence evaluation, evidence integration, and lay use of evidence. There were even fewer opportunities to discuss these challenges metacognitively, despite the value of metacognitive discussion for supporting productive cognitive engagement (Barzilai & Zohar, 2014). We encourage developers of curricula to incorporate opportunities for students to reason about poor and weak evidence, insufficient evidence, and less trustworthy sources and to reflect metacognitively on these reasoning challenges. We also encourage activities that engage students in metacognitive reflections of evidence and sources of varying quality.

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Humanizing College Student Success: The Role of Brave Space, Validation, and Social-Emotional Competencies

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Abstract: Higher education inequities are caused by multiple factors within and beyond the classroom; yet, notions of college student success beyond course grades in formal classes are understudied. Using a sociocultural framework called the zone of proximal self, the purpose of this study is to deepen understanding of how to advance equity in informal learning settings such as counseling and advising spaces. This paper presents three forms of effective equity-oriented and relational practices, drawing from two contrasting student cases from a study of 50 students at a public four-year U.S. institution. The cases highlight how counselors' creation of a brave space, validation, and support for social-emotional competencies can enhance students' pathways towards their possible selves in humanizing, relational ways. These findings illuminate how the ZPS framework can offer broader ways to examine college student success by including students' personal and professional achievements across formal and informal learning environments.

Introduction

When discussing challenges with persistence and retention in higher education, there exists a greater need to theorize the complex relational dimensions that support how students adapt and thrive. There are multiple factors that may contribute to a holistic understanding of declining performance, persistence, and retention rates within and beyond classrooms, such as students' lack of clear future goals, a sense of uncertainty, and poor integration with the college community (Sithole et al., 2017). Frameworks in the learning sciences such as the learning humanities framework have shown the importance of equity-oriented relational practices for students' persistence in STEM through mentorship (Herrenkohl et al., 2019). Equity-oriented interactions in mentorship, counseling, and advising settings are critical in supporting students' holistic navigation of higher education, but are understudied or traditionally measured in terms of academic metrics such as GPA (Swecker, Fifolt, & Searby, 2013). Therefore, this study reimagines college student success through a framework called the zone of proximal self, which foregrounds relational practices in supporting student's learning across formal and informal spaces.

The zone of proximal self framework

The zone of proximal self (ZPS) offers a framework to examine college student success through relational practices that can improve students' pathways towards their personal, professional, and academic goals. ZPS is the distance between a learner's current and possible selves that can be bridged with the support of individuals and resources. ZPS extends Vygotsky's (1978) zone of proximal development from a focus on children's academic problem-solving to considering college students' pursuit of their possible selves (i.e., the imagined selves they want to become and feared selves they are afraid of becoming) across a wide learning ecology (Markus & Nurius, 1986; Barron, 2006). By using the ZPS framework to examine sociocultural practices within settings such as counseling and advising, this study contributes to nuanced understandings of college student learning and development as a cultural process (Rogoff, 1995; Nasir et al., 2006).

Methods

This paper reports a qualitative case study designed to define equity-oriented, relational practices within ZPS for college students from first-generation, low-income, and minoritized (FLM) backgrounds. Therefore, this paper addresses the following research question: What practices from advisors and counselors do students from FLM backgrounds describe as supporting their college success? To answer this question, this study employs Merriam's (2002) case study methods by being 1) particularistic with student-counselor interactions, 2) descriptive with student examples, and 3) heuristic with dimensions of effective practices.

The study includes 50 undergraduate students from a large public university on the US West Coast. A majority of the participants were first-generation (74%), women (74%), and Latinx/Chicanx (52%). Students were recruited from federally-funded TRIO programs such as the Educational Opportunity Program (EOP) and the

Student Support Services (SSS) Program. Students met virtually with a counselor, advisor, or mentor figure at pre-, mid-, and post-semester time points over 14 weeks in spring of 2021. Students completed three diary entries, three surveys, and one post-interview. Professional and personal goals were assessed in an open-ended question of “What are your [professional/ personal] goals?” followed by a 1-7 Likert-scale response item. This study focuses on two students for the case analysis. The interviews were qualitatively coded using a mix of deductive and inductive coding via the Dedoose software. For internal validity and reliability, the study triangulates data from interviews with diary entries and survey data. Thick descriptions of cases are provided for external validity.

Findings

Equity-oriented and relational counselor practices

The creation of a brave space, validation, and support for social-emotional competencies emerged during thematic coding as the main categories of equity-oriented and relational practices. The creation of a **brave space** category includes practices such as *sharing experiences* and *vulnerability*, *creating a welcoming environment*, *understanding a person holistically*, *relating personal experiences*, *establishing a working partnership*, and *expressing low and high arousal positive emotions*. The second category of **validation** includes practices of *validating strengths and continuous growth, validating negative emotions and experiences*, and *validating decision-making processes*. The third category of **social-emotional competencies** includes practices of *encouraging self-awareness, promoting self-management, and advancing relationship skills.*

Contrasting cases of brave space, validation, and social-emotional competencies

Using identical surveys, we measured students’ change scores from pre- to post-study on their personal and professional goals. We examined their change scores for these goals to examine their progression towards their possible selves. One student from each of the low- and high-progression categories were selected as a pair of contrasting cases, August Mohammed and Celeste Rodriguez. August reported low progression in professional, personal, and academic goals from the beginning to end of the study, while Celeste showed the opposite, a high progression in all her goals over time.

Low progression towards goals in the zone of proximal self: August Mohammed

August Mohammed’s story reveals a tale of a low progression in the ZPS framework, in which he did not feel he was effectively supported by individuals and resources in his learning ecology. August identifies as a man and comes from a mixed-race background that is “mixed Brown, White, and Black.” Coming to the university at a young age, August was 18 years old at the time of the interview and was a fourth-year student in college. For this study, August met with a college advisor for all of his meeting sessions.

Lack of a Brave Space and Vulnerability. During his interview, August described the practices he wished his college advisor engaged in with him during their meeting sessions. In particular, August felt a need for his college advisor to be more transparent, direct, and honest with him. When asked about the importance of this directness, August explained:

> … if the [college advisor] can honestly speak their mind about what they've seen in the past or their feelings or something that they've experienced in a very direct way, that can give a lot of clarity rather than having to dance around an issue and not wanting to express what they think.

August did not feel that his college advisor was honest with him or provided relevant knowledge for his life goals. In other words, he did not feel that the counselor *shared experiences or embraced vulnerability*, which were important practices for creating a brave space. August’s experience with his college advisor resulted in him feeling a sense of depersonalization, in which he stated that, “If you talk to [a college] advisor, even for an entire year, they don't actually know you…They know what you tell them and not necessarily how you feel about something. They might have their own inherent biases.” August’s words reveal that a brave space was not created during the session, since he felt that no matter how many times he met with his advisor, they would never really know who he was, and they judged his goals and his ideas for achieving them.

Lack of Validation in Decision-making. Additionally, August felt that his college advisor did not understand how his backgrounds and interests led to his aspirational goals. In his interview, August began to talk about his college advisor and then generalized to academic advisors broadly on campus:

> It's hard to go to any academic advisor and explain a more nuanced issue to them. Even though a lot of students have a lot of the same problems, if you have a different outlook on life or a

> different background or personal feelings towards something or aspirations, again, it's harder for them to understand why you want to do something differently.

In other words, August did not sense that his college advisor was *validating his decision-making processes*, especially as they related to his personal interests and background. Instead, he felt that his college advisor, as mentioned previously, held certain biases against the decisions he was making.

Lack of Support for Social-emotional Competencies. Finally, August did not describe his college advisor providing support for strengthening his social-emotional competencies. On the other hand, he wished that his advisor was able to work on something more concrete with him during the session to help him navigate his various interests in the future. In his first diary entry, August wrote: “I’m trying to figure out my life and my plan. I’m kinda lost.” In his interview, August shared wanting strategies and support from his advisor:

> I think a concrete plan would reflect coming up... having a solution for not knowing what I want to do, specifically in tone with me. Figuring out specific avenues that I can approach in order to either figure out what I want to do that might fit all my needs rather than just saying, ‘You'll figure it out. It'll take some time, or you can try to look at different fields’

As shown in the quote above, August felt frustrated with the lack of support and organizational brokering from his advisor. Taken together, a traditional approach to examining August’s success, or lack thereof, may focus on the decline in his academic performance throughout the semester. However, a ZPS lens draws attention to the conditions that he experienced, including counseling and advising practices that did not address his needs.

High progression towards goals in the zone of proximal self: Celeste Rodriguez

In contrast to August, Celeste Rodriguez’s narrative highlights a high progression in ZPS that was created by her counselor despite the challenges she faced. Celeste identifies as a woman and comes from a Latinx cultural background. She is the first in her family to go to college. For her first meeting session, Celeste met with a college advisor, but Celeste also met with EOP counselors for her second and third meeting.

Presence of a Brave Space. In her interview, Celeste provided detail on how an EOP counselor was able to enact a brave space during their meeting sessions through relational practices that contributed to creating *a welcoming environment* and *understanding her holistically as a person*. In her own words, Celeste revealed:

> It's always like, ‘Oh, hi, how are you?’ and very genuine and very kind, which is something that's really important to me because I think that a lot of my questions have to do with not just about myself, but also about my family, because I don't do anything without, I wouldn't say without my family, but without thinking about my family. And so I think family is such a huge, important part of me. Like I said, my uncle went to jail and my mom had COVID, and other things. And I think these are important factors for people to understand why I'm choosing to go in a specific way.

In her explanation of how her EOP counselor created a welcoming environment, Celeste highlighted consideration of her learning needs, family, and home context when understanding her motivations for her future goals.

Validating Decision-making. In a similar vein to understanding Celeste’s family and cultural background, Celeste described how her counselor manifested validation through *validating her decision-making* processes related to her family. In her diary entries, Celeste wrote: “She always listens to my entire story so she can give advice before cutting me off, she asks if something sounds good and if not she offers other options.” When probed about this entry in the interview, Celeste shared how the counselor explicitly listened to her interest and needs and validated the decisions that she felt were important for her future goals:

> I feel like sometimes when I go ask for an advisor I need help, as soon as I start talking and someone recognizes a problem, they want to offer advice. But sometimes that doesn't even seem like a problem to me. I remember going to [an advisor] one time and saying that I wanted to decrease my units because my uncle had gone to jail and they said something along the lines of, ‘Oh, well you already made it into [this college]. The best way for you to take care of your family is to take care of yourself first.’ And I understand, and I get where they're coming from, but that's not the issue that I needed help with. And so I appreciate that [this EOP counselor] listens to what I have to say before giving me advice on problems that she thinks are the problems.

In her description of her interaction with the EOP counselor, Celeste highlighted how the counselor validated what she perceived are problems in her life. Most importantly, the counselor's validation came from a place of active listening and understanding of Celeste as a person, which are actions that August did not perceive in his interactions with a college advisor.

Practices for Supporting Social-emotional Competencies. Focusing again on the same EOP counselor, Celeste further mentioned how the counselor was able to support her social-emotional competencies related to relationship skills for her professional career. Specifically, Celeste described her counselor as a broker:

> So, well, first she gave me [a career counselor]'s email and it was pretty easy to schedule a meeting with [the career counselor], but also she told me about the work that they do, and some of the questions I can ask, which I think is really helpful because sometimes I know I need the help, but I don't know what to ask because I don't even know where to start. […] I have really good experience in my field, but some of my work experience started when I was in high school and I was doing retail jobs and stuff like that. So [the counselor] also said that I should ask [the career counselor] some of the questions on how I can implement that.

As Celeste's quote foregrounds, the counselor not only helped Celeste make the connection with a career counselor, but also supported her in making this connection by describing how to interact with the career counselor. Moreover, her counselor recognized the wealth of experiences Celeste gained in high school and encouraged her to leverage her strengths in future meetings with the career counselor. This support and advice are in contrast to the experiences that August faced in interactions with college advisors, where he felt that his experiences were looked down upon or disconnected from his future possibilities. In sum, traditional approaches might capture how Celeste was able to achieve her academic goals in college and persist at the institution. However, a ZPS lens provides greater understanding into how Celeste's counselors acted as organizational brokers to support her social-emotional competency of *relationship skills* and cultivating a network of support.

Discussion and conclusion

This paper offers a ZPS framework highlighting three equity-oriented, relational practices that institutional figures can use to support college student success in humanizing ways that recognize their academic, social, emotional, and basic needs. Themes across student interviews and in-depth contrasting cases further provide practical significance into supporting a brave space, validation, and social-emotional competencies. Moving forward, there is an opportunity for future research to 1) broaden measures of college student success and 2) work in partnership with institutional figures to examine how relational practices impact students' pathways and possible selves. The hope of this paper is to reframe college student success holistically as an act of humanization to increase equity.

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A Temporal Toolkit for Analyzing Agency in Open-Ended Work

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Abstract: Open-ended work provides opportunities for learner agency. We pose a temporal toolkit for analyzing how learners express their agency and for how others support this agency. Drawing on Emirbayer & Mische (1998) conception of agency as temporally embedded, we track how learners' decisions and actions in the present, are informed by habitual past resources, and projective futures. Using examples from two domains (a theater improvisation exercise and a parent-child circuit design project) we apply temporal dimensions, processes and linguistic markers to provide analytic description on how agency is expressed and supported.

Introduction

Agentive action in the world involves a kind of time travel: to make decisions and execute actions in any *present* moment, we continually revisit our *habitual past* selectively attending to recognize relevant types of experiences, knowledge and resources to inform our actions, and imagining and improvising to select possible *futures* to move towards. Emirbayer & Mische (1998) argue that this temporal embeddedness is the characteristic feature of human agency.

In many educational situations, students' agency is highly constrained. Relevant past resources are provided and future goals are identified. Teachers seeking to support students' agency within these constraints may offer choices, encourage students to find personal connections and interests to the identified problem, and provide explanations about their decisions (Stroet et al., 2013). However, in open-ended work, such as in art and design, students often have latitude in finding a problem to work on, choosing how to approach it, and revising throughout the process (Gravel & Svihla, 2021; Sawyer, 2018; Sheridan et al., 2022,). To do so, they mine relevant past experiences, knowledge and resources and recombine possibilities for future directions.

We outline a temporal framework and methodological tools for qualitative analysis of agency in open-ended creative work. Prior analyses suggest the temporal frame gives insight into teacher scaffolding of learner agency in visual arts (Sheridan et al., 2022). We build on this work through analytic description of examples in two additional open-ended learning areas, a theater improvisational exercise and a parent-child design project to consider how these tools can provide insight into how and when learners are operating agentively and how dimensions of agency are scaffolded in diverse learning situations.

Temporal toolkit for studying agency

We draw on Emirbayer & Mische's (1998) theoretical frame of agency as inherently temporally embedded. As we make decisions and take actions in the present, we are informed by our habitual *past*, yet also oriented toward the future to imagine alternatives (p. 963). Emirbayer's & Mische suggest each temporal dimension involves sub-processes that reflect how agency is expressed (Table 1).

Table 1
Temporal dimensions of agency and sub-processes in Emirbayer & Mische's 1998 framework.

	Habitual Past	Practical-Evaluative Present	Future Projective
Processes	Selective attention Recognition of type	Problem Characterization Decision-making Execution	Symbolic recombination Narrative construction

To draw on habitual past resources, we employ *selective attention* to identify relevant aspects of prior experiences and *recognition of types* to identify "typical patterns of experience" from our past (p. 979). The projective future employs the sub-processes of *symbolic recombination*-- using existing resources in new ways-- and *narrative construction*, creating stories and making meaning about possible futures. Both the habitual past and the projective future inform how we *characterize problems* in the present, make *decisions* on how to proceed, and *execute actions* as part of present practical-evaluative agency.

Tracking temporality of agency

These temporal dimensions (habitual past, practical-evaluative present and projective future) can serve as an organizing structure for qualitative data analysis. In what follows, we apply the temporal frame to a theater improvisation exercise and then to a family co-design activity to illustrate how agency is enacted, distributed and supported in a given activity. We then discuss how functional linguistic markers can aid in analysis.

Temporal dimensions of agency in theater improvisation exercise

For improvised scenes in theatre classes, students are provided initial constraints within which they are encouraged to experiment and explore. Teachers scaffold this process, emphasizing more generalized concepts such as how to quickly establish a setting or scenario, how to elaborate on another's contribution, and how to explore and experiment to find dramatic and comedic potential in a scene as it evolves. A temporal lens on agency helps us understand how and when students express their agency in this open-ended problem, and how teachers strategically support dimensions of student agency.

In Table 2, we track temporal dimensions of agency in a group improvisational exercise. When high school students were prompted to improvise a cafeteria scene, they responded by carrying imaginary cafeteria trays, walking and talking as a group about their classes, imagining seeing new characters to gossip about, each responding dynamically to new concepts others introduced. The teacher paused their activity, saying, "You cannot enter the cafeteria with your tray. You have to like *establish your space*, so use your imagination!" In their next iteration, the students show a more elaborated sense of setting: they walk in, obtain imaginary cafeteria trays, go in the food line. One student then takes on the role of cafeteria worker, creating new possibilities for interactions.

Table 2

Temporal embeddedness of agency an improvisational theatre exercise

	Habitual Past	Present Practical Evaluative	Future Projective
Students initial response to prompt	Draw on memories of cafeterias, improv concepts	Decide to use imaginary props (trays, shared table), move in a group to a table,	Imagine new possibilities in response to each other (e.g. gossip about imagined characters).
Teacher scaffold	Prompts for nuance "You cannot enter a cafeteria with your tray," reminds of concept "establish your space"		
Student revisit prompt	Draw on more specific processes in cafeteria (how you enter, obtain trays and food, varied roles)	Student actions establish the space of a cafeteria (e,g,entering the cafeteria, going through line).	Students imagine possibilities for diverse roles and interactions (e.g., student becomes cafeteria worker)

This analytic description suggests students express broad agency across all three temporal dimensions in both iterations. They drew on relevant *habitual past* resources from their memories of cafeterias and their knowledge of improvisational techniques (e.g., pantomime with imaginary props to signal space and action, introduce new ideas and characters to propel the story forward, elaborate on what others have contributed) to *characterize the problem* and make *decisions* in the present. Each also needed to continually re-imagine the *projected future* of where the scene was going based on the actions and contributions of others.

The teacher uses minimal scaffolding, but her brief interjection directs students to reconsider their broader set of *habitual past* resources of processes connected to cafeterias promoting *recognition of type* of the disciplinary concept of "establishing space." This informs students' *practical-evaluative present* of how they *characterize* the problem and make *decisions* and *actions*. This re-characterization invites new *narrative construction* and *symbolic recombination* of *projected futures* connected to diverse roles and settings in the cafeteria. Thus the teacher's intervention briefly supports *habitual past*, but students readily use that information to return to expressing agency independently across the three temporal modes.

Temporal dimensions of agency in a family making workshop

The dynamic iteration across temporal dimensions of agency is seen in other open-ended work. Here, we use the temporal frame to understand how agency is distributed and supported in a workshop facilitated by a maker educator, where a 7 year-old boy and his mother, after using circuit blocks to learn about how circuits work, are now co-designing and building their own circuit- powered creation (Table 3).

Table 3
Tracking temporal dimensions of agency in a family making workshop

	Habitual Past	Practical-Evaluative Present	Future Projective	General Encouragement
Child's initial response to prompt	Draws on prior knowledge of rockets. Uses skills from circuit activity.	Decides to make a rocket, draws plans, builds and assigns tasks to mother.	Imagines flight of rocket (e.g. "Let's go with 2 engines, the ceiling is not that high")	
Mother's response		Mother executes actions assigned by son (e.g. cutting thick materials)		"Oh it can fly? Oh my goodness, that's going to be good."
Child Stalls/Frustrated with project		Rocket unable to fly, characterizes problem: "It's too heavy to fly." Stops project, upset.		Mom sympathizes, acknowledges his disappointment.
Educator's prompts	Suggests habitual strategies (change outputs, materials as inspiration).	Agrees that motors are not powerful enough to fly.	Suggests alternatives (launch a propeller? make something new?)	
Child restarts project		Decides to build a flashlight with new materials. Then revisits his rocket project.	Invents new possibilities for "abandoned" rocket—a "tickler," a "bug distracter".	

In this family pair, the child strongly expresses agency across the temporal dimensions: he *decides* what they will build (a rocket), draws the plans, discussing prior knowledge of boosters and engines. He instructs his mom to *execute* specific actions such as cutting out parts according to his plans. Much of his mother's support focuses on following his directions and general encouragement—when her son says he's building a rocket that will fly she responds: "Oh it can fly? Oh my goodness that's going to be good." As he looks up, *projecting the future* flight of the rocket, he *decides* "Let's go with 2 engines, the ceiling is not that high." They build a model that resembles his plans, but after testing he *characterizes the problem* "It is too heavy to fly." He abandons the project, sadly tearing up paper into small pieces. His mom sympathizes, acknowledging his disappointment.

Noticing his frustration, the educator first supports his *present-practical evaluative* agency by agreeing with his *characterization*, subtly shifting focus by elaborating that these motors, rather than his design, weren't powerful enough for flight. She scaffolds the *projective future* dimension of agency by *symbolically recombining* alternatives on his existing design, asking "Maybe you can make something else fly or flutter from it?" He rejects this. She later draws on a more general principle, or *recognition of type* "I wonder if a way to make yourself less frustrated is to put all of this aside and think about a different output…one thing I do is I go look at my materials." Here, she draws on a *habitual past* strategy for responding to design setbacks. She points to a table with materials he could use to change the output and offers support for a new projective future: "Can you make something cool with lights?" He initially rejects all suggestions, but after a few minutes says, "Maybe I could make a …" and goes over to the materials and finds materials to quickly build what he first calls a flashlight, but then later says it is "another kind of rocket" that he's later going to add fins to. He then revisits his first rocket, *symbolically recombining* and *narratively constructing* new possibilities for it, such as calling it a "tickler" then touching his skin with the moving motor to test it. Later he says it is a “bug distractor” to keep insects away. The *projective future* seems an important dimension for sustaining and expressing his agency after frustration.

Tracking agency linguistically

Both temporality and agency are expressed through the content of speech, and in underlying grammatical structures (Konopasky & Sheridan, 2016; Sheridan et al., 2022). For instance, a study comparing two groups of students on a making task with circuits found that students who participated in an open-ended making task used more linguistic markers of agency—such as personal pronouns and material and mental verbs-- to describe their work than students who followed more structured instructions (Konopasky & Sheridan, 2015).

Grammatical forms can serve as indicators of the temporal dimension of agency, and thus support analytic description of temporal dimensions. For instance, the projective future is often expressed by a modal verb indicating possibility (e.g., could, may, might), with its sense of tentativeness further marked with “maybe.” (e.g., the child says “Maybe I could…” as he’s thinking of new designs). The present-practical evaluative may be framed in the present tense (“It’s too heavy to fly”) or marked by modals of obligation when characterizing the dimensions of the problem, (“You need to…”). Habitual past resources may be objects within these sentences, identifying resources to inform decisions and actions in the present, or to be recombined in the projective future.

Educator language also shows patterns in how they support agency—for instance, the theater teacher uses a modal of obligation “You have to-like-*establish your space.*” to re-characterize the problem, referencing a habitual past resource. Educators often soften their directions on open-ended tasks, often by posing advice as a question or mitigating it with a “maybe” when offering a projective future idea (e.g.,“Maybe you can make something else fly or flutter from it?”). Similarly, educators may highlight the learner’s agency by downplaying their own authority, giving directions from a personal perspective, (e.g., “I wonder…”, “one thing I do…”. These patterns mirror findings in studio arts class where teachers typically use language to highlight student agency, such as by posing their own advice as questions or from a personal point of view to consider rather than an instruction (Sheridan et al., 2022; see Konopasky & Sheridan, 2016 for a full account of linguistic markers of agency).

Conclusion

Understanding how agency and scaffolding of agency is temporally embedded allows us to see the past resources and potential futures individuals are drawing on to inform their present decisions and actions. These tools also allow us to examine how agency is distributed between learner and teacher or among collaborators, including tracking who poses relevant past resources, who recognizes relevant types, who characterizes the problem, makes decisions, takes actions, and who poses and interprets potential futures for the project. In open-ended work, tracking the temporality of this agency helps us understand the resources learners draw on, the possibilities they imagine, and how these shape their evolving characterization of the problem and their decisions and actions in the moment.

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Preschoolers' Embodied and Shared Self-Regulation Through Computational Thinking

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Abstract: Despite shared characteristics and developmental significance of self-regulation (SR) and computational thinking (CT) in young children, existing research mainly focuses on the positive correlation between these two while neglecting the underlying processes of influence. To fill this gap, we examine how preschoolers are engaged in *embodied* and *socially-shared* SR through CT with a tangible programming toy in teacher-guided small groups. Through interaction analysis, we show how a teacher and preschoolers leverage embodied knowledge together and with a tangible programming toy to successfully engage in *focused attention* and *inhibitory control*, two key components of SR. Our findings challenge and expand the existent conceptualization of children's SR as individual and confined to the mind, and illustrate how embodied and collaborative CT activities in early childhood are generative occasions for SR.

Introduction

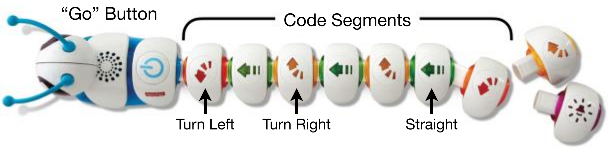
Self-Regulation (SR), the ability to regulate and control cognition/emotions/behaviors to achieve goals, entails basic executive functions (EFs) including working memory, focused attention, and inhibitory control as well as higher-level EFs including reasoning, problem-solving, and planning (Diamond, 2016). As a burgeoning area of practice and research in early childhood, computational thinking (CT) typically encompasses planning, critical thinking, and problem-solving skills (Bers et al., 2022). Both SR and CT are empirically proven to be positively related to young children's social adjustment and educational outcomes (Bers et al., 2022; Diamond, 2016). Given the positive association between CT and SR (e.g., Arfé et al., 2020; Di Lieto et al., 2017), it would be advantageous to co-develop SR and CT in early childhood. However, little is known about how *social, interactional processes* in CT activities can support young children's SR.

To address the gap, we examine how preschoolers engage in embodied and shared SR through CT with a programming toy in teacher-guided small groups by employing a *we-syntonicity* framework (Wang, et al., 2021). Papert (1980) defined *body syntonicity* as the identification and resonance between learning tools and learners' "sense and knowledge about their own bodies" (p. 63), while *ego syntonicity* is the identification and resonance between learning tools and learners' "sense of self as people with intentions, goals, desires, likes, and dislikes" (p. 63). The "we-relationship" proposed by the phenomenologist Schutz (1967), a reciprocal embodied experience of togetherness resulting from bodily co-presence and close attunement with others, extends our understanding of how body/ego syntonicity can be achieved *on a social plane, collectively as a group.* The group, as a collective, can form a shared understanding together – a *we-syntonicity* – based on ego and body syntonicity with the learning tool (e.g., a tangible programming toy).

Methods

Our study is part of a larger investigation examining young children's CT learning at a preschool in the US using a programming toy (Fisher-Price's Think and Learn Code-a-pillar, see Figure 1) whose body segments can be programmed for varied movements. Twenty-two children and two teachers participated in the study. Guided by teachers, children worked with the Code-a-pillar (named Rapunzel) in small groups once or twice a week (average 15 minutes per session) for over 12 weeks. All sessions were video recorded, creating a corpus of about 15 hours.

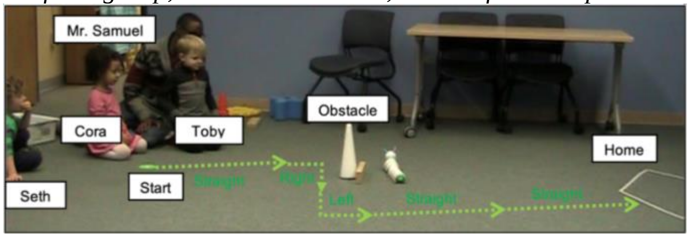
Figure 1
Code-a-pillar (named Rapunzel)



We conducted multimodal microanalyses of small groups navigating the "Obstacle Challenge" informed by Interaction Analysis (Jordan & Henderson, 1995). In each case, we examined how participants (including

Rapunzel) use multimodal resources (e.g., speech, whole body movement, gesture, gaze, etc.) to coordinate their activity to complete this challenge and achieve associated regulatory functions.

Figure 2
The focal group, the obstacle course, and the final completed route



In this study, we focused on a group led by Mr. Samuel, a teacher with 7 years of experience, working with three 4-year-old students, Cora, Seth, and Toby, to navigate a route (see Figure 2). The chosen excerpts from this session demonstrate how the group utilized shared body/ego syntonicity with the toy Rapunzel and among each other (we-syntonicity) to exhibit two forms of collective self-regulation: focused attention and inhibitory control, within the context of CT practices. We created detailed transcriptions of two excerpts using conventions adapted from conversation analysis: degree signs for quiet speech (°°); capitals for louder speech; question marks for rising intonation (?); colons denote elongated syllables (::); double paratheses for actions/body movements; braces for analyst comments or descriptions ({ }); and square brackets show overlapping actions or speeches ([ ). Embodied actions are illustrated using screenshots; co-timed speech is outlined with boxes.

Findings and discussion

Focused attention through we-syntonicity

Figure 3
Embodied/shared attention regulation


Screenshot A
Screenshot B

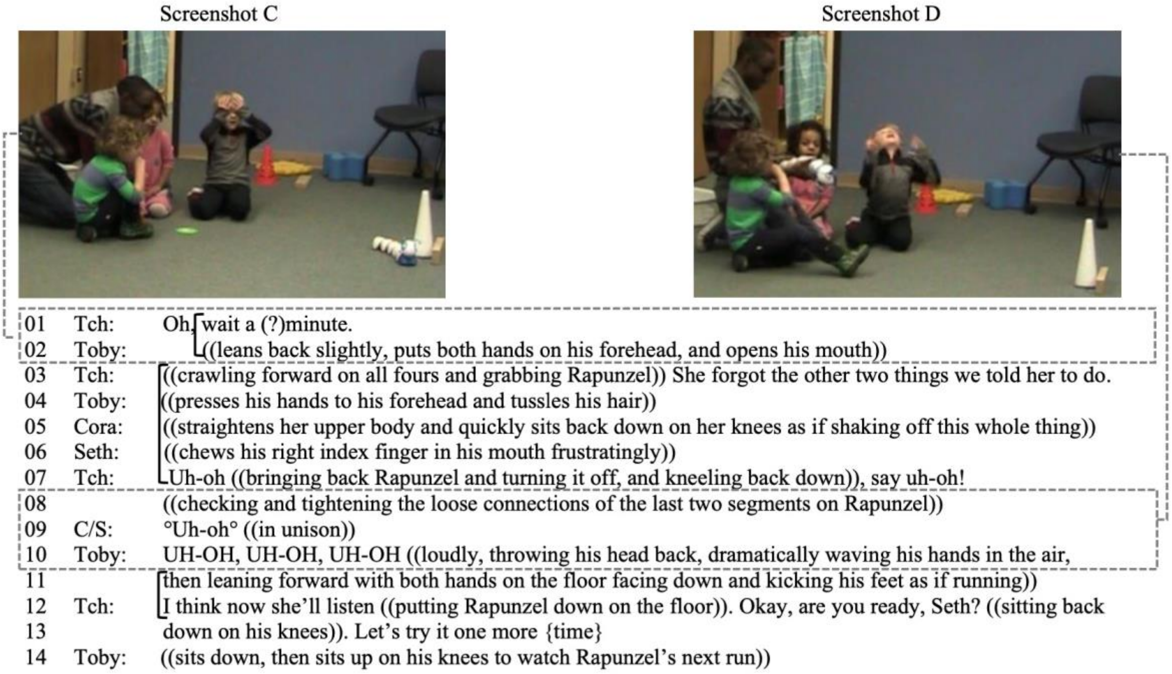
01 Seth: ((looks down and plays with the "straight" segment in his hands))
02 Tch: Do you think she should start [by turn::ing ((holding Rapunzel in his right hand while manually steering
03 Rapunzel to turn left on the floor))
04 Seth: [((looks up to the right at Stanley briefly and look back at the piece))
05 Tch: Is it a good way? Is it gonna get her home if we turn first ((pointing his left hand
06 at Rapunzel's home to his left while holding the "left turn" segment that children attached initially))
07 Cora: [((bends and leans forward to look in the direction of Rapunzel's home))
08 Toby: [((turns right to look at Rapunzel's home and shakes his head quickly))
09 Tch: No. What- Which way should we start heading first? ((pointing his left hand at Rapunzel's home again))
10 Toby: ((shaking his head several times)) Straight and tur::n! ((flapping his hands in midair excitedly))
11 Tch: Maybe a straight and turn, maybe! ((raising Rapunzel in his right hand and taking off a "left turn"
12 segment children attached earlier)) So let's try that.
13 ((looking up at Seth)) Seth, you have a straight in your hand. Can you add the straight on? ((putting
14 down Rapunzel, placing it in the middle of the circle and angling its tail directly in front of Seth))
15 Toby: ((Sits up on his knees and moves to the right))
16 Seth: ((looks up and then back at his hands, scooches over slightly right toward the circle while holding
17 forward the "straight" segment in the right hand))
18 Tch: [We will try a straight and then a turn.
19 Toby: [((excitedly turns his body right and moves over on his knees to face the obstacle))
20 Cora: [((sitting up excitedly)) Now …{inaudible}
21 Seth: [Mmmm ((bending over forward and attaching the "straight" piece to Rapunzel while holding her head))

In Figure 3, Mr. Samuel and the children were working to debug and figure out the solution to their first failed run, which they attached two left turns and Rapunzel ended right in front of Cora's feet. While Mr. Samuel, Cora and Toby were discussing Rapunzel's next steps (lines 2-3 & 5-12), Seth was playing with a spare, unattached coding segment (line 1). The spatial-orientational pattern in Screenshot A shows Seth outside the group, with his attention diverging from the group's. Inside the joint transactional space marked by red lines, Mr. Samuel, Cora, and Toby's attention – as evidenced by their gaze and body posture – were jointly focused on Rapunzel as they discussed her desired movement (lines 2-3, 9-11) and her goal of going home (lines 5-8). In line 13, Mr. Samuel explicitly invited Seth to rejoin the joint space by asking him to add the straight segment he had in his hands. Subsequently, the group adjusted their bodies/positions to integrate Toby into the space: Mr. Samuel placed Rapunzel in the center directly in front of Seth to reinforce his verbal invitation (line 14), Toby moved to the right to create an opening (line 15), and Seth responded by scooching into the space and offering the straight segment (line 16-17). As a result, the group formed a new joint space incorporating Seth, marked by the green lines in Screenshot B. In this newly formed space, joint attention was re-established and all four participants worked together to re-direct Rapunzel to her home (lines 18-21).

Directing and managing one's attention is an important basic executive function and foundational SR behavior (Diamond, 2016). Without focused attention, learning would not be possible. As illustrated above, Rapunzel constituted an anchor for attention in the center of their joint transactional space figurately and literally. By taking up Rapunzel's needs and goals of going home (ego-syntonicity), the children eagerly coordinated and directed their attention towards her (body syntonicity). When such focused attention broke as shown in Screenshot A, the group worked to repair and restore the space to include everyone as shown in Screenshot B. Although the teacher played a more explicit role in directing/managing their attention to Rapunzel, the children also supported each other in their embodied positionings to reform joint focused attention. Toby's move to the right created a critical opening to allow Seth to join and form a new "o-space" and rejoin the group's joint focused attention on Rapunzel. In other words, embodied attunement among the children and awareness of each other's body/position, a form of we-syntonicity, also supports the formation, maintenance, and repair of their joint focused attention.

Inhibitory control through we-syntonicity

Figure 4
Embodied/shared inhibitory control


Screenshot C

Screenshot D

01 Tch: Oh, [wait a (?)minute.
02 Toby: [((leans back slightly, puts both hands on his forehead, and opens his mouth))
03 Tch: [((crawling forward on all fours and grabbing Rapunzel)) She forgot the other two things we told her to do.
04 Toby: ((presses his hands to his forehead and tussles his hair))
05 Cora: ((straightens her upper body and quickly sits back down on her knees as if shaking off this whole thing))
06 Seth: ((chews his right index finger in his mouth frustratingly))
07 Tch: [Uh-oh ((bringing back Rapunzel and turning it off, and kneeling back down)), say uh-oh!
08 ((checking and tightening the loose connections of the last two segments on Rapunzel))
09 C/S: °Uh-oh° ((in unison))
10 Toby: UH-OH, UH-OH, UH-OH ((loudly, throwing his head back, dramatically waving his hands in the air,
11 [then leaning forward with both hands on the floor facing down and kicking his feet as if running))
12 Tch: [I think now she'll listen ((putting Rapunzel down on the floor)). Okay, are you ready, Seth? ((sitting back
13 down on his knees)). Let's try it one more {time}
14 Toby: ((sits down, then sits up on his knees to watch Rapunzel's next run))

As Figure 4 began, Rapunzel executed only first two of four attached code segments and stopped prematurely. Mr. Samuel was surprised by this (line 1) and made a light-hearted observation (line 3). In response, the children used embodied displays to show their disappointment and frustration (lines 5-6) and Toby's was particularly intense (line 2, Screenshot C). Noticing this, Mr. Samuel orchestrated a collective vocalization of this emotion, "uh-oh" to verbalize and label the felt tension (line 7). Toby took up the suggestion, saying "uh-oh uh-oh uh-oh" loudly while throwing his head back and waving his hands in the air (line 10, Screenshot D) and then leaning forward with both hands on the floor facing down and kicking his feet as if running (line 11). After the physical display and using a shared word to describe the embodied display ("uh-oh"), the children quickly resumed the task with Mr. Samuel (lines 12-14).

This excerpt illustrates the group's collective effort to regulate their emotional reactions and achieve inhibitory control in responding to Rapunzel's premature stop at the obstacle. Inhibitory control, a central component of executive function, involves the ability to inhibit automatic but incorrect responses or to resist interference from distracting stimuli (Diamond, 2016). Difficulties or challenges in a task can cause young children's distress and frustration to overwhelm them, which can then lead to giving up on the task (an ineffective response). Mr. Samuel prioritized managing emotions and inhibitory control as a group, and appealed to children's body/ego syntonicity with Rapunzel by offering a relatable explanation ("She forgot the other two things we told her to do") and helped them label and vocalize their embodied feelings ("Uh-oh" like Rapunzel might have responded). While the children's initial emotional response was intense, their strong empathy with Rapunzel's goal of getting home without crashing into the obstacle (body/ego syntonicity) and the opportunity to express and label their responses to frustration together (we-syntonicity) allowed them to take a pause, process their shared visceral emotional reaction, and recover quickly. Through their body/ego syntonicity with Rapunzel as well as we-syntonicity with each other, the group effectively engaged in embodied/shared inhibitory control.

Conclusion

Our close examination demonstrates that preschoolers leverage their sense/knowledge of their own body/self and attunement with Rapunzel and with each other to engage in rich self-regulatory actions through CT practices with a programming toy in a teacher-guided small group. Children's embodied SR through body/ego syntonicity with Rapunzel is closely intertwined with their embodied attunement with each other (we-syntonicity), and thus *socially shared* and *distributed* (see also Danish & Enyedy, 2020). Their shared body/ego syntonicity with Rapunzel motivated such we-syntonicity, which in return allowed the group to collectively regulate their attention and inhibitory control. These findings lend support that SR, especially in early childhood, should be viewed and examined as embodied as well as social/situated in nature, with implications for the identification and measurement of SR. Our study also lends support to some of the suggested mechanism between CT and SR: joy and sense of belonging derived from CT activities, active engagement with CT, and characteristics of robots that help children to learn to wait and focus (Arfé et al., 2020; Di Lieto et al., 2017). Our we-syntonicity framework captures these potential pathways between CT and SR and provides a useful approach to employing CT practices to support SR in practice.

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“Accessibility is Important to Everybody”: Unpacking Students’ Understanding About Accessibility

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Abstract: Existing research on accessibility in computing courses identifies barriers and practices for teaching web accessibility, but little work has been done to leverage students’ acquired understanding of accessibility as a meaningful topic of study. In this paper, we use students’ assignments to offer insights about what students take away when they learn about web accessibility. Our analysis begins to unpack how students recognize the importance of accessibility, the affordances they associate with it, as well as a considerable willingness to implement accessibility features beyond minimum requirements.

Introduction

From a website’s inaccessibility preventing the purchase of necessities such as food (“Another Big Win in the Domino’s Pizza Accessibility Saga,” 2022) to it inhibiting the completion of a job application (Cahalane, 2018), web accessibility is a social justice issue. Existing work on accessibility in web development courses tends to focus on instructional approaches (e.g., Baker et al., 2020; Putnam et al., 2016; Rosmaita, 2006; Shinohara et al., 2018; Wang, 2012). As such, students’ understandings of accessibility are often considered in relation to course or instructor evaluation, rather than its own meaningful topic of study. Research that centers student perceptions and understandings of accessibility provides meaningful insights into structural barriers impacting students’ understanding of accessibility, and how instructors and institutions might design courses and programs to better support students’ cultivation of accessibility practices (Alonso et al., 2010; Cao & Loiacono, 2021; Conn et al., 2020). Additionally, more research in this area could help expand the conversation around student motivations for learning accessibility (Conn et al., 2020; Putnam et al., 2016; Wang, 2012). Contributing to this important and needed area of research, this paper, which is part of a larger study of accessibility teaching and learning, seeks to answer two research questions: 1) What affordances do students associate with accessibility? In other words, how do students begin to identify all that accessibility offers, and 2) To what extent did students take up supplementary opportunities to implement accessibility features?

Course context

This study was conducted in a large web development course offered as an elective in the Computer Science (CS) department of a large private university in the U.S. The course has an average enrollment of about 150 students ranging across years in the CS major and enrolled students have taken at least two prior programming courses. The course is broad in scope and covers a variety of front-end (i.e., user-facing aspects of a site) and back-end (i.e., components required for dynamic features and functionality of a site) topics. Students work on developing full-stack applications (i.e., websites requiring both front-end and back-end development) and assignments build on each other to create an Instagram-like web application. Assignments consist of labs which are graded pass/fail based on effort and homework assignments are graded on a point-scale according to each assignment’s corresponding rubric. Accessibility is embedded in over half of all lab and homework assignments.

Data and methods

The data used for this paper consist of the submissions for three course assignments. Lab 1 is the first assignment students complete in the course and is designed to help them set up their development environments while offering a brief HTML and CSS introduction. Homework 2 and Homework 4 both focus on creating an Instagram-like web application using different technologies: server-side templating and client-side templating, respectively. The three assignments are representative of various accessibility-related tasks including reflections, accessibility testing, and accessibility feature implementation. The data from the three assignments was analyzed using a combination of open coding as well as summative statistics.

Open coding for RQ1: Affordances associated with accessibility

To answer RQ1, we analyzed the responses to two open-ended reflection questions, one from Lab 1 and one from Homework 4, asking about the importance of accessibility. In Lab 1, students responded to “Why, and to whom, is accessibility important?” while in Homework 4, the prompt asked “Do you think that designing for accessibility also improves the usability of the site for all users? Why or why not?”. We grouped the student responses for both questions and free coded for topics.

Summative statistics and open coding for RQ2: Supplementary opportunities

For RQ2, we analyzed implementation details for Homework 2 and Homework 4, which both offered opportunities for students to implement accessibility features beyond what was required to receive credit. In Homework 2, we asked students to “Download the WAVE Extension using either Firefox or Chrome, and use it to generate an accessibility report. Correct as many accessibility errors as you can. Then take a screenshot of your final accessibility report.” We also asked students “What corrections did you have to make?”.

The WAVE Browser Extension (WebAIM, n.d.-a) is a tool that provides information regarding the accessibility of a webpage by displaying accessibility errors, warnings, and features. Students can click on any of these messages to get more information about what it means and, if it is an error, how to address it. WAVE reports return counts for various categories of issues, including (1) “errors” – indicating failure to include essential accessibility markup tags and attributes in the code, (2) “color contrast” – indicating that the color choices interfere with readability, and (3) “alerts” – indicating potential accessibility issues. We manually extracted the total counts from each student’s submitted screenshot and used Microsoft Excel to automatically calculate and plot five number summary statistics to assess the distribution of each. Furthermore, we compiled all the possible errors for each category (see WebAIM, n.d.-b) and assigned codes to the ‘alert’ category. We used the coding scheme from this list of possible alerts to code students’ responses of what corrections they made.

In Homework 4, students were asked to implement three accessibility features that enable users relying on assistive technology to interact with a web application without using a mouse: basic keyboard navigation, screen-reader friendly toggling behaviour, and change of focus for a modal. Students were also given the opportunity to implement an additional feature for extra credit, namely, allowing the ‘Escape’ key to trigger the closing of the modal while preserving the appropriate keyboard focus. To facilitate grading, students were asked to self-report whether they implemented the extra credit feature. As such, we read through student’s submission comments and counted how many of them implemented the extra credit feature.

Findings

What affordances did students associate with accessibility?

One salient theme that emerged from the open coding of students' responses to Lab 1 and Homework 4 was that accessibility benefits everyone— including the students themselves.

Accessibility benefits everyone

Across the responses for both assignments, 62.5% of students wrote about accessibility being beneficial for all users of a website. Below we include an illustrative student response from each assignment:

Lab 1:	“Accessibility is important to everybody. Accessibility dictates the usability of applications across populations, and it is to our advantage that applications are widely available. In addition, a large percentage of the population requires accessible interfaces.”
Homework 4:	“Designing for accessibility does improve the usability of the site for all users. The screen reader components don’t necessarily impact all users, but many may want the option to use the keyboard instead of the mouse only.”

Additionally, 74% of student responses included an example to elaborate on or justify how or why accessibility benefited everyone. Some examples shared by students in Lab 1 included: “Making a website accessible may also benefit everyone (e.g., closed captioning used in a crowded bar)” as well as “ [Accessibility] leads to better designs and more readable code, and it makes using the site easier and more pleasant for everyone”, and some examples from Homework 4 consisted of: “I think all users can benefit from things like alt text (i.e., your browser might be slow one day and images don't load properly)” as well as, “although someone is able to use a mouse, it’s just easier given a situation where they would want to tab through the site instead. Another example is color contrast, where although a user might not be colorblind, having a well-contrasted site would just be more visually pleasing.”

Accessibility is relatable

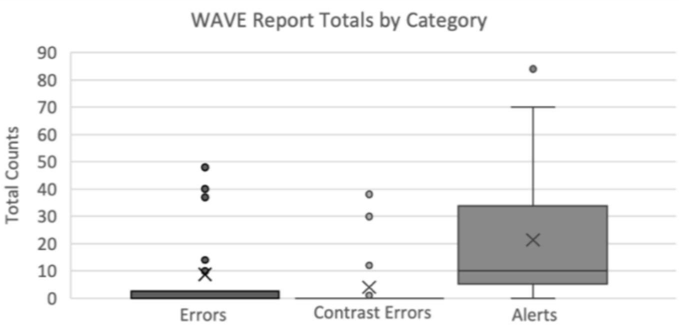
Across both assignments, 20 unique students shared examples of accessibility being beneficial to everyone. Of those, 40% of them gave examples from their own experiences navigating websites using accessibility features. For example, one student shared "it was really easy to just hit enter twice to open and close the modal (and test modal functionality), rather than clicking the "view more button" and then the "close" button. I believe tabbing (and using the enter or space key) can be a useful tool for anyone." In identifying the ease of use that accessibility features— such as tabbing— can provide, students unlock a novel way of navigating and interacting with the web. Interestingly, half of the students who shared similar examples explicitly described these examples as stemming from testing the accessibility features they had implemented for their assignments.

To what extent did students take up supplementary accessibility opportunities?

Students implemented accessibility features beyond those required for credit, which is a strong indication that students *want* to implement accessible websites and when given the appropriate tools, will do so. When given the opportunity to implement an additional accessibility feature for extra credit in Homework 4, over half of all students (54%) implemented it. Implementing the extra credit feature was worth an additional two points for an assignment graded out of 40 points.

Furthermore, in Homework 2, most students corrected all 'errors' and 'contrast errors', while many corrected 'alerts', when the prompt asked for them to "correct as many errors as [they could]". As Figure 1 demonstrates, Homework 2 errors and contrast errors were both tightly grouped around zero, demonstrating that a majority of students were able to correct simple accessibility errors such as empty fields, non-descriptive links, missing alt-text, and low contrast, among others (see WebAIM, n.d.-b).

Figure 1
Student WAVE Report Totals by Category



Despite not being grouped near zero, about half of all students had 10 or fewer alerts. This is likely an indication that students *chose* to address the alerts they received from WAVE, despite not being required to do so— a theory supported by 60% of student reflection responses for this assignment mentioning specific types of alerts they addressed. This evidence suggests that students were motivated to address as many issues as they felt they had the skills to do.

Discussion & implications

As evidenced in this paper, there is incredible richness in how students are taking up the value and importance of accessibility. However, existing research on accessibility focuses on pedagogical practices, interventions, and course design and evaluation (see Baker et al., 2020; Lewthwaite & Sloan, 2016; Nishchyk & Chen, 2018 for in-depth literature reviews on these topics), with little attention given to students' thoughts and practices regarding accessibility. Importantly, while existing work on teaching about accessibility highlights students' and web developers' lack of interest (Putnam et al., 2016) and their disregard for the importance of accessibility (Conn et al., 2020; Putnam et al., 2016; Wang, 2012), the findings presented here offer insights into the many ways in which students value accessibility, and how willing they are to go above and beyond minimum requirements of assigned accessibility implementation. This finding is not only encouraging for instructors who may be feeling discouraged about teaching the topic, it also highlights the need for better understanding how educators can enable and motivate students in this area. For example, while conducting the analysis across student responses for Lab 1 and Homework 4, we noticed a considerable difference in the number of students who recognized accessibility as important and beneficial for all users in each assignment (Lab 1: 36%, vs. Homework 4: 89%). It is unclear how much of that recognition came from the positive bias in the wording of the Homework 4 question as opposed to students' learning through the course (the assignments were even weeks apart). Understanding whether this discrepancy was due to student understanding fomented through the course overall (i.e., students learned to recognize that accessibility benefits everyone) or through the question's positively biased wording (i.e., question wording helped surface students' underlying understanding) could impact course design to better foster this learning. Relatedly, understanding whether the ambiguity of asking students to "correct as many errors as [they] can" helped motivate students to address more errors than they would have had they been given a specific threshold, could also help frame assignment question design. Lastly, while it is encouraging that students appreciated the added value of accessibility as benefitting all users, it is important that students recognize that accessibility primarily impacts how users with disabilities navigate the web and a site's conveniences for abled users must not undermine its access and functionality for disabled users.

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“Wait, Wait, Go Back”: Investigating Social Supports for Homework During Do-Design Sessions With Teachers

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Abstract: Teachers use interpersonal classroom skills to support their students’ learning in the classroom, but homework is done in isolation without the affordances of classroom interactions. Here we investigate how a homework tool could empower teachers to utilize their interpersonal classroom skills and provide new ways to support students outside of the classroom. Through three phases of interviews and co-design, we co-designed software for teachers to create their own robot-assisted homework activities. We found that teachers' existing expertise initially led to wrong assumptions about the tool but after viewing an exemplifying stimulus they shifted their mental model of the tool and of homework in general. These findings can help understand (1) how pedagogical expertise may hinder utilization of new tools, and (2) how a catalyst may shift existing perceptions and facilitate the use of new paradigms to support student learning.

Introduction

Teachers utilize *interpersonal classroom skills* to facilitate meaningful social learning for their students. These socially situated interactions can foster interconnected understanding of content and deeper learning through a process of co-construction of knowledge (Miyake & Kirschner, 2014). However, teachers cannot apply these crucial interpersonal classroom skills to learning activities outside the classroom, such as homework which is typically undertaken in isolation. Some existing technological approaches can be effective in supporting social interactions during learning and offer automated differentiation to support students’ comprehension and problem solving. But these often require teachers to adapt their pedagogical approaches to the needs of the software which rarely allows the teacher to utilize their existing classroom interpersonal skills or tailor their supports to connect to students' individual and collective experiences. There is therefore a need for software that shifts the paradigm of homework to align with classroom practices, thereby empowering teachers to use their existing interpersonal classroom skills to provide meaningful connections to the material and support deeper learning. Our goal is to facilitate this change in homework paradigms by co-designing an authoring tool for middle school science teachers to provide rich socially interactive guidance to students working at home with a social robot.

Theoretical framework

Teachers guide students’ acquisition and integration of domain knowledge by utilizing **interpersonal social skills** to co-create knowledge between teachers and peers (Miyaki & Kirschner, 2014; Cress & Kimmerle, 2018). Teachers actively support their students’ socially situated learning by responsively attending to student questions and misconceptions, prompting verbal reflections on learning, and adapting content to student’s learning preferences (Kucirkova, 2021; Walkington & Bernacki, 2021). To scaffold complex concepts and texts teachers also rephrase or simplify content and use interpersonal and informal language closer to students’ discourse and receptive vocabulary (Bernacki, 2021). Such socially interactive learning is particularly critical for science learning where the focus is on generating deep knowledge through collaboration and discussion (NGSS, 2022).

Homework is a valuable instructional tool that can enhance students’ learning, have a positive influence on students’ academic achievements, especially when connected to classwork and tailored to students’ individual needs (Cooper, 2015, Rosario et al., 2019). While many teachers are aware of the need for social guidance in the classroom, students are left to complete homework as an isolated activity. Teachers also believe students face issues of inequity in time, technical resources, and support outside of the classroom, which has led to a reduction of assigning homework (Hatch & Michaelis, 2021). Given these challenges to providing at-home learning, it is important to bolster the use of homework by facilitating teachers to integrate their interpersonal social skills.

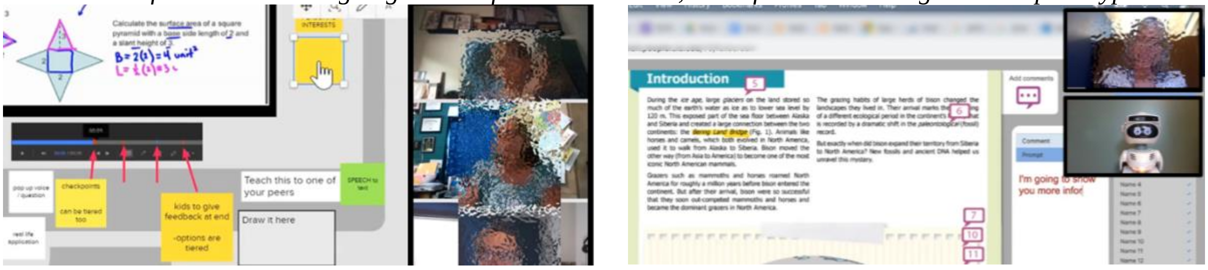
Social robots are becoming more affordable for at-home and classroom use and have the potential to transform isolated activities such as homework into socially interactive experiences and facilitate higher levels of engagement, thus promoting learning and interest (Balpaeme et al., 2018, Michaelis & Mutlu, 2018, 2019).

Earlier research in this study showed that science teachers felt current online learning options do not adequately support socially interactive approaches to learning (Hatch & Michaelis, 2021) and explored the co-design of a homework authoring tool (Hatch & Michaelis, 2022). We now apply a different lens to the teachers’ viewpoints as they developed over time across the research. Specifically, we examine how to empower teachers to use their existing interpersonal skills to support students' at-home learning with a social robot: (RQ1) How do teachers' perspectives differ on ways to support their students' learning in the classroom and in homework? And (RQ2) how do teachers' current pedagogical practices impact their application of a new educational technology?

Method

This study stretches over three phases of participatory research with middle school science teachers to elicit their perspectives on providing classroom and homework guidance using a social robot. First, we elicited their perspectives in 1-hour interviews (n=12) on how they currently provide guidance in the classroom and on how they approach homework. We then populated an online whiteboard 'Mural' with a range of digital features based on their views on how they provide guidance to reading assignments. In groups of 2 or 3 (n=7) the teachers then used these digital features to co-design an online tool to meet their needs while we guided and captured the discussions via Zoom (see Figure 2). Teachers indicated their preferences and discussed their reasoning around the features they chose and the layouts they created. These co-designs became the basis for a subsequent working prototype which we then tested (n=13) teachers' use of it to provide support to students doing homework with a social robot. The teachers could add either questions or prompts, 'annotations', to a reading homework article and we explained how these annotations would eventually be voiced by a social robot at home with the student. The 'Misty II' robot used in prior research (Michaelis & Mutlu, 2018, 2019) was also visible to them via the online Zoom window. After the teacher's first or second annotation, the robot voiced the annotations as it would at home with the child. We then asked the teachers to share their thoughts about their impression of this, before prompting them to continue annotating. The locus of this study is not on the eventual student-robot interaction - the focus of previous work (Michaelis & Mutlu, 2018, 2019) - but on how the teachers' pedagogical expertise shapes how they grapple with a software that presents a new way of interacting with students. All three phases were conducted online using Zoom from which we analyzed the captured video and dialogue using a Thematic Analysis approach (Braun et al., 2018) to inductively construct semantic codes and organize the data into major latent codes. We then co-constructed emergent themes through iterative discussion based on meaningful patterns in the data.

Figure 2
Screenshots of teachers co-designing desired features in Mural; and of a teacher using the later prototype.



Findings

We found two major themes across the three phases that pertains directly to our research questions: (1) Teachers feel the lack of interpersonal supports limits the impact of homework and (2) Viewing the robot's interactions appeared to shift teachers' perspectives on the homework activities.

Teachers described classroom activities as rich interpersonal exchanges where they are able to actively guide and respond to their students' learning. Homework was described as an extension of the classroom where students can deepen their understanding of the topic. Many teachers said they use homework as a structured test of their students' understanding upon which to build in classroom activities. However, they also told us they minimized homework as they are not able to provide the kinds of social supports they do in the classroom and expressed frustration at not being able to immediately address issues and questions as they would in person.

When teachers were asked to annotate the homework reading using the working prototype, their initial approach appeared to align with how they had described homework in the preceding interviews. A high majority of the annotations were formed as questions to test the students' understanding of the material, formulated in concise and *formal* language. However, after seeing the robot enact their initial annotations, many teachers appeared to second-guess their original approach and made immediate changes to their original annotations or started new ones that use a *conversational* or socially rich language. Teachers' new annotations appeared to be less like formal test questions and closer to how the teacher would use interpersonal language to support their students' learning in the classroom. This change in the way they phrased annotations seemed to be aligned to teachers accounting for the student's perception of the robot as a social interlocutor, and teachers spoke about how they viewed the robot as a teacher at home with the student. The teachers' later annotations included ways to prompt verbal reflections, bring emphasis to specific content, and rephrase or simplify complex vocabulary. Many teachers described their later annotations reflected the style of speech they would use in the classroom and greatly expanded the types of annotations to include comments, exclamations, and humorous quips. For example, one teacher's annotation guides the students' attention to a picture, by having the robot say, "Hey take a look at this. Wait, wait, go back, look at that picture again" (Teacher#5), where both content and style appear to be unique to the affordances of social interaction.

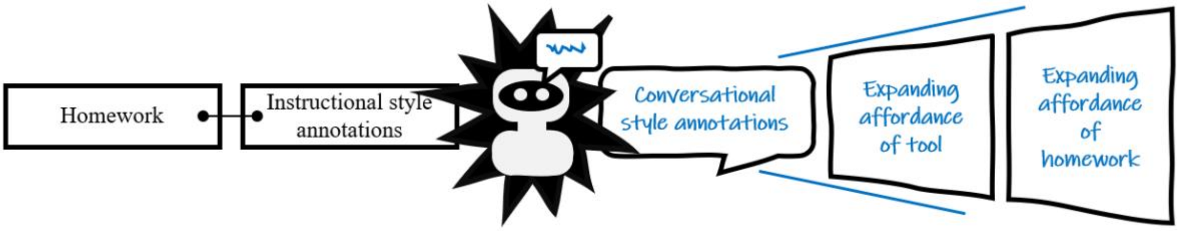
In sum, teachers' initial annotations were instructional prompts and formal questions which seemed to be relate to their pedagogical experience with *homework*, but hearing the robot speak those annotations appeared to demonstrate how impersonal those prompts were and inspired the teachers to then create annotations that reflect the interpersonal dialogue they use in the *classroom* to connect with and motivate students.

Discussion

At the start of this study teachers described how they utilize their interpersonal skills to socially support their students' learning in the classroom, which contrasts to how they described their approach to homework. However, after hearing the robot say their annotations, the teachers explained -and demonstrated- how they could utilize the robot's social skills to support homework in ways similar to how they described supporting student learning in the classroom. Teachers saw this as an opportunity to facilitate meaningful social learning through homework and thereby attend to student questions and misconceptions, prompt verbal reflections on learning, actively support engagement, and engage with students in relatable ways (Kucirkova, 2021; Walkington & Bernacki, 2021). Their approach changed from preparing homework as an isolated, unsupported task (Cooper, 2015) to preparing it as a new way of interacting with the student and facilitating meaningful social learning (Miyake & Kirschner, 2014).

We also consider that seeing the robot enact their homework annotations may have been a critical catalyst to shift the teachers' mental model of homework activities away from their existing construct of homework, only after which were they able to use their interpersonal classroom skills to augment the homework. The teachers in this study did not immediately use the robot's social capabilities, despite knowing that their annotations would be voiced by it. Every teacher in the study started by creating annotations that resembled traditional homework questions and prompts. We believe it may be that teachers' mental model of the homework activity was initially framed by their prior experience in assigning homework, despite this platform's addition of the robot technology. This mental model appeared to be challenged at the very moment the teachers heard and saw the robot vocalize their annotation. It seems the juxtaposition of the instructional-style writing appeared inappropriate as dialogue and brought their attention to the new *social* purpose of the annotation. The experience appeared to act as a catalyst to abruptly shift the teachers' mental model from a homework paradigm to that of a *classroom paradigm*. This shift in perspective allowed them to tap into their interpersonal classroom skills and create homework activities that mimic student-teacher classroom interactions, rather than a student-paper interaction paradigm. Thus, experiencing the robot enact the annotations seemed to be a critical catalyst for reshaping teachers' understanding of the purpose of the annotations, and shifted their mental model of the affordances of the homework.

Figure 1
It appeared a catalyst was necessary to shift teachers' mental model from a homework paradigm to that of a classroom paradigm and expand their perception of what they could achieve with homework through the tool.



Our study echoed current theory on how complex and challenging homework can require substantial guidance which teachers and parents are often unable to provide (Cooper, 2015). Building on current theory around how social robots provide these important supports (Michaelis & Mutlu, 2019; Balpaeme et al, 2022), we provide a way for teachers to provide robot-student homework interactions that utilize their interpersonal classroom skills, crucial for creating meaningful connections to the material and supporting acquisition of deeper learning (Miyake & Kirschner, 2014). We also build on existing theory by demonstrating how a catalyst can shift teachers' mental model and thus enable them to draw from existing skills and experiences.

Learning Scientists often engage in changes to teaching practices, therefore consideration of teachers' difficulties in adopting change is essential. Our findings show that it may be important for researchers to find the right *catalyst* to help shift a mental model to take full advantage of innovative new tools. In this study, the teachers' typical instructional style of writing seemed to jar with the spoken voice of the robot, thereby acting as a catalyst for a mental model shift in which they realized the social affordances of the robot. This may suggest that a mental model of an existing teaching practice can be shifted by creating a form of cognitive conflict between old and new paradigms, thereby necessitating the teacher to actively make a change of approach to resolve the issue. Once the mental model has been shifted, the teacher may be able to freely apply their existing expertise within the new paradigm rather than be limited by the constructs of the old one.

Conclusion

In this study, we found how teachers' existing pedagogical expertise with homework hinders their understanding the affordances of a new system, but once their perspective is shifted, the teachers may be able to freely apply their interpersonal classroom skills and facilitate meaningful social learning in the homework. We recognize one major limitation of this study is the small sample size, mostly made up of teachers with significant classroom experience. As such the findings have limited capacity for generalization. While this work uncovered teachers' views based on their emotional and pragmatic needs, future work will include formal testing within the context of real classrooms, and research on how students and families perceive such socially interactive homework.

We believe the findings of this study can help Learning Scientists engage in designing interventions and changes to teaching practices, where adopting change is often of paramount importance. Because a teacher's pedagogical expertise may prevent them from immediate recognition of the affordances of a new approach, it may be important to find the right catalyst to help change existing mental models, potentially enabling the teacher to bring new, expanded insights directly drawn from that same expertise. We believe this work makes important contributions to existing theory and will help guide future work in this area.

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Expanding Preservice Teachers' Conceptions of Science Teaching and Learning

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Abstract: To support students' sense of belonging in science classrooms, K-12 teachers should recognize and appreciate learners' diverse experiential, cultural, and linguistic repertoires as valuable resources for sensemaking in science. This approach to teaching necessarily entails expanding what has been traditionally considered as ontologically and epistemologically valid and valued in disciplinary learning spaces so that students' diverse ways of thinking, talking, and feeling are honored and built upon, rather than dismissed. This study explores the emergence of such expansiveness in the context of STEM preservice teacher education. Using preservice teachers (PSTs)' written reflections and in-class discussions, we identified different ways in which such expansiveness manifested in PSTs' discourse. We end with some implications for supporting teachers' expanding conceptions of science teaching and learning.

Introduction

Learners have varied and rich life experiences, cultural practices, and linguistic repertoires that serve as valuable resources for their sensemaking in science (Rosebery et al., 2010). In the United States, however, these resources often do not align with the Western disciplinary practices and discourses that are privileged and romanticized in traditional instructional goals (Bang et al., 2012). Such instructional goals are informed by a "selectively appropriated… unnecessarily narrow" framing of science that depicts the discipline as culturally neutral, value-free, and objective (Bang et al., 2012, p. 314). These zero-point epistemologies shape what is ontologically and epistemologically acceptable in science classrooms, often devaluing learners' own experiences and ways of knowing (Warren et al., 2001). This is especially true for learners from marginalized cultural, linguistic, and racial groups, as this narrow framing (re)produces deficit narratives about such students (Nasir et al., 2006; Rosebery et al., 2010).

It is crucial, then, to *expand* teachers' conceptions of science teaching and learning in ways that push the traditional boundaries of "what counts" as intellectually generative for scientific sensemaking and "who counts" as capable of meaningful engagement in science (Rosebery et al., 2016). Such expansive considerations necessarily entail orienting to all students as sensible and brilliant (Robertson & Atkins-Elliot, 2017), recognizing students' diverse ways of knowing and being—their onto-epistemic heterogeneity—as valuable for their science learning (Kayumova & Dou, 2022), and understanding the sociopolitical realities of schooling (Madkins & McKinney de Royston, 2019). Here, we examine how preservice science teachers' (PSTs) begin to develop such *expansive conceptions of science teaching and learning* in an early teacher education course. Toward this end, our exploration in this work is guided by the following: *(1) what are the ways in which PSTs developed more expansive conceptions about science learning? and (2) how do these expansive perspectives influence PSTs' evolving ideas about science teaching?*

Conceptual framework: Expansiveness

By expansiveness, we refer to teachers' broadened conceptions of science teaching and learning along three components: having asset-based orientations to learners, recognizing the value of onto-epistemic heterogeneity, and developing political clarity.

In traditional framings of science teaching and learning, students' own sensemaking resources are often ignored or viewed as deficient, which negatively impacts students' investment in their own learning and the opportunities they have to use these resources (Kayumova & Harper, 2020; Suárez & Otero, 2014). When seeking to expand teachers' conceptions of science teaching and learning, it is essential to cultivate their **asset-based orientations.** By asset-based orientations, we refer to the way that teachers orient to the strengths and merits of students' ideas, experiences, and forms of participation. Such orientations are grounded in the assertions that students are capable of engaging meaningfully in science, and that their own intellectual resources support their sensemaking (Celedón-Pattichis et al., 2018). Asset-based orientations frame students' engagement in the classroom such that teachers orient to the brilliance of students, rather than ascribe to deficit views (Mejia et al., 2018).

Another central component for expansive conceptions of science teaching and learning is recognizing **onto-epistemic heterogeneity**, or "differences in perceived ways of being, thinking, doing, and interpreting," as *valuable* for scientific sensemaking (Kayumova & Dou, 2022, p. 1099). Going a step further than asset-based orientations, valuing onto-epistemic heterogeneity refers to expanded considerations of “what counts” as intellectually generative for students’ scientific sensemaking (Rosebery et al., 2016). Such expansive considerations include, for example, valuing “practices of argumentation and embodied imagining, the generative power of everyday experience, and the role of informal language in meaning making” (Warren et al., 2001, p. 532). This does not entail an ‘anything goes’ view of science instruction nor a rejection of dominant views of science, but rather a “conscious form of heterogeneity of learning and engagement” (Bang & Marin, 2015, p. 542) that centers the varied cultures, languages, and experiences of students as valuable for knowing and being in science.

Expansive conceptions of science teaching and learning also entail a recognition that Western, narrow ideations of science are rooted in colonial historicity, and continue to define “settled” expectations about who counts as a valid constructor of knowledge (Bang et al, 2012; Mignolo, 2010; Warren et al., 2020). This contributes to the systematic cultural exclusion of students who exist outside of these racialized, classed, and gendered norms (Kayumova & Dou, 2022; Ladson-Billings, 2007). It is therefore essential to support the development of teachers’ critical awareness of such power and historicity, the deficit narratives they (re)produce, and structural and systemic inequities that shape students’ opportunities to learn science. Madkins and McKinney de Royston (2019) refer to this “deep understanding of how schools and society operate to reproduce inequalities and are structured to differentially privilege certain experiences and forms of knowledge over others” as **political clarity** (p. 1325).

Methods

This study is part of a larger project aimed at cultivating PSTs’ capacities for understanding, valuing, and responding to students and their ideas in ways that affirm their humanity and dignity. Each of the PSTs in this study are double majoring in a STEM field of their choice and in education, with the goal of becoming a secondary STEM teacher. In the semester from which the data are drawn, nine PSTs participated in the study.

The goals of the course at the center of this study are to develop PSTs’ knowledge and curiosity about learners’ ways of thinking and feeling, promote PSTs’ critical awareness of their own prejudice and biases, and support PSTs to recognize learners’ brilliance and honor their full humanity in designing and enacting instruction. PSTs engage in several course activities in service of these goals: (1) reading research and practitioner articles about student thinking and diverse ways of knowing; (2) engaging as learners in science and mathematics activities that require them to think deeply about concepts; (3) analyzing videos and transcripts of students engaging in mathematical or scientific inquiry; and (4) closely interacting with learners through a capstone “Learning to Listen” project, which requires PSTs to engage a group of learners in an open-ended science or mathematics question. Throughout these activities, PSTs are asked to critically reflect on their own experiences as leaners as well as on K-12 students’ ideas and experiences. Using multiple data sources, including PSTs’ written assignments and in-class discussions, we examined evidence of PSTs’ expansive conceptions and explored how they manifested in their evolving ideas about science teaching.

We first cataloged each of the PSTs weekly discussion board posts where they reflected on course readings and analyzed videos of student thinking. Using a grounded theory approach (Charmaz, 2006), we then took several iterative passes reading the PSTs’ discussion board posts and tracking instances of expansiveness. Examples of such instances included moments when PSTs discussed the merit in a student’s idea and their sensemaking resources or reflected on larger societal narratives that shape classroom experiences. The first and second authors met weekly to discuss such instances and share their analytical noticings around them. Through this work and our ongoing discussions, we identified themes to describe the ways in which expansiveness surfaced in PSTs’ engagement with the course materials, and how this expansiveness manifested in their ideas about science teaching.

Findings

Due to space limitations, here we illustrate our findings using data from only one discussion where PSTs reflected on an essay from Warren and Rosebery (2008), “Using Everyday Experiences to Teach Science.” The themes discussed below, however, apply more broadly across posts and reflections. In this essay, the authors feature vignettes of students using their everyday experiences as resources for sensemaking about water cycle and gravity.

Research question 1: Expansive conceptions of science learning

Our first research question concerns the ways in which PSTs developed more expansive perspectives around science learning. In their analysis and reflection on the piece from Warren and Rosebery (2008), we saw clear evidence of PSTs' expanding conceptions of science learning in how they oriented to students' everyday experiences and their valuing of heterogeneous ways of sensemaking. For example, PST Molly wrote:

> "The students seemed to be very good at applying what they were trying to understand to things that they had experienced in real life… even though their wording was not what I would have expected… it makes sense that students from different backgrounds would have different criteria on what makes water unusable. I just was not thinking about it and it surprised me."

Here, even though the students' language surprised her, Molly recognized the value of students' varied experiences as resources for their sensemaking about a complex scientific phenomenon. Through this comment, Molly acknowledged that her expectations ("their wording was not what I would have expected") and her sense of surprise were stemming from her failing to consider how students' experiences and backgrounds may engender heterogenous ways of sensemaking and expression.

PST's expansive conceptions also manifested in how they problematized deficit discourses. Reflecting on the reading, another PST, Serena, tuned in to "negative assumptions" sometimes held by teachers about the capabilities of students who speak languages other than English, which she refers to as "outlandish and antiquated." Such assumptions, Serena noted, can impact the learning experiences of culturally and linguistically diverse students by making "it seem as though the gap between what these students can learn and what they already know is so large that it might be futile to even try." Relatedly, another PST, Kendall, noted that these deficit narratives are reproduced by "a system where curricula and rules are centered around being White and the White experience." In this system, she writes, marginalized students must either "conform to the Whiteness of the schooling system… [which] is a very large burden to carry" or be "alienated."

Research question 2: Expansive conceptions of science teaching

With respect to conceptions of science teaching, we saw evidence of expansiveness in the ways PSTs described the importance of opening up and holding space for students' ideas as well as in their critical reflections on their own biases and practices. For example, in connecting Warren and Rosebery's (2008) essay to her future teaching, PST Adeline asserted that "Students can't possibly be blank slates, and I wouldn't want them to be," because students' everyday ideas are "resources for learning." Adeline acknowledged that even though it would be "challenging to imagine" how she might work to make disciplinary connections to students' everyday ideas, this is a goal she aspires towards in her future practice. In another reflection, Adeline noted:

> "Students bring knowledge to the classroom that forms their understanding…and teachers need to listen to students, understand their thinking, and then adapt their teaching to best fit their students' needs so they can better understand the whole concept… we need to learn to listen and not assert our own ideas, assumptions, or expectations on our students."

In this reflection, Adeline recognized that an important aspect of teaching is learning how to "listen to students" to "understand their thinking" instead of evaluating and judging learners based on one's "own ideas, assumptions, or expectations." This stance of decentering from one's own perspective to tune into students' is a productive beginning towards a more expansive framing of teaching, a framing that centers and holds space for students' own ways of knowing. PSTs also commented on the importance of attending to and confronting their own assumptions and biases that might stand in the way of enacting such instruction. For example, in thinking about her future teaching practice, Kendall reflected on how such introspective work and critical reflection is an essential "first step":

> "Our first step is to recognize that we can be biased. If we are able to examine our own behavior and biases, then we can also critique and adjust them. It would be beneficial to… ask myself 'who did I talk to the most in class?' or 'what students were most engaged? And did I work to engage some students more than others?'"

Discussion

In science education, there is a call to trouble narrow assumptions that (re)produce deficit narratives and injustices (Kayumova & Dou, 2022). This presents a unique challenge for science educators because dominant portrayals of science depict narrow framings of the discipline that bound what counts as ontologically and epistemologically valid, and marginalize students with divergent ways of thinking, knowing, and participating in science (Bang et al., 2012). As we seek to expand PSTs' understanding and appreciation of students' meaning-making repertoires beyond what has been traditionally valued, it is essential that we understand how PSTs begin to form more expansive considerations for “what counts” as intellectually generative for science learning and “who counts” as capable of learning science. In our study, we found that such expansive considerations manifested in PSTs’ developing insights about the brilliance and capabilities of students, their valuing of diverse perspectives and intellectual resources, and their recognition of the harm that deficit narratives cause to minoritized learners.

Additionally, we found that these expansive conceptions of science teaching manifested in PSTs' ideas about teaching science. As PSTs discussed and reflected on the practice of teaching, they tuned in to the importance of making space for students and their diverse ideas, responding to students’ contributions and forms of engagement in affirming and humanizing ways, and critically reflecting on their own biases and assumptions. These teaching considerations are a crucial first step toward enacting teaching practices that honor students’ humanity and agency in epistemically just ways. When teachers support students in bringing their whole selves to their science learning and value students’ cultural, linguistic, and experiential repertoires as valuable for sensemaking in science, they send messages to students that they are capable, agentive, and brilliant (Robertson & Atkins-Elliot, 2017).

It is important to note here that, while we share here a picture of productive beginnings towards more expansive conceptions of science learning and teaching, we are not suggesting that these orientations are in any way a “finished product” or that these PSTs—or any teacher, for that matter—would “hold” and enact such conceptions at all times and in all contexts. Conceptions may indeed be contextually constructed and may change over time. In future research, therefore, it will be important to explore how these expansive conceptions may stabilize over longer periods of time, and how they might manifest, and perhaps shift, in interactions with students in the complex work of teaching. Relatedly, there is a need for continued research on the design of educative experiences and support structures that uphold both preservice and in-service teachers in the work of problematizing and desettling dominant discourses around science, science learning, and science teaching, towards cultivating more expansive and humanizing science learning environments.

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STEM Education for Sustainability: Finding Grounds for a Constructive Dialogue in Indigenous Contexts.

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Abstract: This paper argues that Science, Technology, Engineering, and Mathematics (STEM) education can overcome an instrumentalist perspective on these challenges and provide spaces for transdisciplinary dialogue to affront the loss of meaning when facing complex and divergent problems that cannot be solved logically or that rely on ethical assumptions. The present work corresponds to a section of a doctoral dissertation that provides an inductive and holistic perspective for early science education (from age 4 to 10), based on local challenges to affront sustainability dilemmas. The paper provides a five-domain framework to plan and develop STEM projects that promotes a dialogue with local and indigenous knowledge.

Context and aims of the paper

The physicist and mathematician G.N.M Tyrell proposed the terms "convergent" and "divergent" to distinguish between problems that can be solved logically from those that are not. The positivist perspective, the reductionism, and hyper-specialization of science, sometimes fail to provide a practical solution, especially when facing complex challenges such as climate change or socio-ecological dilemmas. What can science education do about it? How can the schools become part of the solution? What happens in intercultural and indigenous contexts where diverse worldviews collide during the educational experience?

Sustainability and complex socio-ecological problems (e.g., climate change, land-use conflicts, responsible consumption, production) are usually divergent problems that cannot be easily solved instrumentally or logically. All the frameworks referring to the so-called challenges of the XXI century are aware of this complexity and the necessity to adapt the educational systems to understand that the instrumental or standardized scope in science education is neither sufficient nor an adequate path to follow. The present paper makes an effort to land the global challenges of sustainability in kindergartens and schools. It emphasizes the importance of an inductive, integrated, and place-based scientific approach to give tools for constructive dialogue and the development of new localized knowledge in indigenous contexts, providing small solutions for sustainability challenges. In this way, it presents evidence on how to conduct learning experiences to develop basic argumentative and practical skills to attend to local sustainability issues and provide the possibility of a fruitful dialogue in indigenous and intercultural contexts.

Besides the necessity to re-think the scientific scope to affront the complex problems of the XXI century, there is also the need to reach all students with scientific education, particularly those who have been historically marginalized for their cultural distance to science. Scientific structure, logic, and scientific narratives are sometimes far away from real-world situations and could be considered external or imposed in regions with a colonial history. The idea of initiating a genuine dialogue and open discussion on the ethical and epistemological foundations of science is necessary to promote change and give tools to the new generations to affront a complex future scenario.

This paper elaborates how integrated and context-relevant scientific education opportunities can raise students' motivation and develop agency towards sustainable futures. It also observed how STEM education opens to local knowledge in indigenous contexts and helps understand how children, teachers, and the community can benefit from these initiatives. As a result of the research process, this paper will provide a conceptual framework to guide further research in the area, providing ideas for further research to measure skills, motivation, and contextual aspects to consolidate what nowadays is an emergent field of research.

The idea of rethinking scientific education at an early stage implies not only proposing new methods to learn scientific content but also being aware of the importance of the ethical foundations of the scientific perspective, how permeable sciences are to the diversity of contexts, and assuming the ethical foundations behind the positivist scope. The scientific evidence about the limits of the earth, and the prediction about climate all over the globe, urges the necessity of building diverse and contextualized ethical foundations along with solid scientific skills and integrated educational opportunities.

This does not mean by any chance the idea of replacing the specialized for a holistic scope in science. It would be naïve to neglect the remarkable progress of scientific knowledge through the reductionist lens. However, understanding that the new challenges for science cannot be entirely solved by reducing complexity (since we are facing many divergent problems) opens a path for transdisciplinary dialogues and collective constructions with practitioners in diverse contexts.

At the school level, the idea of approaching divergent problems through active STEM methodologies and the development of inductive thinking to creatively affront real-world problems will be discussed in this paper. This framework contributes to the relatively new discussion on education for sustainability and STEM education, providing a theoretical basis for the implementation of coherent and inclusive STEM educational opportunities based on the latest articles, reviews, international frameworks, and the empirical work conducted after eight years of implementing a STEM education program in the south of Chile. I will elaborate on the importance of including the school's context to provide culturally relevant learning experiences, focusing on indigenous contexts, presenting a five-domain frame to promote a dialogue between scientific and indigenous knowledge.

Constructive dialogue with Mapuche knowledge

Mapuche means people (che) of the land (Mapu). Like those of many Amerindian and eastern civilizations, their worldviews and traditional practices are essentially ecological, recognizing humans, plants, bodies of water, and other beings as co-inhabitants. (Rozzi, 2013). Opening the scholar culture and the STEM education research in specific, making it permeable to these diverse worldviews under a broad understanding of what STEM education means, can make a big difference in the challenge of sustainability and environmental degradation.

When talking about Mapuche learning and worldviews, it is vital to avoid falling into stereotypes and essentialist views about their traditions and ways of living. Nevertheless, there are some previous efforts to establish a constructive dialogue between scientific education and Mapuche learning traditions. Torres et al. (2011) stress the importance of a sociocultural perspective on learning, which puts on the center the idea of learning by doing to incorporate culturally relevant knowledge. Knowledge about nature and society are embedded in social memory and transmitted from generation to generation, and new pedagogical approaches can be an opportunity to incorporate new sources to establish a fruitful respectful dialogue.

Studies focused on Mapuche ways of learning have observed interactions between learners and teachers, finding that the teacher figure does not exist. Instead, there is an image of wise people who share knowledge through interaction in outdoor spaces and everyday life situations rather than by formal means (Quilaqueo et al., 2010; Quintriqueo & Torres, 2012). Parents and adults are knowledge managers in children's environment and model how to put knowledge into practice, either through play or in the daily chores inherent in community and home life (King & Schielmann, 2004; Llanquinao, 2009). In this adult-child relationship, the autonomy of children in resolving the situations they face is privileged, and few instructions or orders are observed (Ibáñez-Salgado, 2015).

School dynamics can dramatically break local epistemologies, approaches to learning, and the relationship with adults, setting new structures under the umbrella of "good behavior". As a result, the school contents can lose their experiential character, often becoming distant, odd, and foreign to the students. Teachers have a central role in the classroom, giving orders and shaping the practices and ways of learning in the classroom. However, this situation can be remedied and redirected by the school by using educational approaches that integrate students' prior knowledge and learning dynamics in their cultural systems. (Bascopé & Gutiérrez, 2019; Bascopé & Reiss, 2021). Here STEM4S projects with the previously defined characteristics can establish a path to promote culturally relevant learning and create the spaces for a dialogic and constructive learning experience for the students to confront complex challenges in their daily lives, both during their school experience and in their future.

In this direction, we developed a five-dimensional framework to build STEM4S projects (Bascopé & Caniguan, 2016). After proving its usability during the ethnographic work in 2019, a summary of this five-domain framework was published (Bascopé & Reiss, 2021). To build this five-domain framework, we conducted comprehensive fieldwork with a group of five schools and their external communities in 2014 and 2015, covering different territories of the Araucanía region in Chile. Using a qualitative methodology based on in-depth interviews with teachers, traditional educators, families, and indigenous community leaders, we aimed to find suitable sources and topics of local knowledge that might be included in a scientific inquiry-based learning curriculum (Bascopé & Caniguan, 2016). The five domains were produced after a systematization and coding process and compared to the Chilean national curriculum to examine curricular objective coverage at the primary level, revealing many objectives per dimension across the primary curriculum. The following is an overview of how these domains apply to STEM4S projects, based on the experience of 2019:

Health and the human body

This domain connects with several UN sustainability goals, being a fruitful space for connecting global with local challenges. Traditional medicine and knowledge about medicinal herbs are used daily in Mapuche communities, with profound knowledge connected to the native forests and traditional green gardening practices. Therefore, recognizing these traditional sources of knowledge to establish a dialogue with the curricular objectives is a fruitful field to start STEM4S projects. This domain's contents can be developed both inside and outside of the classroom, and they can be supplemented with specific knowledge of native flora and its peculiarities. The chemical processes behind the preparation of the medicines, the importance of the relationship between species for socio-ecological systems' conservation, and the historical struggles associated with the perpetuation of this ancient knowledge are just some examples of the fruitfulness of this domain

Traditional foods and culinary processes

Cooking recipes and food preparations represent another area for profound dialogue between scientific and indigenous knowledge. Processes of dehydration, fermentation, and decomposition of food are linked with different flavors, textures, and techniques that allow food preservation. The knowledge present in the kitchen is intrinsically connected with family traditions and everyday routines. It is a trendy topic for the schools' external community, especially to generate an intergenerational dialogue with a significant presence of grandparents. The elders can share their history and the reasons behind the recipes and dishes that have started to be forgotten due to the scarcity of the ingredients or the replacement of familiar traditions and rituals. Sustainable food consumption and production are at stake, along with health and alimentary sovereignty topics that can be explored and discussed in this domain. It provides a solid ground for creating STEM4S projects giving diverse routes for exploration, all of those with the potential of gaining interest and producing impacts in the community.

Crafts and tools manufacture

Tool manufacture, goldsmithing, and other crafts are connected with local traditions and the ongoing work and expertise of parents in the school community. For example, the dyeing of wool with vegetable species is a traditional practice, and it connects the importance of the local environmental conditions with ancestral sources of know-how that have been losing their strength as working opportunities for the new generations. Same with all the locally relevant manufacturing techniques that use local resources. This is another fruitful field for starting STEM4S projects. It connects local environmental challenges with local and scientific knowledge and provides an opportunity to revitalize ancestral techniques renewing their value and providing opportunities and start new endeavors based on a solid research path conducted by the school in collaboration with the local community.

Ecosystems and agriculture

This could be the more straightforward domain for the implementation of STEM4S projects. It is not about the blind incorporation of traditional agricultural practices but rather about exploring local practices with all the accumulated knowledge on agroecology and sustainable management. Local traditions can be connected with modern agroecological perspectives, allowing learning about traditional practices and combining them with other sources to improve land use and diminish the impacts that traditional practices might have on the ecosystems. The traditional conservation focus of environmental education, which has been criticized in the literature as a "not good enough scope", can be combined with a modern technological solution and complemented with perspectives from the community to provide new ideas for local development. The identification and naming of flora and fauna and local legends about different species and their relationships are all part of previous generations' narratives and can be a significant source of constructive conversation and meaningful answers to local concerns. The soil types found in their territories, for example, will be crucial in deciding the agriculture and varieties of planting to be established, as well as enabling for activities such as pottery, vegetable fiber work, and others, depending on the species found in their territories. This topic also gives space for discussing the importance of biodiversity or understanding the complexity of the ecosystemic balances.

Worldviews and spatial-temporal notions

There are specific ways of measuring and interpreting time to guide domestic work, ceremonies, and other locally-relevant activities. Learning about ancestral calendars and symbolic representations of time are also fundamental aspects to connect and understand the local environment and social characteristics around the educational facilities. These structures are designed to track how much time one spends doing or should spend doing specific activities. Knowing some natural cycles, for example, can help determine the best times of day to do particular agricultural or other traditional activities. In addition, local knowledge about space, the stars, and other signs, that may be related to weather and other social and environmental phenomena is a highly appreciated local knowledge that can inspire motivating STEM4S projects. Furthermore, local worldviews, myths, tales, and oral traditions also reveal the value system of the previous generations, giving sight to the ethical and aesthetic perspectives grounded in the schools' contexts that can contribute to the debate about sustainability. Value-based discussion can help to create a climate of open dialogue and understanding of the moral dilemmas present in the complex sustainability problems that schools face in their surroundings.

Although the five domains presented here seek to connect local knowledge in indigenous contexts with STEM knowledge and skills, it is worth noting that local knowledge should not be trivialized or reduced to scientific thought codes. The inclusion of these topics, on the other hand, creates a place for discourse on historical and cultural issues, which, despite not directly agreeing with the scientific perspective, allows official learning opportunities to be placed in dialogue with other worldviews.

This analytic exercise does not intend universality in terms of covering all possible connections with local knowledge in Mapuche contexts. It is just a way to open the debate about the significant number of possible connections that can be proposed with an integrated and transdisciplinary scope, to open the schools to their territories, complexity, and main problems. It also opens the door to educational practitioners to find routes to transform educational opportunities, generating a real connection of the curriculum with their contexts and creating a space to build small solutions and make contributions to solve actual local and global challenges.

It is important to remark that this is not by any chance an attempt for a comprehensive understanding of the Mapuche perspective. Any attempt will end with a reductionist vision of the great diversity present in the Mapuche community. Instead, this analytical exercise tries to overcome the common essentialisms and provides opportunities to create constructive dialogues to affront real socioecological challenges. The Mapuche context is just an example that can be extrapolated to other indigenous and non-indigenous territories, like schools with high immigration populations willing to work in connection with their communities.

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"Shake the Slinky More": Exploring the Medley of Meaning in Middle School Science Students' Language

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Abstract: Learners routinely struggle to adapt to the rigorous nature of scientific language. Discrepancies between scientific terms and their casual counterparts can create challenges for science communication and instruction. We observed the language used by a classroom of middle school science students as they learned about mechanical waves. We documented instances in which the same language was used to convey different meanings. Specifically, students used "speed" to refer to both velocities and frequencies and used scientific terms like "force," "energy," and "power" interchangeably. The teacher was dedicated to helping students make sense of the meanings behind the words they were using, however, time constraints made it difficult for her to address all the terms. Developing tools and interventions to identify language challenges and providing educators with the skills and resources needed to implement those tools are important tasks for the Learning Sciences.

Introduction

The language of science can be difficult to master. Casual, everyday words can transform into rigid, definitional vocabulary in the physics classroom, sometimes with radically different meanings and connotations (Williams 1999). Experienced physicists have years of practice exercising precision in scientific language. Novices must develop their language practices while simultaneously incorporating novel terminology into their lexicon. Often, physics educators and textbooks will use physics terms without considering the disparity between their technical definition and students' informal definitions. Students then formulate conceptual connections based on how they understand the terms in use, leading to alternative conceptions that can increase the challenge of learning normative science conceptions (Touger, 1991). Student difficulties with language can persist beyond introductory courses; Itza-Ortiz et al. (2003) found that a majority of nonscience majors surveyed in a traditional physics course struggled to articulate the difference between the everyday and formal definitions of words like force, momentum, and impulse. Going further, intermediate physics students who have completed the introductory courses and moved on to more advanced classes still misplace terms and use imprecise language (Arnell et al., 2022).

Refining students' use and understanding of scientific language is paramount to supporting their learning. Linguists have long examined the profound influence language has on cognition (Lakoff & Johnson, 1980). Every aspect of language, from definitions to grammar, shapes the way our minds conceptualize the subjects of our communication (Evans & Green, 2006). Such influences are especially important in science communication, where conceptual models can be encoded by the grammatic and semantic components of language, even when the speaker is unaware of the subtext (Brookes & Etkina, 2007; Talmy, 1988). This work positions the natural language of novices as a window into student understanding; our goal in this paper is to attend to the words used by young learners during sense-making activities and decipher their meaning.

Theoretical framework

The development of the featured instruction and the subsequent analysis of its data were guided by a cognitive perspective called knowledge in pieces (KiP; diSessa, 1993), which views knowledge as a complex network of atomized elements and resources that guide sense-making when activated. Novices tend to both under- and overextend resources due to inexperience, misleading cues, or context. For novices to cultivate expertise, they must gradually reorganize and repurpose knowledge elements and their contextual applications. This view of refinement over replacement makes KiP a constructivist, anti-deficit framework (Smith et al., 1994) and sets KiP in contrast to "misconceptions" perspectives, which label prior knowledge as an obstacle to learning (McCloskey, 1983). Where these perspectives would frame the purpose of instruction as identifying and confronting students' incorrect ideas (Maclin et al., 1997), KiP advocates encouraging students to articulate and reflect on their own thinking (Hammer et al., 2012).

KiP is well suited to analyze the language of naïve learners. In his foundational monograph, diSessa (1993) postulated that primitive knowledge resources would be situated in "areas of strong descriptive (representational) capability" (p. 122), predicting a close relationship between student intuitions and the language they use to describe their reasoning. Later KiP work would refine the methodological considerations for applying the theory to language analyses (diSessa et al., 2015). Redish and Kuo (2015) discuss in depth how KiP and the wider cognitive linguistics field have many congruent tenets, such as conceptualization through bodily experience, flexible application of ancillary knowledge, and context-driven synthesis of meaning. As a language-centric example of KiP, Parnafes (2007) compared the way physics students speak when reasoning about a swinging pendulum or a vibrating spring. Parnafes found students used terms like “fast” and “quick” to refer to both the velocity of the pendulum and the frequency of the spring, despite these characteristics being conceptually distinct. The ambiguity seemed unproblematic from the student’s perspective but presented a challenge for their learning, as the blended concept interfered with their ability to attend to relevant system features. The application of KiP theories to these episodes elucidated both the origin and consequence of students’ language decisions.

Methodology

The data discussed in this paper come from the classroom of one teacher, whom we call Mrs. K, who teaches in a rural middle school in the Intermountain West region of the US. Mrs. K’s classroom had 31 eighth-grade students who worked both alone and in small groups. We partnered with Mrs. K as part of a larger design-based research project to co-design instructional units that engaged students in scientific theory-building practices. This study comes from one unit that scaffolded students’ construction of sound wave models. The sound wave unit covered two weeks and included a wide variety of demonstrations, activities, and visual aids. We draw our observations from one activity, in which the students were split into small groups and given a slinky, which they used to physically model waves. The students were given a worksheet which prompted them to state their predictions, record their observations, and articulate their reasoning while engaging in a theory-building process. We selected two open-ended questions from the worksheet for analysis: the first (Q1) asked the students how they might make a wave with higher frequency, while the second (Q2) asked how they might make a wave with higher amplitude.

Data analysis was done in accordance with knowledge analysis (KA; diSessa et al., 2015), a methodological approach which often accompanies KiP research. KA uses an iterative process of coding which allows patterns to emerge organically from the data. The students’ answers to each question were initially categorized by the language used in each response. These categories were then analyzed to understand how the students were using various scientific terms to represent their underlying reasoning. Video recordings of Mrs. K leading a classroom discussion at the end of the sound wave unit were also collected. These transcripts were reviewed to analyze Mrs. K’s reaction to the students’ language use.

Findings and discussion

Shaking the slinky

The focal activity asked students to stretch a slinky along a table and shake it to create mechanical waves. Q1 and Q2 asked the students to consider how they might alter the frequency and amplitude of the waves, respectively. The most common responses are shown in Table 1, along with a characteristic example.

Table 1

Frequency and Examples of Common Response Categories from Q1 and Q2

	n (Q1)	Q1 examples	n (Q2)	Q2 examples
Speed	7	“Move the spring way faster”	6	“Move hands faster”
Movement	0	*N/A*	8	“Shake the slinky more”
Effort	3	“Use more force and energy”	5	“More force moving the slinky”
Trade-off	4	“Go smaller”	1	“Make waves that are kind of slow”
Precise	2	“More pulses”	5	“Move the spring farther out”

Statements that incorporated the concept of *speed* were the most common response to Q1 (how to raise frequency) and featured prominently in Q2 (how to raise amplitude) as well. This is noteworthy because the physical motions to achieve higher frequencies and amplitudes are distinct: higher frequencies are made by making the slinky perform more wave cycles in a given time, while higher amplitudes are made by moving the slinky farther from equilibrium with each wave. At first, it may seem surprising that students would describe two experientially unique movements with nearly identical language. However, as was experienced by the students, both movements do result in the lateral movement *speed* of the slinky (or the hand holding the slinky) increasing. The tendency for students to use generic *speed* responses for both circumstances is in line with the findings of KiP. Novices have not yet developed the overarching or global connections of experts, resulting in a narrow focus on whatever concepts are deemed most relevant to the immediate problem. This contextual limitation was exemplified by three students who provided *speed* responses to both Q1 and Q2, despite the activities being only minutes apart. From the vantage point of the students, it was irrelevant that their *speed* statements could have also applied elsewhere; the salience and relevance of *speed* within the immediate context was enough to justify its use in describing the phenomenon.

The *speed* answer can be correct in either case, but only conditionally: increasing *speed* would increase frequency only if the amplitude remained constant, and it would similarly increase the amplitude only if the frequency remained constant. None of the students who provided *speed* answers gave these conditions; instead, they categorically provided short, simple answers like “go faster,” “do it faster,” and “move it faster” in both Q1 and Q2. These minimalistic responses were likely perceived by the students as being wholly sufficient. After all, they could see the increased *speed* of the slinky directly causing a change in the properties of the wave. With such an easily observable causal mechanism, further clarification would seem unnecessary. The lack of specificity in the students’ *speed* responses means that these answers have multiple interpretations, only some of which may be correct for a given question. For an instructor attempting to assess the accuracy of their students’ conceptions, such responses could indicate success but could also hide crucial misunderstandings.

Another common response was to use more *effort* when shaking the slinky. This response had the most variation, with statements ranging from the casual “move it harder” to the more scientific “use a greater force and energy” and “more force and power.” These responses seem to be a more embodied version of the *speed* responses, focusing instead on the *effort* needed to grant the additional *speed* rather than the resulting *speed* itself. Once again, these answers are technically correct, but lack necessary precision. Increasing the *effort* used to shake the slinky could increase the *speed*, frequency, and amplitude in any number of combinations depending on the way the *effort* is expended. However, these numerous possibilities for the applications of *effort* were likely not present when the students were reasoning through their responses. Instead, they were merely reporting on the bodily sensation they felt when trying to impact the frequency and amplitude of their wave, and they used familiar language to describe the experience. Notably, the students’ *effort* responses appear to use the terms force, energy, and power somewhat interchangeably. This looseness with vocabulary also reflects the casual relationship the students have to the language used in their responses; they have likely heard force, energy, and power used similarly to describe *effort* in everyday conversations and are applying that informal definition here.

Overall, the students did not appear to struggle with conceptualizing the wave characteristics or how to modify them. In fact, the students showcased a variety of productive resources to explain their experiences; they were merely using accessible or casual language to describe their observations. This informality was seen as the students used identical *speed* language to describe multiple phenomena while also using a variety of *effort-related* language to describe a singular embodied experience. As a result, most responses (34 out of a total 40) were statements that may indicate correct reasoning but lack the precision necessary to interpret meaningfully. Only one student gave an answer that could only be interpreted as incorrect (saying “go shorter” for Q2).

Making sense of students’ language

At the close of the sound wave unit, Mrs. K invited each group of students to reflect on their experiences and summarize the most salient lessons they had come to understand through the activity. Mrs. K asked each group to share one lesson or observation in a class-wide discussion. She added each group’s on the board at the front of the classroom. Mrs. K noticed that several groups’ suggestions had similar imprecise wording. Four groups provided statements which described the relationship between volume and the size of a sound wave, though their language was inconsistent and unclear. Among their responses were “the closer the person is, the sound is bigger” and “the louder the volume, the greater the sound wave.” Mrs. K sought to bring the students’ attention to their use of language, saying “We have people saying things like ‘faster, greater, louder,’ and I’m not sure we’re all talking about the same thing… what does ‘greater the sound waves’ mean and look like?” Students attempted to clarify, suggesting that it meant “there are more waves moving through” and “the waves look bigger.” For each suggestion, Mrs. K offered methods for how the students could verify if these suggestions were valid, such as counting the number of waves in a period of time. If more time had been available, it may have been possible for Mrs. K to review more student responses, recognize these patterns, and address the problem areas. However, as is seen often in secondary education, she needed to move on to keep pace with the curriculum.

Conclusion

Helping novices develop precise language is of utmost importance to science education. Young learners need more experience to comfortably wield scientific jargon in the manner of experts, and so resort to using comfortable or familiar language. In doing so, they may inadvertently sow seeds of misunderstanding by entangling scientific words with their often-dissimilar lay counterparts. To compound the matter, novices should not be expected to be aware of such discrepancies, which means they will go unaddressed unless attention is actively directed to them by guiding experts. Catching these incongruities early and course-correcting is crucial to ensure students' knowledge systems develop in the direction of normative science.

We observed numerous examples of middle school science students using vague or ambiguous language when studying wave mechanics. They regularly gave answers which contained productive elements but lacked the context or clarity to ensure an accurate interpretation. The most prominent example was the students' application of the concept of *speed*, as students simultaneously applied the vague notion of *speed* to refer to conceptually distinct phenomena. The students also routinely used "force," "energy," and "power" interchangeably. When attempting to address the inconsistencies of her students' language, Mrs. K began to help her students disentangle the multiple meanings they were giving their words, however, she did not have sufficient time to allot to the discussion and was forced to move on, leaving a number of language issues unattended.

Misalignments between students' understanding and articulation can create challenges for later conceptual learning. The refinement of student language is an important facet to consider when designing interventions, curriculum, or learning tools. The utilization of KiP frameworks can help researchers identify the many diverse meanings underlying language used by students and locate productive resources for building scientifically precise and appropriate vocabulary.

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Exploring Algorithm Building Through Designing and Making Kinetic Sculpture

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Abstract: Algorithm building, creating a step-by-step procedure to carry out a solution, is a challenging concept for youth to learn and practice. Kinetic sculpture is a novel context for examining how students may learn algorithms through designing and making. As part of a larger study, we collected and analyzed a total of 18 student pre- and post-tests on computational thinking, physical computing, and arts. To examine how students build algorithms in the process of designing and making a kinetic sculpture, we analyze two vignettes from two small groups in a STEAM-based workshop. Findings show that while designing and building kinetic sculpture, students learned computational thinking and applied algorithms by incorporating inputs, outputs, and variables during the process. This study offers a springboard to investigate how students create and apply algorithms in designing and making kinetic sculpture and provides empirical evidence on how students learn algorithms in a STEAM learning context.

Introduction

Computational thinking (CT) includes conditional logic, debugging, distributed processing, and algorithm building (Wing, 2006). In computer science, algorithms are step-by-step responses to problem-solving and used to generate solutions as well as serve as heuristics to design processes to solve complex problems. Additionally, algorithms are identified as a required concept to learn in K-12 computer science (CS) education (CSTA, 2020). Applying algorithms allows learners to create a suitable output for a given input (Denning, 2009). Furthermore, algorithms are primarily explored within CS courses in K-12 schooling (Ciccone, 2021), which creates missed opportunities for developing students' algorithm building in other disciplines or multidisciplinary contexts. In this paper, we define an algorithm as the practice of creating a step-by-step sequence of procedures for carrying out a solution or process.

Studies have examined how students learn CT and algorithm building in robotics and STEM (Ioannou & Makridou, 2018). However, recent studies have shown how students can learn CT more effectively in STEAM-based learning environments than traditional programming activities due to participation of design-based activities (Wang et al., 2022). Kinetic sculpture is a promising application for learning complex concepts in arts, STEM, and computing for college students (Yilmaz, 2014). Sculptures take three-dimensional space, requiring both visual and structural balance. Kinetic sculpture may be designed and programmed to interact with nature, using wind or water to exert force, or it may incorporate technologies like simple crank motors or preprogrammed servo motors and LEDs. As such, interacting with a kinetic sculpture supports the learning of complex CT concepts, such as parallelization (Chowdhury, 2015). However, it was unclear how students learn CT, particularly algorithms, through the process of making and designing a kinetic sculpture. Therefore, we argue that it is compelling to investigate how students learn and build algorithms through designing and making a kinetic sculpture in a STEAM-based learning environment. In this study, we ask: 1. To what extent do students learn CT in making a kinetic sculpture? 2. How do students apply and build an algorithm in the process of designing and making a kinetic sculpture?

Workshop design

Grounded in a constructionist approach to learning through hands-on designs (Papert & Harel, 1991), we understand learning of CT to be both an individual and social process mediated by the design and sharing of external artifacts (Kafai & Proctor, 2022. Additionally, this study is guided by Wing's foundational work defining algorithm building to identify targeted key practices of algorithm building in action in a classroom setting. Kinetic sculpture was chosen because of its promising application for applying complex concepts in arts, STEM, and computing. In our lessons, fifth- and sixth-grade students designed sculptural movement using inputs like sensors, buttons, and potentiometers, and preprogrammed outputs like servo motors and LEDs. Over the course of a 4-day workshop, students started by learning and programming inputs and outputs of their kinetic sculpture with varied variables. Later in the workshop, we gave students freedom to create any abstract or representational design they wished. Creating kinetic sculptures required students to think across multiple domains and apply CT and algorithms to building an original design that moves.

We designed the lessons in this study with consideration of both media arts standards (NCAS) and engineering design standards (NGSS) as well as California computer science standards in two core concepts: 1) Decompose problems and subproblems into parts to facilitate the design, implementation, and review of programs; and 2) Seek and incorporate feedback from team members and users to refine a solution that meets user needs. According to the standards these two concepts centered on algorithms which students create and build step-by-step procedures to solve a problem or carry out a solution. In this paper, we focus on the ways students apply algorithm building by using the components and concepts like inputs (e.g., potentiometer), outputs (e.g., servo motor), and variables (e.g., speed, time) as well as design materials during the process of designing and making a kinetic sculpture. Over the course of the workshops, objectives were sequenced around learning arts concepts through kinetic sculpture and physical computing with the Grove Beginner Kit for Arduino and a block-based Arduino coding platform, Grove Blockly, designed by the research team. Students worked collaboratively to design and create kinetic sculptures by using computational and electrical (e.g., Grove Blockly, servo motors), structural (e.g., cardboard, foamboard), and aesthetic materials (e.g., feathers, colored felt). Students apply and create algorithms, step-by-step procedures (sequencing), in order to solve the problem they identified in iterative design processes. Table 1 shows the workshop sequence and duration.

Table 1
Lesson Sequence and Duration

Day 1	Day 2	Day 3	Day 4
Pre-Test Administered 30 minutes	Group A: Physical computing and coding lesson (identify the inputs and outputs, program LED and servo motor with push buttons and potentiometer) 1 hour, 15 minutes	Group A: Art and design lesson 1 hour, 15 minutes	Combined making: All students making kinetic sculptures (coding, connecting, building); Post-Test Administered 2 hours, 20 minutes
	Group B: Art and design lesson (identify elements and features of kinetic sculpture, plan and design using servo motor or sensor with LED) 1 hour, 15 minutes	Group B: Physical computing and coding lesson 1 hour, 15 minutes	

Methods

This study was conducted in spring 2022 at a charter school in Orange County, California in a combined 5th-6th grade classroom. A total of 25 students participated in the study (and a near equal split of students that identified as girls and boys in the classroom). Based on the results of pre-survey from students, 9 students were White, 6 were mixed race, 2 were Latinx, 2 were Asian, and 6 were other. Most students (over 70%) had no prior experience with physical computing but reported prior arts experiences (e.g., painting, crafting) before the workshop. We used 360° cameras placed next to students in small groups and collected a total of 15 hours and 44 minutes of video across four focus groups (3 dyads, 1 triad). The lesson sequence occurred over four days (see Table 1).

A total of 25 students participated in the workshop and seven were removed from the analysis due to absent consent and incomplete pre- or post-test. To answer the research question, we analyzed 18 students' (M =7, F =11) pre- and post-test to examine the learning of STEAM concepts, focusing on physical computing, CT, and arts on the topic of kinetic sculpture. Particularly, this paper will focus on the results of physical computing and CT to examine students' learning gains on algorithm building. The pre-test included demographic questionnaires and questions regarding prior knowledge on physical computing and arts for researchers to better understand students' backgrounds. We applied paired sample t-tests to examine if there were learning gains from pre- to post-test. Building on the results from pre- and post-test, we then included two vignettes to unpack the ways in which students applied and built step-by-step algorithms with outputs and variables from the processes of design and making. The vignettes included one dyad and one triad group. In this paper, we chose to focus on these groups because, as we reviewed the collective video data, we noticed the unique ways they negotiated sequential design choices for their sculpture including sophisticated decisions around sequencing and problem solving. The video selected is from the final day of instruction where students were finalizing their designs and building their sculptures with minimal teacher-led direction.

Findings

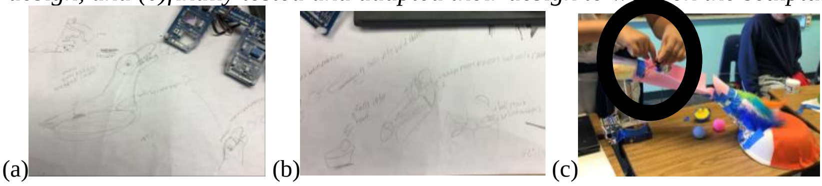
In this study, we explored how students build, develop, and modify algorithms during a co-design process including the use of inputs, outputs, and variables. First, the paired sample t-test results showed that students improved significantly from pre- ($M = 3.83$, $SD = 3.92$) to post- ($M = 17.11$, $SD = 5.32$) test $t(17) = 10.19$, $p < .001$. Particularly, students showed improvement on the questions of CT and physical computing from pre- to post-test. The results indicated that students had better understanding on electrical components and concepts (e.g., servo motor, input, output), computational (e.g., loops, conditional logic) and arts concepts (e.g., shape, form, texture) from pre- to post-test. Ten out of 19 questions focused on CT and physical computing also indicated students' learning on algorithm building, including – describe an output of an algorithm, create step-by-step procedure with inputs, outputs, and variables, and identify inputs and outputs from a step-by-step procedure. The results of the paired sample t-test inform the qualitative analysis to further examine how students apply algorithms with inputs, outputs, and variables during the designing and making processes.

Applying algorithms in design

To understand how students incorporated inputs, outputs, and variables in building an algorithm, we include two vignettes as examples to show how these elements were used in the process of design and making a kinetic sculpture. First, the dyad group with Dolores and Amber (pseudonyms), considered revised their sculpture design for balance and functionality, considering how they could use the motor (output) to "feed" ping pong balls to a bird sculpture, filling its stomach. Vignette 1 shows how the group decided to use the servo motor (output) in their design and then used planning and testing to solve a problem in making the sculpture.

Figure 1

(a)The group modified design drawing of the kinetic sculpture for balance and movement, (b)planned a step-by-step motion of ping pong balls by applying an algorithm with motor design, and (c)finally tested and adapted their design to work on the sculpture



Vignette 1

Line	Transcript
1 2 3 4	**Dolores**: It was originally just going to be the head but then it wouldn't balance great, so then we decided to do the body of it too (see Figure 1 left). When you put ping pong balls up to the motor it goes like right there (indicates the top of the cup shoot; see Figure 1 center, drawings numbered 1 and 2) and then the ball gets, it's like right there, and then when you turn it, it goes in (see Figure 1 center, drawing numbered 3).
5	……..
6 7 8	**Dolores:** (picks up a structure made with a wooden base, 6 inch dowel, paper cup attached on its side, bottom cut out) This is where these (the balls) are gonna come out (moves a ping pong ball to the cup opening). We're going to have a motor and it's going to go through (see Figure 1 right).

Dolores explained to the researcher that they planned to feed balls into the bird's mouth using a separate tower structure with the servo motor releasing the balls as it moved (Line 1-4). However, during the making process, they realized that there was a balance problem with their sculpture, and they decided to give the bird a wider stomach as the base. From there, they designed a step-by-step motion plan as building an algorithm (Figure 1 center; numbered 1, 2, and 3 in the drawing) to illustrate how the servo motor will move and spin, so ping pong balls will fall into the bowl and then tested and adapted their design as they built (Line 6-8). This vignette indicated how the group incorporated a servo motor (output) in their design by applying a sequence algorithm based on the motion of the servo motor in an iterative design process.

Building algorithms in making

In Vignette 2, the group discussed what design materials (e.g., paper bowls, cups) to include for the sculpture and how they incorporated the output components (LED light and servo motor) into the design.

From Line 1-6, Naia identified a problem (weak base) of their sculpture, and Simon provided his opinions regarding the size and weight (variables) of the sculpture design. Linda asked a question about the materials they used which led to the conversations regarding where the servo motor can be placed in the sculpture. Line 9-18 shows how the group made a step-by-step design decision by incorporating the servo motor, LED light, and variables like the size of the materials. Using the servo motor to drive the design of sculpture, the group created a sequence of decision-making in the process of making.

Figure 2

(a)The group discussed the components of their spinning sculpture, (b)The final look of the sculpture

Vignette 2

Line	Transcript
1	Naia: I don't think this is strong enough for the base.
2	Simon: It's not like we're making something big and heavy though, the servo motor is really tiny.
3	Linda: Yeah, we just need it to be big enough to support the (picks up the paper bowl and indicates the sides) (see Figure 2 left).
4	Are we using this for the whole thing?
5	Simon: Yeah, that's what I was thinking.
6	Naia: Um yeah. So this (picks up the paper bowl) would be on top of this (puts it over the small pie tin)?
7	Linda: And then this would spin. [Linda demonstrates the spinning motion]
8	Naia: But then how would that work?
9	Linda: Let's take everything out [Linda dumps balls and pipe cleaners from the bowl] and we could try going like this but then I
10	think that's (a single small pie tin) too small. Oh wait, but then we could go like this, put them all together [Linda places three
11	pie tins in a triangle formation for the base] and then this one would go like [Linda places the paper bowl on top].
12	Naia: Yeah, all of these three can be together.
13	Linda: Yeah but then how do we get the servo motor through there.
14	Naia: We could have the motor going though these (indicates the center of the base) like this.
15	Linda: Yeah I guess that would work.
16	Naia: [picks up the bowl] Or instead of having it spin we could make it with lights.
17	Linda: Simon doesn't want lights.
18	Naia: Really? I think it would look really cool. Okay, Let's start by hot gluing these (indicates the three pie tins) together first.

Discussion

This study aims to explore how students create and apply algorithms in the process of designing and building a kinetic sculpture. At first glance, algorithms seem to be a linear, one-way direction in building a step-by-step instruction toward a problem solution. However, the layer of algorithms can be complex regarding the elements and variables that are used as part of the algorithms. Particularly, the process of design and making are iterative and it is critical for students to review and modify the proposed algorithms to ensure they achieve the desired outcomes. This study not only offers a springboard to understand how students incorporated inputs, outputs and variables in building the algorithm through design and making, but also includes empirical evidence on learning CT and algorithms in a STEAM-based workshop.

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Towards the Design of a Culturally Relevant Curriculum for Equitable, Data Mining-Based CS Education

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Abstract: As both data science and computer science (CS) grow increasingly ubiquitous as a part of professional practice and daily life, efforts are needed to design and implement equity-driven CS curricula that can leverage the affordances of online platforms as valuable and engaging data sources. To this end, this work reports on the systematic design of a culturally relevant curriculum for pre-college students that uses the social media platform Twitter as a source of user-driven big data on real-world contemporary topics. Developed and refined through co-design with teacher and youth stakeholders, the design of the "Coding Like a Data Miner" curriculum consists of four iterative modules that apply an inquiry-based learning approach with different levels of support to guide students through the examination of topics of their choosing using computer and data science techniques. The paper concludes with implications of this work for future CS research and education initiatives.

Introduction

Data and Computer Science (CS) are widespread, and their increasing ubiquity has revolutionized modern society in myriad fields (NSF, 2022). In this landscape, online platforms that make large-scale user datasets available (e.g. Twitter) are a valuable resource for learners to use data science techniques to examine diverse opinions and perspectives on socially and culturally relevant topics (Carpenter & Krutka, 2014). One example of the impact of data science literacy on social media occurred during the COVID-19 pandemic, when computationally savvy content creators significantly impact public awareness (Wu, 2018). This underscores the need for design principles that support data science education consistent with prevailing national calls for CS4ALL (Adams, 2020) at earlier stages of the data science CS education pipeline: pre-college learners who represent the next generation of public consumers. Fulfilling this need not only supports pipeline innovation, but would also create a cohesive and federated infrastructure for the job industries and public awareness, which are quintessential to developing a 21st-century computationally literate and data-capable workforce (NSF, 2022).

Efforts to address this need have flourished in higher education, typically through math and computer science departments (Adams, 2020; Berinato, 2019). Fewer efforts have gained traction in high school (Harris et al., 2017), an age group that shows promise for productive CS engagement (Lee et al., 2021; Hendrickson et al., 2021). Others have cited problems in literature and coursework among pre-college groups, where learners use pre-generated datasets instead of datasets they create themselves that have potential to be more socially and culturally rich (Lee et al., 2021). While exemplary applications exist in research through the use of digitally and culturally-mediated STEAM projects such as e-textiles (Tofel-Grehl et al., 2017), and authentic, socially relevant data science curricula for female high school students (Grover et al., 2022; Alvarez et al., 2022), applications are still needed that connect to students' personal values, culture, and sociopolitical contexts. Such an approach would support equity-driven, constructionist educational praxis by providing opportunities for learners to connect with data science and acquire CS technical skills (Kafai et al., 2020; Fields et al., 2021).

This short paper reports on the systematic design of a culturally relevant computer science data mining and data science curriculum for pre-college students that responds to participation challenges associated with underrepresented groups. This in-progress research and design project was conducted by an interdisciplinary team with expertise in computer science, data science, and learning sciences as part of a CS demonstration and project learning implementation entitled "Coding like a Data Miner" that addresses these issues by providing learners with opportunities to access and leverage big data drawn from social media platforms (e.g., Twitter) to explore real-world contemporary issues. Two groups of teachers and youth co-designers who serve or identify as members of underrepresented groups engaged in two rounds of co-design with the research team to create and refine the culturally relevant data mining and analytics curriculum with the goal of answering the research and design question: What critical learning and instructional resources are needed to productively sustain a CS curricular intervention that emphasizes culturally relevant data mining and analytics?

Coding Like a Data Miner curriculum

The Coding Like a Data Miner curriculum leverages Twitter's application programming interface (API) to teach learners how to gather, process, analyze and then communicate insights learned from big data sets. Learners choose a topic or question, then edit and run Python code to mine tweets from the Twitter application processing interface (API) using chosen search parameters (e.g., hashtags, date) that can address the question. Students then process, analyze, and visualize results from their datasets with the support of slides, worksheets, tutorial videos, and the execution of further Python code using Google Colaboratory (Colab). The project concludes with a final showcase of project outcomes through a variety of potential activities (e.g., news report, website, etc.). All curricular materials are designed to flexibly adapt to the needs and contexts of future participating educators and schools, such as optional introductory slides on data science for students new to CS. Artifacts will be tailored by educators for each class, but may include records of learners' execution of python code on Colab, outputs from code (e.g., analyses, visualizations), written worksheet responses, and students' final showcases (e.g., slides).

Culturally relevant and responsive design

Design of the "Coding Like a Data Miner" curriculum was informed by culturally relevant (Ladson-Billings, 2008) and responsive (Gay, 2018) pedagogies as asset-based perspectives that constructively center diverse learners and the social and cultural assets they bring to STEM (Johnson & Elliott, 2020). From these perspectives, learning experiences start with relevant topics for students and affirm lived, social, cultural, and linguistic experiences (Mensah, 2021). These pedagogies were applied through three primary design features.

First, design emphasized student access to datasets from the social media platform Twitter. In line with Papert's description of accessible learning platforms (Resnick & Silverman, 2005), Twitter provides access to data sources that are innately familiar to existing generations of social media natives (low floors), but also expansive in terms of topics and opinions represented, enabling users to participate along trajectories couched in their personal and ranging interests (wide walls). Twitter users who create potential future datasets are also particularly diverse (Uddin et al., 2014), allowing learners to explore topics from a variety of perspectives.

Second, curriculum development was structured around student understanding and use of Twitter's Application Programming Interface (API): a software intermediary that can allow learners to systematically access and download large-scale datasets of tweets on their personalized needs and interests with search parameters they can tailor and curate (e.g. specific topics, types of hashtags, etc.) (high ceilings). Ultimately, these design decisions were intended to create a sandbox-like environment that empowers learners to go beyond their typical roles as consumers of information, and instead to actively serve as producers of that knowledge on their own terms. Accessing API datasets also requires students to learn and use programming languages, providing an embedded opportunity for the development of practical computer science skills.

The third feature of culturally relevant and responsive design in the project involved the adoption of a participatory approach to curriculum design that invited educator and youth stakeholders to actively share feedback, design ideas, and sample curricular artifacts during iterative co-design sessions. The co-design approach proved valuable as a way to center participants alongside researchers in critical action and reflection on the content of the future curriculum (Bang., & Vossoughi, 2016). Feedback from student co-designers impacted design in terms of content (e.g., pop culture dataset examples for guided data collection activities), difficulty level (e.g., providing different levels of programming complexity), and pedagogical scaffolds (e.g., more in-depth explanations in worksheet activities). Teacher co-designers offered step-by-step guides for curricular implementation and suggested the development of professional development sessions for future educators as part of the application of the curriculum (see www.cs.utep.edu/DataMiner/ for developments).

Modeling authentic data science practices

The initial goal of curriculum design was to position students as data scientists engaging authentically with data science skills, knowledge, identities and values in ways that are self-directed, collaborative, and multi-modal. This aligns with calls for data science-based computing education that leverages humanistic approaches (Lee et al., 2021) to connect CS processes to real-world issues and contexts. Through co-design with youth and educators, a series of typical steps taken as part of data science praxis were identified and modeled through guided activities centered around Twitter data that could be aligned with student and teacher needs and interests (See Figure 1). The first step was characterized as (1) Data Gathering, which includes identifying the appropriate tools (e.g. Application Processing Interfaces), choosing Twitter hashtags or keywords related to a topic of interest, and using those hashtags to mine a sample of data from Twitter. The second step was labeled (2) Data Pre-processing, and involved cleaning, checking, and preparation of sampled Twitter data to prepare for analysis. Next, the curriculum supported student engagement with (3) Data Analysis techniques including assessments of data variability, data variance, and identification of outliers. Data Analysis was designed with flexibility in terms of the complexity level of statistical analyses introduced to adapt to the learning context. Finally, students using the curriculum could engage in (4) Data Visualization using tools to create different models of patterns (e.g. pie chart, word cloud) in their chosen datasets. Curricular design guides students through these four steps repeatedly with different degrees of scaffolding to support the exploration of questions and data they find personally relevant and meaningful from a humanistic perspective.

Figure 1

Design examples from co-designed curriculum for each step of the data science process

1. Context or Interests

   #tiktok, #covid19, #tacotote, #whitesandsnationalpark, #pridemonth, #fitness

2. Socio political Issues

   #schoolsafety, #election2024, #blm, #gunsafety, #roeversuswade

3. Cultural issues

   #elpasostrong, #johnydeep ,# babysharksong, #chihuahuas

N.B. One or more search keywords. For example: @cdcgov.

STEP 5: Visualize the wordcloud

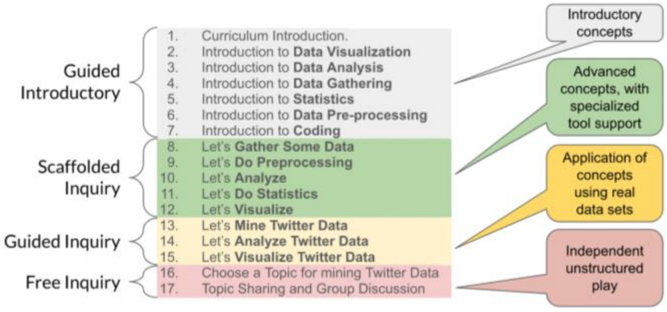
```
[6] plt.figure(figsize = (20,20))
    wc = WordCloud(
        width = 1600 ,
        height = 800).generate(" ".join(dataframe['Text']))
        # change 'Text' to 'Language'
    plt.imshow(wc)
```

Inquiry-based constructionist approach

As students repeatedly engage with the four steps of data science practice, the arc of activities in the curriculum was grouped in to four modules with a learning progression designed to shift from guided introduction and scaffolded inquiry of topics to increasingly open engagement, where learners have greater freedom to choose and carry out pursuits (See Figure 2). The aim of this design model was to provide foundational information and skill development so that students with emerging understanding of data science and CS practices might have access to needed supports, all while gradually shifting students to practices of greater autonomy in data collection, pre–processing, data analysis, and data visualization decisions. Building on the success of existing research on constructionist approaches in CS education (Fields, et al., 2021), four inquiry-based modules also leveraged constructionist design to emphasize real-world, project-based activities intended to empower learners to use their emerging awareness of CS practices to further develop their knowledge and skills.

Figure 2

Structure of curriculum modules to support iterative inquiry-based learning



1. Curriculum Introduction.
2. Introduction to **Data Visualization**
3. Introduction to **Data Analysis**
4. Introduction to **Data Gathering**
5. Introduction to **Statistics**
6. Introduction to **Data Pre-processing**
7. Introduction to **Coding**
8. Let's **Gather Some Data**
9. Let's **Do Preprocessing**
10. Let's **Analyze**
11. Let's **Do Statistics**
12. Let's **Visualize**
13. Let's **Mine Twitter Data**
14. Let's **Analyze Twitter Data**
15. Let's **Visualize Twitter Data**
16. Choose a Topic for mining Twitter Data
17. Topic Sharing and Group Discussion

Conclusions and implications

The goal of this in-progress research and design project is to provide a roadmap of the systematic development of a culturally relevant curriculum for pre-college students that iteratively guides students through CS processes using Twitter data and an inquiry-based, constructionist approach to model authentic data science practices. Detail on the design and development of the curriculum is intended to serve as a potential model for future practice on (1) how to extend learner engagement with data beyond consuming and navigating information to producing their own interpretations and meanings, and (2) how to connects CS activities to culturally and personally relevant real-world issues and contexts from a humanistic perspective. Research and development is ongoing; future work will involve piloting the curriculum with underrepresented high school student groups in the South Central United States to explore what learning experiences and outcomes result when implementing a CS education program that emphasizes culturally relevant data mining and analytics.

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Data Comics: Using Narratives to Engage Students in Data Reasoning

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Abstract: Comics are a familiar art form that has been underexplored as a tool for data-driven storytelling in K12 classrooms. Making data comics provide an opportunity for students to contextualize data within a visual style and narrative structure. This paper focuses on the second-year implementation of an interdisciplinary curriculum in seventh grade classrooms with one art and one math teacher. Students compared sample data from a national survey conducted by Pew Research Center, a nonpartisan US-based think tank, and data taken from their own survey on friendship perceptions and experiences. Students created comics based on those data using Pixton, a digital comic-making tool. Our study asks: *How do students' use narratives to demonstrate different kinds of data reasoning?* Thematic analysis of 47 data comics revealed the ways students constructed narratives, showcasing how the comic-making process cultivated students' reasoning around data and their informal inference-making skills.

Introduction

As data becomes increasingly central in youth's social lives, there is a pressing need to connect data reasoning to their lived experiences. However, the way youth learn about data is often disconnected from its context leading to a simplification in how data is created, situated, and perceived. In recent years, approaches to statistics education have focused on developing students' informal inferential reasoning, or reasoning about claims that generalize beyond the data and represent limitations through the language of uncertainty. Generalizing beyond the data requires an understanding of the data context (Pfannkuch, 2011; Wolff et al., 2016), including characteristics of the environment and people represented or affected by data, as well as how the data were generated—i.e. the study design and how variables were defined and measured (Pfannkuch, 2011).

Narratives can facilitate communicating about and with data through supporting elaborations and integration of context as students reason around data (Knaflic, 2019; Lund, 2022). Comics, in particular, act as syncretic texts by providing a visual and narrative structure (Bach et al., 2017) that supports learners in exploring personal connections to data (D'Ignazio & Bhargava, 2016) and leveraging students' lived experiences, cultural perspectives, and local ecologies (Gutiérrez et al., 2020). In this current study, we present findings from the second year of co-designing a seventh-grade arts-integrated data literacy unit. The unit engaged students in making comics that examine personally-collected data about friendships and Pew Research data on teens and technology. Students practiced data analysis skills such as graph reading and proportional reasoning, while creating digital comics to communicate stories about and with the data. The primary research question guiding this study was: *When creating their own comics, how do students' use narratives to demonstrate different kinds of data reasoning?*

Methods

Participants in this study included 84 seventh graders from three classes in a public middle school in a large urban area in the Northeastern United States. The team of four researchers and two middle school teachers, one who taught math and another who taught art, met over several months to design and plan the data comic unit that teachers then implemented in their classrooms in Spring 2022. This unit was the second iteration of a data comic unit that was initially implemented in Spring 2021 (Year 1) with the same art and math teachers (Vacca et al., 2022). Based on feedback from the math teacher, we aimed to incorporate more targeted scaffolds for mathematical reasoning, which she felt was largely missing from students' data comics in Year 1. We amended the curriculum to include opportunities to reason about proportions and make predictions when comparing two samples. To scaffold this process, the co-design team developed worksheets that guided students through the calculations of sample proportions prior to creating their final data comics. The data included students' responses to a 32-item survey about their friendships that was adapted from a national study conducted by Pew Research

Center on teens' views on friendships, technology, and social media use (Lenhart, 2015). Students analyzed and interpreted graphs from the national survey and compared these to findings from their grade and classroom data.

Our data set included 47 student-generated data comics; incomplete data comics were excluded from the analysis. In order to answer the question of *how do students use narratives to support different kinds of data reasoning*, we first identified the types of data reasoning represented in students' comics. Drawing from the literature on the central concepts and practices for data literacy and informal inference-making, we coded for instances of describing data, situating an instance of the data, comparing, predicting, making meaning (connecting to the real world), reasoning why, and questioning the validity of data (Franklin et al., 2020). Additionally, we used narrative coding, which applies literary devices and conventions to qualitative, story-based texts such as comics (Saldaña, 2021). In the narrative codebook, these categories emerged: non-narratives, data inquiry (meta-narrative), vignette, exposition, and narrative arcs which are described in Table 1.

Table 1
Codebook for how narratives from students' data comics were categorized

Narrative Codes	Description
Non-Narrative	May include data but does not have any storytelling elements related to the data
Data Inquiry or Meta-Narrative	Where character is involved in the data investigation or inquiry process (e.g., ask questions about the data; discusses how data was collected)
Vignette	Includes a short sketch to demonstrate context and instances of data, which can work as standalone frames; however, vignettes do not tell complete data stories on their own.
Exposition	Contains storytelling elements other than vignettes (e.g., context/setting, character backstories, plot, etc.) but does not have a complete story arc.
Narrative Arc	Has a story arc that contextualizes the data within a problem and resolution (e.g., plot involving the data)

Findings

Students reason with data through lived experiences and real-world contexts

Students demonstrated different kinds of data reasoning in their comics. About 87% of the comics were identified as *describing data* in which they described, explained, or reported descriptive statistics, including percentages and measures of center, by having characters speak directly to the audience or with other characters. In Panels 4, 5, and 7, the main character explains the pie charts embedded in the panels, which were based on data from the survey question: "In a typical week, how often do you get together with friends online?" (see Figure 1). Approximately 79% of the data comics went beyond this description of data by illustrating specific data-contexts—i.e. placing characters in real-world situations to make sense of the data—this type of data reasoning was coded as *situating an instance of the data*. In Figure 1, Panel 1 sets the scene and context of the data. The narrator explains how being "a busy student" competes with time spent with their friends introducing the audience to a specific context and identifying online apps on which they communicate with their friends. In some cases, students went beyond the data and began to make inferences. They *made meaning* by sorting through implications and consequences of the data (15% of the data comics), provided *reasons why* the data looked the way it did (51% of the data comics), and questioned the soundness and *validity of the data* (13% of the data comics) by asking about its source, reliability, or whether the data was an accurate representation of how kids their age feel about friendships. In the comic in Figure 1, the narrator provides a reason why they believe there were differences between the two samples as evidenced in the caption at top: "Difference in the population sampled". Lastly, as exhibited in Panel 5, the narrator begins to question the validity of the data as they discuss the degree of its accuracy: "These statistics would be more accurate due to the larger sample size".

Students used different types of narratives to support their data reasoning

In Figure 1, each frame represented in Panels 2 and 3 included *vignettes* that showed how the character spends time with their friends by doing homework together on Zoom (Panel 2) or keeping themselves accountable online so that they can meet in person after their homework is done (Panel 3).

Figure 1

This comic excerpt highlights data reasoning skills through vignettes and data inquiry

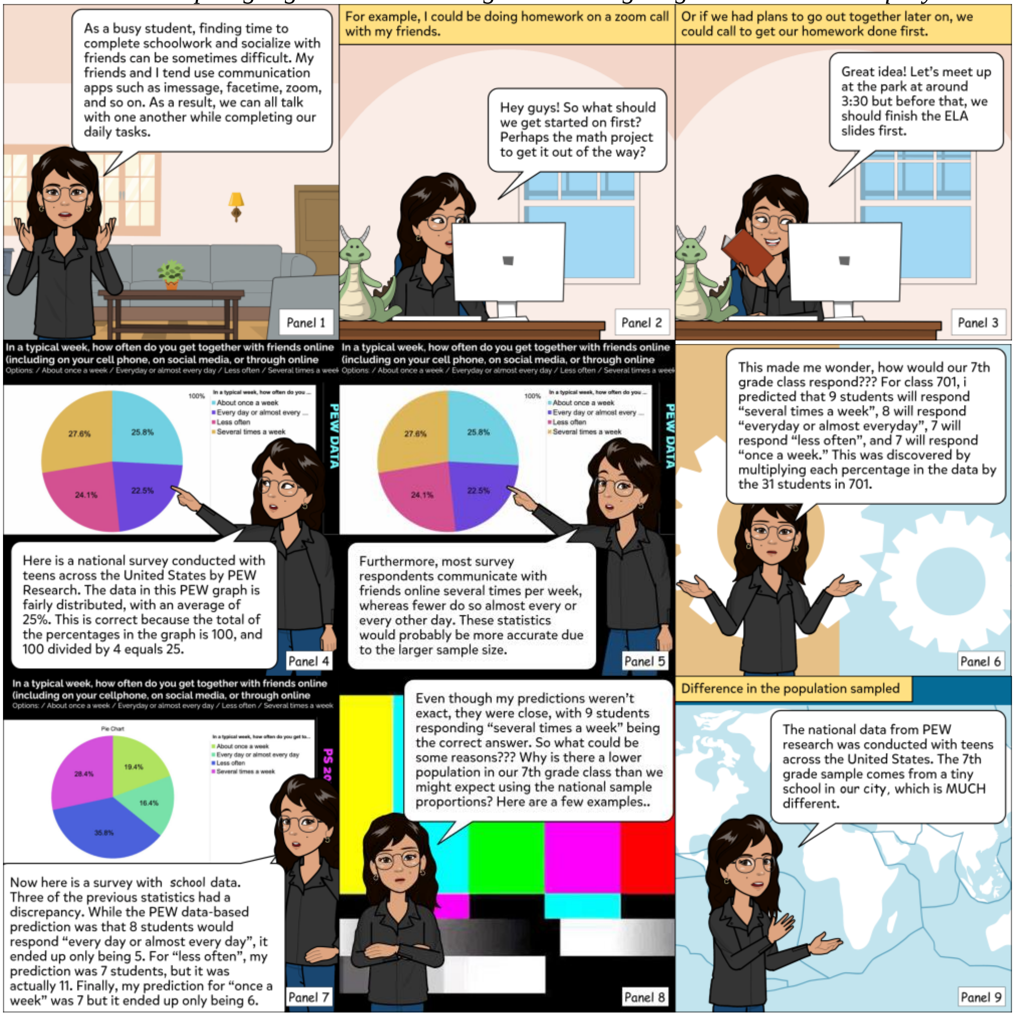

Table 2

Heatmap comparing frequencies of data reasoning by narrative type

Narratives **Data Reasoning**	Non-Narrative	Data Inquiry (*Meta-Narrative*)	Vignette	Exposition	Narrative Arc	**Total**
Describing	9	17	18	2	7	**53**
Situating Data	4	16	17	2	10	**49**
Makes Meaning	1	4	5	0	1	**11**
Reasoning Why	3	12	12	1	5	**33**
Data Validity	0	3	6	0	0	**9**
Total	**17**	**52**	**58**	**5**	**23**	**207**

The comic in Figure 1 was also identified as a *data inquiry* (see Table 1 for narrative codebook description), since the narrator discusses the survey and questions how the data were collected (Panels 7-8). Across the 47 data comics, students engaged in different kinds of data reasoning by integrating different storytelling elements as evidenced in Table 2. For comics coded as *data inquiries* or *meta-narratives*, there were

17 instances of *describing data*, 16 counts of *situating an instance of the data*, 4 instances of *making meaning* beyond the data, 12 counts of *reasoning why*, and 3 instances in the data comics where characters began to question the *validity of the data* (Table 2). In particular, *vignettes*, which were the most prevalent of the storytelling elements used by students, provided more opportunities for students to elaborate on their conceptual understanding of the data. Finding a *narrative arc,* where students create a story that contextualizes the data within a plot, was not as common. One explanation for this might be that comics written with a *narrative arc* require a level of abstraction from the data–moving beyond the given data–where students at the early stages of statistical thinking will eventually reach. The findings suggest that, more often, when creating their own data comics, students in our study reasoned with data through *vignettes* and *data inquiries*, positioning themselves directly in the data exploration process (e.g., making explicit the process of data collection and survey administration), and in some cases, characters became data detectives.

Conclusion

Narrative construction, specifically the use of comic creation, affords students opportunities to contextualize data using their own lived experiences in ways that support informal inference making. While some students used the comics to explain their data reasoning, other students used the comics to construct narratives that connected the mechanics and procedures of making predictions to broader contexts of variability within data and relationships between variables which is the basis for more advanced statistical thinking. Future work may focus more explicitly on how scaffolds can guide students to move from data explanations to richer narratives that further contextualize data and wrestle with issues of variability, related data relationships, and validity using their lived experiences and funds of knowledge. It seems apparent that this, like any artistic and interdisciplinary process, needs to be iterative, and perhaps serves as a jumping off point for further discussion, where explanations, elaborations, and discussions become the heart of students' conceptual and contextual understanding of data and leverages their lived experiences.

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The Expansive Framing of Engagement Survey: Instrument Validation Insights From Confirmatory Factor Analysis

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Abstract: *Expansive framing* is a situative instructional approach hypothesized to promote learning transfer. The Expansive Framing of Engagement survey measures students' perceptions of their engagement to explore the relationships between expansively framed instruction, learner engagement, and learning outcomes. Building on a prior exploratory factor analysis (EFA), confirmatory factor analysis (CFA) was used to validate the theoretical alignment of the survey's hypothesized factor structure. The initial analysis yielded evidence of strong internal consistency for all six scales (alphas ranging from 0.77-0.87) and suggested collapsing two of the hypothesized six factors into a single factor. Following the initial findings, the results of the CFA for the five-factor model structure yielded an acceptable model fit with *CFI*=0.929, *TLI*=0.909, and *RMSEA*=0.091. A second CFA was conducted with six-factor model specification and yielded slightly better model fit with *CFI=0.939, TLI-0.917,* and *RMSEA=0.087*. These findings support our expectations of theoretical alignment with the expansive framing principles.

Introduction

Online learning has influenced the higher education landscape for decades (e.g., Castro & Tumibay, 2021; Wallace, 2003). Opportunities to take online courses expanded rapidly during the COVID-19 pandemic, and the discussion of corresponding issues and challenges have expanded accordingly (e.g., Dhawan, 2020). But the point that Kozan and Richardson argued in 2014 remains: Extended research is needed around *specific* theories of learning in online contexts to maximize the quality of online learning opportunities. In this light, the situative framework for expansive framing (Engle et al., 2012) may offer a useful lens through which to study online course design and the experiences of students taking fully online courses. Expansive framing insists that students should problematize course content from their own perspectives and experiences.

We designed the Expansive Framing of Engagement (EFE) survey to gather evidence of expansive framing in online courses. This work presents an alternative to the well-known *Community of Inquiry* framework and survey (CoI; Arbaugh et al., 2008). The CoI framework and survey concern the three *presences* (*social, cognitive,* and *teaching*) that Garrison et al. (2000) used to define a socio-constructivist framework for online education. The hypothesized factor structure of the CoI survey has been strongly validated (e.g., Swan et al., 2009; Kozan & Richardson, 2014). Numerous studies have used the survey to study the three presences in online courses and to document their (almost always positive) correlations with learner satisfaction and *perceived* learning outcomes (e.g., Stenbom, 2018).

Despite validation and widespread use of the CoI survey, there is no evidence showing that increased perceptions of presence from the CoI survey are related to *actual* learning outcomes (see Rourke & Kanuka, 2009; Maddrell et al., 2017). An underlying assumption of our research is that perceptions of expansive framing may be more strongly associated with actual learning outcomes than those of the CoI framework. The EFE survey promises to support future studies to test the hypothesis that expansive framing is more strongly associated with learning outcomes than *expert framing* (i.e., when course content is framed from the perspectives of instructors and other established sources of authority; Itow, 2020).

Further validation and refinement of the EFE survey is necessary if it is to be used to study engagement and learning outcomes in online course contexts. Following Kozan & Richardson's (2014) approach to validating and refining the CoI Survey, this study follows up the exploratory factor analysis (EFA) reported in Hickey et al. (2021) by carrying out confirmatory factor analysis (CFA). These responses were gathered when a proposed EFE survey was included as experimental items in an administration of the National Survey of Student Engagement (NSSE). Future administration of the refined survey will explore the relationships between expansive framing and other constructs of interest, including constructs measured by other scales included in the NSSE survey.

Expansive framing

Expansive framing emerged from situative views of learning and transfer (e.g., Greeno, 1998) and Engle's (2006) examination of how *framing* of learning impacts transfer. Engle (2006) studied aspects of engagement that supported transfer through the lens of *intercontextuality* (e.g., Floriana, 1993), which is attained when learners form numerous connections between their prior experiences, the learning environment, and future transfer contexts. As elaborated in Engle et al. (2012), instructors can foster intercontextuality by pushing students to find personalized connections with people, places, topics, and times outside of a given course context and by positioning learners as authors of disciplinary knowledge at these intersections, rather than as passive consumers of that knowledge. Engle et al. (2012) contrasted expansive framing with *bounded* framing, where instructional frames are tied to a given learning setting at a given time, which may constrain future transfer. Engle et al. (2011) experimentally showed that learners in expansively framed tutoring sessions demonstrated dramatically stronger transfer than learners in bounded tutoring sessions that positioned learners as "spokespersons" for disciplinary resources. Hickey et al. (2021) argued that by focusing on three forms of *presence* rather than learners' connections with contexts beyond the course, the CoI framework is relatively bounded and less likely to support learning that transfers readily.

Engle and colleagues (2012) offer five testable explanations of why expansive framing should support transfer: (1) Learners expect that they will use what they are learning in future settings, which leads them to adopt more effective and more active learning strategies; (2) Learners view what they have previously learned as relevant as they engage in potential transfer opportunities, which helps them recognize those opportunities; (3) Learners view previously learned knowledge as consequential for current learning. This leads them to *transfer-in* relevant prior knowledge during initial learning; (4) Authoring content in the learning environment leaves learners with more confidence using (i.e., authoring) that knowledge in the transfer environment; (5) Authoring content repeatedly in the learning environment generalizes to future experiences, leaving learners more confident authoring new knowledge in new contexts (including actively generating and adapting new knowledge).

Systematic reviews (Harris et al., 2023; Freedman et al., 2023) confirmed that the expansive framing principles have been used in dozens of peer-reviewed studies. But other than Engle et al. (2011), there is little evidence supporting these compelling theoretical explanations of expansive framing and no other experimental or quasi-experimental evidence from studies comparing expansive framing with other engagement strategies in face-to-face *or* online settings. The EFE survey aims to lay the groundwork for such studies.

Expansive framing survey instrument

The EFE survey builds on the original survey of expansive framing that Engle et al. (2011) created for their tutoring experiment in a face-to-face high school biology classroom. The 16-item EFE survey was created to represent six scales associated with expansive framing (*time:past*, *time:future*, *other places*, *other topics*, *roles:authoring*, and *roles:accountability*; the 16-item limit was imposed by NSSE policies for experimental items). These scales were designed to capture the degree to which students experience each of Engle and colleagues' (2011, 2012) design principles for fostering expansive framing (i.e., the extent to which students perceive opportunities to make connections between course content and people, places, topics, and times outside the bounds of their coursework, position themselves as authors of disciplinary content, and hold themselves and their peers accountable for defending their interpretations of disciplinary ideas).

Method

This data was collected from student responses to the experimental items of the EFE survey included in NSSE in 2019. Among the included respondents, 6,452 fully online college students completed the 16 experimental EFE survey items on the survey. Of these, those who completed all items (6,200 participants) were included in Hickey et al.'s (2021) initial EFA and were retained for the CFA.

We extended the EFA in Hickey et al. (2021, conducted using odd-numbered respondents) which suggested collapsing two of the scales (*time:future* and *other places*) into a single factor. We split the response set and conducted a CFA with five factors on the even-numbered responses to validate the hypothesized factor structure and its alignment to the elements of expansive framing. Since the initial EFA suggested that six factors could *potentially* be present in the response set, we ran an additional CFA on the even-numbered responses with a hypothesized six-factor model specification that separated *time:future* and *other places* into two distinct factors.

Results

The CFA for the five-factor model yielded acceptable fit (x^2=2511.21, df=94, p<.01). The results for comparative fit index (CFI) and Tucker-Lewis index (TLI) were both greater than 0.90, and the Root Mean Square Error of Approximation (RMSEA) was less than 0.10. This suggested adequate fit for the model with *time:future* and *other places* collapsed into a single factor (*CFI*=0.929; *TLI*=0.909; *RMSEA*=0.091; Levesque et al., 2004).

The CFA conducted with six-factor model specification also suggested adequate model fit (x^2=2181.933, df=89, p<0.01). Notably, the results for this six-factor specification indicate slightly better model fit according to both the comparative fit and Tucker-Lewis indices, as well as the RMSEA (*CFI*=0.939; *TLI*=0.917; *RMSEA*=0.087), compared to the five-factor model. We hypothesize that NSSE's 16-item constraint hindered the model fit by requiring us to eliminate items from certain scales—resulting in some scales with three items and others with two. Further, these findings indicate that a six-factor model with *time:future* and *other places* separated into two different factors provides a slightly better model fit (as opposed to collapsing the two into one factor as in the five-factor model specification above).

These findings align with our theoretical expectations that *time:future* and *other places* should represent two separate factors. It is certainly plausible that learners could make connections between course content and other places, in which they encounter those other places in future times (and in which case the two factors would collapse into one). But we contend that learners are more likely to make connections to other places that are not specifically bound to *future* times. Rather, we assume that they are more likely to make connections to other places that they have encountered during the past, present, *and* future, and even to places with which they have no specific timeframe association (e.g., other places they have never encountered nor envision themselves encountering in the future). This assumption is grounded in Engle et al.'s (2012) view of intercontextuality where learners participating in expansively framed course settings recognize connections between disciplinary content and their own social contexts without bounded framing imposed by their instructors.

The confirmatory validation offered by these results—taken together with our earlier results showing evidence of correlations between the survey scales and perceived learning gains—will contribute to the refinement of the EFE instrument. Further refinement will help researchers explore students' perceptions of framing of course interactions and activities and the relationships between framing and outcomes, especially when this survey is administered alongside interviews with students enrolled in fully online, hybrid, and face-to-face courses.

Conclusion and next steps

Given that the 16-item constraint imposed by NSSE required that two of the EFE survey scales have only two items, we find these results encouraging. Interpretive analysis of the items in the two scales that failed to diverge in the initial EFA results suggests that these items could be reworded to make them more distinctive for respondents (specifying, for example, that learners' envisioned connections to *other places* are not inherently embedded within *future times*). With the rewording and the addition of one more item to each of the two-item scales, we will administer the expanded 18-item survey to students enrolled in online courses. In the longer term, we plan to administer the revised survey to students in online and face-to-face courses, and to explore the relationships between perceptions of expansive framing and various indicators of learning transfer, achievement outcomes, and other NSSE scales associated with academic engagement.

Given the continuing expansion of online course options in higher education, the burgeoning market for fully online degree programs at both the undergraduate and graduate levels, and the widespread challenges presented by emergency remote teaching and learning at the beginning of the COVID-19 pandemic, it is more important than ever to invest in research and development of online learning innovations and to explore students' perceptions of online course features that may promote transfer and other desired outcomes. Given the massive (and sometimes, seemingly, exclusive) reliance on the CoI survey, we belief that the EFE survey has the potential to support theoretical diversity and advancement in studying online learning. Results from future broader use of the EFE survey in targeted online contexts will also contribute to future research seeking to support the implementation of expansive framing in remote learning settings.

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Ecological vs. Construct Validity of Persistence in Game-Based Assessment

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Abstract: Persistence is a well-defined construct that has been researched in various contexts; technology-enhanced learning environments, such as games, have been successful at providing evidence for construct validity of feature-based measurements of persistence. However, questions arise when considering whether these construct valid interpretations align with teacher expectations and understandings that would be considered ecologically valid. By investigating a subset of co-design sessions that teachers participated in to develop analytics and visualizations for persistence in a game-based assessment called Shadowspect, this paper explores the tensions between the two types of validity.

Introduction

Game-based assessment (GBA) has the capacity to simultaneously generate instruction and assess learning in a performance-based and process-oriented way situated in simulations of authentic contexts (DiCerbo, Shute, & Kim, 2017). GBA has shown to be successful at supporting and measuring various academic domains (Klopfer & Thompson, 2020) as well as non-cognitive skills, such as persistence (Kim et al., 2022) and creativity (Chuang et al., 2015; Kao et al., 2017). While GBA has shown to be effective at measuring "soft skills" or "21st Century skills" (Shaffer & Gee, 2012), these skills are deemphasized in school-based education compared to standardized testing (Shute & Becker, 2010) leading to relatively little focus on working with teachers to both incorporate these skills into instructional time and assess students to foster their growth. Thus, questions arise as to how teachers might use such assessments in their classrooms.

These questions led to our interest in understanding the utility of a game-based assessment of persistence, Shadowspect, in classrooms. Shadowspect was intended for mathematics classrooms to assess spatial reasoning skills, one of the foundational skills that has high predictive power for later involvement (and ultimately success) in STEM fields (Uttal & Cohen, 2012). However, the game also was designed to incorporate elements which would lend it construct validity for assessing persistence. Construct validity is well-documented for persistence (Ventura & Shute, 2013), but in working with teachers to co-design a learning analytics dashboard for Shadowspect, we recognized that there was potential for misalignment with the ecological validity of teacher's needs. This work serves as an example of how learning science scholars may begin to reconcile these discrepancies and continue pushing our work to align to the contextual realities of the classroom.

Operationalizing persistence

Construct validity regards to what extent the assessment measures what it intends to measure (Trochim & Donnelly, 2001). Repeated measurement and validation of persistence in technology-enhanced learning environments provide evidence for construct validity in future implementations. Yang et al. (2018) included features related to challenges learners face: number of reattempts to unsolved problems, proportion of difficult problems attempted, and time spent on resources after failure. Ventura and Shute (2013) investigated construct validity of persistence in a puzzle game using time spent on unsolved problems over all player events over the five sessions. Similarly, DiCerbo et al. (2014) measured persistence in a game using four features per quest: time spent on quest events, number of quest events completed, maximum time spent on an individual quest event successfully completed, and time spent on the last event prior to quitting. The algorithmic metric measuring persistence in Shadowspect draws on these earlier examples to ensure construct validity.

By investigating applications of assessment tools in natural real-life settings, one can investigate to what extent these measures are ecologically valid (e.g. Krolak-Schwerdt et al., 2018). It is well-documented how teachers' use of validated assessment tools in practice can vary across contexts, and this discrepancy is likely to amplify when and how the construct is being defined and operationalized. This tension between what the research team could build, a persistence measurement algorithm based on the validated features and definitions in the literature, and what teachers see as useful and actionable in their own contexts leads us to the following research question: How do ecologically valid teacher perspectives on measuring persistence in a mathematics educational game compare to the metrics and algorithm designed with construct validity in mind?

Method

Educational game context

Shadowspect is a 3D geometric puzzle game that was intentionally designed to assess spatial reasoning skills, persistence and common core geometry standards using the evidence-centered design framework (Kim et al., 2016; Mislevy et al., 2003). The primary mechanic of Shadowspect includes players arranging various 3D geometric primitives to match perspectives along three axes. As players move the shapes around, they are constantly comparing their current perspective with that of the shadowed "goal" (Figure 1).

As players move through the game, the levels build on additional constraints by either removing shape types (i.e., having to complete the puzzles without cubes) or limiting the number of figures players can use (i.e. only being allowed to use 4 shapes total). These added constraints push students to construct more creative solutions as they must reassess the utility of certain shapes. A cone, for example, may serve the same purpose that a cylinder and prism did previously. Levels become intentionally challenging; scaling difficulty beyond the threshold of student capacity has the affordance of allowing students to demonstrate persistence.

Figure 1

Shadowspect players move figures around a platform to match snapshot perspectives.

The silhouettes hint that some objects will need to be rotated 45 degrees.

There is no way to move the camera to view this assembly as a vertical cross.

You can add 0 more objects

Measuring persistence in Shadowspect

Gameplay in Shadowspect is captured via an event logging system. Events were categorized into three sources: game, task, and player. Game events include the logistical events of beginning and ending gameplay as well as assignment of user information. Task events include puzzle specific events: screen changes (moving from a menu into a puzzle), starting and ending a puzzle, and restarting a puzzle. Player actions are most diverse capturing every move that a player may take.

These events were then aggregated through multiple iterations to identify metrics that both aligned with prior research and helped to describe differences in student gameplay. Because students were participating in play alongside teacher participation in dashboard co-design, their gameplay could be compared to one another, thus percentile aggregates of several features were calculated based on all students' gameplay. For example, instead of using the raw number of events from level X in models, the student's play would be compared to how many moves each student made in level X to yield a percentile. This also allowed for the combination of metrics into similar weights for use in the persistence assessment algorithm (See equation below).

Analyzing and understanding teacher perspectives

Eight teachers participated in a co-design process of building learning analytics and dashboard for Shadowspect over the course of 12 months, in 2021. All 10 co-design sessions were conducted via Zoom due to Covid-19. All meetings were recorded and transcribed for analysis, and activities and artifacts were digitally preserved.

The research team conducted a thematic analysis of teacher verbal and artifact contributions to understand teacher's perspectives on Persistence. Transcripts were filtered for all conversations that were relevant to persistence, and each reference was identified as belonging to a current theme or creating a new one. Once all of the transcript references and design artifacts were reviewed, we began to whittle the themes to the most salient thoughts teachers were voicing especially attending to features which connected with the algorithmic measurement of persistence. In our analysis, we provide a summary of the teacher's perspectives as a description of ecological validity for persistence and offer a comparison between the ways they envision persistence operating in practice and how Shadowspect's persistence algorithm provides insights.

Analysis

In this analysis, we begin by outlining the features of the persistence algorithm used by Shadowspect to assess students before contrasting the teacher's description of persistence as they would utilize it in their classrooms.

Construct valid assessment of persistence algorithm

Persistence is measured in Shadowspect at the granularity of a given level attempt. The student-based, per-level features incorporated into the metric include the level's difficulty, student's active time, number of actions, and number of times students checked their solution. Additionally, puzzle difficulty, which was determined a priori by the design team, is included in the final, weighted average which aggregates performance across puzzles:

$$\boldsymbol{Persistence} = \frac{difficulty_i \quad \frac{percentile\ active\ time + percentile\ \#\ of\ events + percentile\ \#\ solution\ checks}{3}}{\sum_{i=1}^{n} difficulty_i}$$

Percentiles are used for active time, number of events, and number of solution checks because they standardize the relationship between the three metrics. They are also specific to the population of students who participated in the sample; the percentiles are between players on a given level, not between one player on many levels. Shadowspect's persistence algorithm aligns with prior work in the way it selects features from player data.

Teacher perspectives on difficulty

Difficulty was one of several metrics used in the persistence algorithm that were revoiced by teachers during the co-design workshop. They noted that there is a zone before students quit where difficulty might showcase a student who is being persistent in conjunction with other metrics: "Like, some of these levels, like 14, you know, this looks like great persistence to me. Like, you know, they spend a good seven and a half minutes working hard on this level, and then succeed on it and move on."

However, not all teachers thought of difficulty as a puzzle characteristic as the Shadowspect team had. Instead, teachers were interested in honoring the way difficulty is perceived by the student. Low difficulty was important for explaining low persistence scores in context, if "they had zero failures, [...] they're not gonna get a strong persistence score." Difficulty needed to be thought of relevant to the student's perception.

Activity through time, moves, and solutions

Time was able to give definition to how teachers made sense of multiple aspects of student behavior. One teacher asked, "So, is that a way that we could try to break down what persistence looks like? Time spent on a puzzle, time spent before trying something new, whatever. Versus, here are the actions that I'm actually using to try to show my persistence." Other teachers wanted more specificity for what time represented. One method of representing time was to only consider times when the student was active because, "total time isn't necessarily a good indicator of, of production." The teachers valued production as a basis for persistence.

Moves serve as a proxy for production in the algorithm, but teachers noted that the sheer number of moves might not be enough to classify a student as being persistent: "I don't think somebody could tell me that a kid made 15 moves, and I would know from 15 moves whether those were an indicator of persistence or not. Like, what 15 moves was it? Was it 15 moves of them just spinning the same shape 45 degrees? 'Cause then, that's not persistence, that's just time-wasting." This became an important distinction for teachers. They wanted to be able to interpret the meaning behind aggregates, to uncover the nuance that differentiated productivity and wasting time. Persistence seemed less important if it meant "sitting there working on the same puzzle, bashing your head against the wall." Unproductive persistence was associated with struggling for extended periods of time, and teachers wanted to ensure that students were still making progress in the game, "'cause it's one thing to not demonstrate persistence, but to also never solve anything." Solution checks seemed like one way to tell if students were moving ahead, although in implementation the metric muddies the water between students who are successfully completing (low numbers of solution checks) and those who are struggling or time wasting. Ultimately, teachers reached similar conclusions to the developers suggesting that is may be beneficial to "weight the persistence score also by whether or not it was completed successfully."

Discussion

In this paper, we review the similarities and discrepancies between an algorithmic assessment of student persistence which was designed with construct validity in mind and teacher perspectives regarding the utility of persistence as a metric in the classroom. Overall, the teachers valued similar aspects of student gameplay to the algorithm: amount of action, time spent working on the puzzle, and attempts. However, we also identified several ways in which these perspectives were misaligned. Namely, the level of personalization demonstrated by the features feeding into the algorithm was not at the level that teachers believed would be useful. It also seems that teachers needed to be able to see the components of the algorithm to make sense of the outcome.

Tensions appear between data science practices and the practitioners that their products are intended to serve. The metrics practitioners ask for are not always feasible for implementation even if they would generate a better model for practical use. For example, attempting to derive the difficulty of each puzzle for each player may be possible, but it would not be efficient for creating a metric that teachers could act on in the moment. Similarly, adding specificity about type of move or distribution of moves might have improved the persistence model, but it would have involved a more nuanced metric, specific to a given level.

This study presents a key limitation in that we have not yet presented a means to operationalize the teacher's thinking to find a middle ground between construct and ecological validity. It seems that a critical component of the process includes testing cases of each iteration to determine if a given algorithmic model is close enough to meeting the ecological validity of classroom implementation while not losing its connection to construct validity. A more comprehensive study of algorithmic use in practice or through case vignettes (Krolak-Schwerdt et al., 2018) may be helpful in identifying alignment issues beyond our isolated examination.

The work of educational assessment has often used construct validity as the gold standard for design, but this has led to minimal adoption in classroom due to the disconnect with what teachers need in practice. As learning scientists, we must not lose sight of the forest for the trees. Broadening the scope of our understanding of how our work manifests in context with stakeholders can help identify and bring forward questions on how construct and ecological validity work in tandem and in conflict in our respective areas.

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Data in the Wild: An Exploration Into Hobbies as Contexts for Data Literacies

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Abstract: This research investigates the data practices of two hobbyists who have learned to recognize and take action with data in self-directed and goal-oriented ways. Drawing from research on data literacy and informal learning, a conceptualization of hobbies is used to attend to the contexts and voices of non-professionals who routinely engage in sophisticated data practices in activities that occupy large parts of adult life and, yet, are largely absent in discussions of data literacy. We draw from two interviews in which Astrid, a video gamer who enjoys playing Massively Multiplayer Online Role-Playing Games (MMORPG), and Tony, a musician who enjoys playing his guitar for others, describe how they have learned to recognize and use data for the enjoyment of participating in their respective hobbies.

Introduction

Data literacy represents a growing area of interest among researchers and educators, especially as discussions around growing fields, such as data science education, continue across professional spaces. Entangled in these discussions exists a tension in how data should be positioned in schools (D'Ignazio & Bhargava, 2020). While some researchers have focused on the technical skills involved in data literacy, others have called researchers to critically attend to the personal (Pangrazio & Selwyn, 2019), theory-laden (Hardy et al., 2020), and situated (Jiang et al., 2022) nature of data. In part, the presence of data generation and data use in virtually every aspect of society has demanded an examination of how people come to understand and use data as they produce it across contexts. The subject of this demand includes not only how experts, such as scientists and engineers, analyze and interpret data, but how non-experts and non-professionals actively and routinely integrate and use data in their everyday lives; this includes how they make sense of current events (Calabrese Barton et al., 2021), worldwide pandemics (Radinsky & Tabak, 2022), or life-threatening conditions (Lee & Dubovi, 2020). While some research has begun to examine and speculate around the situated nature of data literacy, many voices and contexts remain absent in these discussions. These include the data literacies that are lost to the mundane (Pink, et al., 2017) and everyday routines (Kennedy, 2018) that are obscured in plain sight. This study adds to this burgeoning area of research by exploring how two hobbyists learned to use data in self-directed and goal-oriented ways.

What are hobbies?

To describe both hobbies and the learning that occurs within them, we draw from two theoretical lenses. First, hobbies are defined from an informal learning perspective (Rogoff et al., 2016) as activities that are non-didactic and both personally meaningful and interesting to the learner. Engagement in a hobby is driven by the hobbyist's care for the activity (Azevedo, 2013) rather than by occupational or academic demands. Second, hobbies are historically established activities that perpetually develop within and across larger communities. This conceptualization of hobbies emphasizes participation as self-directed while also attending to the larger social structure of the activity. We hope to give voice to the contexts and practitioners who have developed and deployed ways of producing and using data in activities far from those found in occupations or schools. Thus, this study examines *how and why hobbyists produce and use data in relation to their hobbies*.

Methods

Context and study design

This study reports the findings from two semi-structured interviews that were conducted with participants who identified themselves as using data in their hobbies. Recruitment occurred in two ways. First, recruitment posts on general and specific hobbyist forums were made in collaboration with forum moderators, and second, snowball sampling was included as a recruitment method for additional participants. Each interview lasted approximately 60-minutes and followed a semi-structured interview design in which questions for data use and hobby participation were developed in advance of the interviews alongside potential follow-up questions.

The intent of this study is not to generalize results to larger populations but to explore and compare the reasons and conditions hobbyists attribute to their data practices and to make explicit the history of their experiences with data. A case study design is used because it affords the comparison of similarities and differences within and across cases (Moss & Haertel, 2017).

Participants

The two cases presented in this paper are of two hobbyists, with the pseudonyms Astrid and Tony, who identified data as being useful in their practice. The first hobbyist, Astrid, is a 32-year-old logistics operator who has an extended history playing Massively Multiplayer Online Role Playing Games (MMORPG) as his hobby of choice. MMORPGs are video games in which players control online avatars in a virtual world. These characters generally have swappable clothing, armor, skills, and weapons. This case focuses on how Astrid learned to use damage-per-second (DPS) as a quantitative metric to help them defeat challenging foes in a popular MMORPG. Astrid learned to manipulate various factors involved in the production of DPS in order to optimize the number they produced. Astrid discusses how the use of quantitative and qualitative forms of data can be effectively used to evaluate their own performance and the performance of others.

The second hobbyist, Tony, is a 29-year-old retail manager whose hobby is playing guitar for the enjoyment of both himself and others. Tony began playing at the age of 11 and has had extensive training from teachers. Although he is no longer enrolled in formal lessons, Tony continues to challenge himself with music he enjoys. He also performs for local audiences and with other musicians. In terms of data, this study focuses on how Tony uses beats-per-minute (BPM) and video recordings as quantitative and qualitative metrics to assess progress. These forms of data have continued to help him through challenges in learning new, enjoyable music.

Analytic method

The analysis for this study uses a qualitative coding approach to generate codes, categories, and ultimately descriptions of each case. This process was iterative and involved discussions with other members of the research team. The interviews were first transcribed and read through as a process of familiarization. Initial ideas were developed through memos, and a subsequent round of In vivo coding was conducted to retain the voices of each participant. This process allowed us to identify how participants were describing and using data in relation to their hobbies. We then traced each type of data and associated practices through each interview, which was necessary as each participant mentioned different data practices and different forms of data.

Findings

The analysis of both interviews produced three central findings related to data use. These findings are presented with excerpts from both hobbyists in order to make explicit the similarities and differences between how and why both hobbyists use data.

Data practices are shaped by communities

Astrid and Tony attributed their initial data use to individuals they met as they pursued hobby specific goals. To Astrid, who plays an MMORPG as a hobby, using data came from interacting with senior players who were engaged in difficult, yet desirable, content. They recounted, “I was specifically wanting to play some harder and more difficult content. So I would say it started off with mimicry, you know, doing what other people did and then doing it so often that it got to the point where I started recognizing the data.” To Astrid, data use started as a social practice for evaluating performance, typically in the form of DPS, that was taught to them by experienced players. They continued, “it became less of a community thing and more of a now I know how to do this…. [I] start looking for what exactly I wanted out of the game and uh, what data to use to kind of get me there.” Although data were initially byproducts of Astrid’s interactions with others, data evolved into an integral part of their practice.

Tony learned to measure BPM at an early age when learning to play guitar. He attributes this practice to his guitar teacher, saying, “[My] guitar teacher taught me to register a certain BPM and a limit for myself. And then pushing that limit and recording the BPM to make a comparison.” Learning to recognize BPM as a source of data has helped Tony in learning to play his guitar. In fact, while he has not had formal guitar lessons in years, he has continued to integrate BPM into his practice, saying, “So now-a-days if I have a metronome going, that’s a way to kinda analyze where my starting point [is] and how fast I can progress as far as BPM.” Like Astrid, Tony’s use of data started as a lesson from an experienced player and quickly became interwoven in his practice. In the cases of Astrid and Tony, the lessons of recognizing and using data developed from interactions with other practitioners, and these interactions had a lasting effect in shaping their participation.

Data are a source of feedback

In examining how both hobbyists used data, similarities and differences were discovered that situate data in the uniqueness of each hobby. For example, Astrid described the process of testing methods for maximizing performance as an important practice of data use, saying, “A lot of video games produce numbers…. When I’m coming up with the DPS build, trying to test things is how to maximize my output [DPS].” To Astrid, the process of testing a “DPS build” refers to revealing how a specific combination of items and skills equipped by their character are reflected in the character’s total DPS. Put differently, Astrid actively manipulates various inputs in their character’s performance to produce DPS. This process involves pressing different skills at different times or using different gear modifiers. Astrid stated, “I see if changing which skills to use in what order might change the numbers.” This led Astrid down a path of testing how to accomplish their goal: “I go in and actually test the DPS and that produces another data, which is I did that much DPS at that point.” The act of figuring out how to maximize their DPS involved the production of a new dataset. In many ways, the goal of playing harder content became a goal of optimizing performance, and data were the central and necessary components to how Astrid played the game.

Tony described the way he integrated BPM into his practice, saying, “I will play for five minutes on whatever BPM is comfortable, and then jump it up by five bpm. This difference isn’t really noticeable to the ears, but it’s very noticeable to the hands.” Tony described using this method of practice for every song he is interested in learning to play. During this process, Tony described the potential for encountering trouble while learning to play particular styles of guitar. Consequently, he would record himself with video data to further interrogate the issue: “If I’m really struggling then I can go to the video recording to kind of get a visual on what I’m doing. It is much different when seeing yourself from a completely different angle.” While difficult to capture in any one quote, Tony noted that the use of video data was only necessary if he had identified an issue using BPM, such as a plateau in his performance. Looking across cases, Astrid and Tony had independently developed a system of data use that involved multiple forms of data. Both hobbyists were using data as a source of feedback in developing their skills.

Data are felt phenomena

An important distinction so far between Astrid and Tony relates to how they experience the production of data. Throughout the interview, Astrid went into great detail concerning how they felt in relation to the data they were producing, saying, “There are definitely times where I have been way more angry about a video game than I should have been just from viewing data of me underperforming. You know, it’s frustrating.” Astrid continued by describing how these emotions became so intense they had to stop using data for a short period of time, “I just stopped paying attention to the data. I had to do that for a few weeks. I had to cool myself off for that.” Apart the unpleasant emotions Astrid experienced, there were instances of pleasant emotions around their general data practice, “It can also be very satisfying when you do hit the numbers.” From Astrid’s description, the interpretation of data appears more than a cold, mechanical process; it seemed to amplify and create emotional experiences that were partly different from the actual hobby Astrid was experiencing.

To Tony, emotions were equally present in how he described his data practices, saying “It feels really good when you can nail something at the correct tempo or build to it very quickly and see how far you’ve progressed.” Writing down the BPM gave Tony a way of seeing himself progress over time. Conversely, experiencing stagnation leads to feelings of disappointment and frustration, saying “being frustrated on the other end. it is very frustrating and kind of drive me back to other styles [of playing].”

Discussion and conclusion

This study examined how two hobbyists learned to produce and use data for their respective hobbies, and three findings were discussed. First, Astrid’s journey with senior players and Tony’s music lessons highlight the importance of communities in fostering data literacies in hobbies. For both hobbyists, the integration of data was a byproduct of engagement with others, which fundamentally shifted how both Astrid and Tony. These cases provide a reminder of the profound effect data literacies have in shaping people’s future activities. We can see in Astrid’s description that this integration fundamentally shifted how they experienced other MMORPGs: Optimizing performance became a way of approaching other games. Similarly, Tony continued to record and measure BPM despite not participating in formal lessons for many years.

A function of data in informal contexts is to provide feedback on how hobbyists make progress toward their goals. Astrid modified their character gear and skill rotation to optimize DPS, and Tony evaluated progression and technique using BPM and video footage. The production of performance data brought about a process of problem identification that led to the creation of new forms of data. Tony and Astrid used the forms of data they created to troubleshoot issues related to their performance and to develop their skills in self-directed ways.

Furthermore, Astrid and Tony cared deeply about their performance and this passion had implications in how they used data. Both hobbyists expressed frustration as well as satisfaction from using data, and in both cases, there were changes to how data were being used: Astrid needed to stop using data entirely for weeks because of their frustration while Tony was driven back to familiar styles of guitar playing by frustration with the lack of progress.

The cases of Astrid and Tony provide only a limited perspective into how data literacies can involve social, technical, and personal experiences. However, more research is needed in understanding the influence data use has in directing future participation and in shaping future experiences. Similarly, more research is needed in exploring how we might support hobbyists and learners alike in managing the emotional and personal impact of data.

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Signals of Teachers' Readiness for Change in Next Generation Science Professional Development

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Abstract: Change in the domain of education is complex. Research has begun to uncover factors that influence the success of proposed initiatives. This paper examines factors influencing science teachers as they wrestle with implementing innovative teaching practices. We present a theoretical framework that unpacks a construct we call *signals of readiness for change (readiness signals).* We define readiness signals as elements of teachers' talk that signal a teacher's sentiment toward a proposed initiative. Signals often reflect tensions that must be resolved for initiatives like the Next Generation Science Standards to succeed and endure. These tensions exist in teacher beliefs, confidence in their ability to implement innovative practices, and motivation to invest in change. The investigation of readiness signals adds insights into struggles surrounding the adoption of change in education.

Introduction

The Next Generation Science Standards (NGSS) urge educators to radically transform the way they teach science. To help teachers shift their classroom practices to align with the NGSS vision, researchers and educators have introduced teachers to the new standards through professional development (PD). Despite the learning this PD supports, many teachers struggle to implement innovative NGSS-aligned curriculum in their science classrooms. The tensions teachers experience between traditional science teaching practices and NGSS standards are significant (Shelton, 2021). A shift to NGSS practices requires change at multiple levels and across multiple dimensions (Holt & Vardeman, 2013). Teachers communicate their feelings on the change being asked of them through a myriad of signals. We call these signals: *signals of readiness for change*, or simply, *readiness signals*. This paper examines the readiness signals teachers communicated during a PD focused on creating NGSS-aligned lessons featuring computational modeling activities. We present a theoretical framework that identifies the tensions teachers experienced during the PD. The framework can be used to identify readiness signals, which can be examined to understand teachers' change aptitude, or their inclination and ability to change. Comparing counts of positive and negative readiness signals can provide a measurement for change aptitude. We use Epistemic Network Analysis (ENA) to understand how positive and negative readiness signals co-occur, as a measure for change aptitude.

Understanding the tensions

Teachers work in complex epistemic frames, or ways of knowing in a community of practice (Shaffer and Ruis, 2017). In these frames, the rules that shape their actions and the norms they use to interpret classroom interactions can be established at legislative, district, administrative and personal levels. Common educational epistemic frames have practices that include preparing lessons, delivering lectures, and proctoring assessments. Current research suggests that experiences where students explore phenomena and define their own problems provide richer learning. When teachers attempt to implement innovative research-aligned approaches, the new approach can create tensions for teachers as the rules and norms can require significant shifts in time allocation, teacher, and student roles, and evaluation. Phillips et al. (2021) used Epistemic Network Analysis to show complexity in the teacher decision-making process by illuminating co-connections between tensions. We suggest that readiness signals can capture the tensions that arise when teachers are pressed to adjust rules or norms in their epistemic frames. The overarching goal of this work is to use *readiness signals* to help education leaders identify tensions that need to be addressed before innovations such as the NGSS can be successfully implemented. The specific research questions to be addressed in this paper are:

- What readiness signals do teachers communicate with respect to proposed innovations, when engaging in professional development around NGSS?
- Do our partner teachers' *change aptitudes* shift after participating in PD?

A framework for assessing aptitude for change

Our work began in the summer of 2020 working with three middle school science teachers in a 4-week synchronous online professional development (PD). The purpose of the PD was for teachers to create and implement novel science curriculum where students construct their own computational models of phenomena. Throughout the training, various remarks from the teachers regarding their thoughts and feelings implementing the novel curricula caught our attention and raised questions about their readiness, or aptitude, for the change we were asking of them. Words connected to their ability, beliefs, and motivation showed up repeatedly in the teachers' utterances. These themes were expressed at the following levels: personal, students, other teachers, the school, and the education system requirements. Some of the facets emerging in our data were mentioned in the change readiness literature (Rafferty et all, 2013). Yet the current change frameworks, mostly focusing on corporate change, failed to represent all the elements found in our science education data. Thus, we integrated frameworks (Bandura, 2001; Grenny et al., 2013) to produce a framework featuring the elements we saw in our data.

Bandura's (2001) framework provided an initial characterization for the emerging readiness signals in our data. Self-efficacy, belief, ability, and motivation appeared to be critical factors for teachers' willingness to innovate. While Bandura's perspective shows the multidimensional influences surrounding agency, the research of Grenny et al. (2013) clarified that ability and motivation must be present at personal, social, and structural levels for individuals to adopt change. Our framework provides a guide for taking a deeper look into the complex system of abilities, beliefs, and motivations associated with the adoption of innovative practices in science education (Jones & Swanson, 2022). The vertical levels in our framework are personal, school (students, staff, administration), and education system. The horizontal dimensions are abilities, beliefs, and motivations. This guide is meant to support reflection and discussion that uncover tensions in how the dimensions intersect, which can then be considered and addressed.

Methods

Participants

The inspiration for this work came from the teachers' talk during a 4-week summer PD with daily meetings conducted by two of the authors. The participants, Katie, Mary, and Rebecca (pseudonyms) were science teachers working at middle schools in a Western United States city with 25, 7 and 17 years of experience, respectively. Katie and Rebecca taught at the same school. For the summer PD, they attended daily online meetings, created lesson plans, and worked with software developers to co-design computational models on a topic included in one of their lessons. Participants explored how they might integrate NGSS practices such as developing and using models, asking questions, conducting investigations, and constructing explanations.

Data sources

As part of the PD, we held daily morning meetings via Zoom to build team connections and to get a daily read on how everyone was doing. The conversations and activities provided an opportunity for teachers to communicate their feelings on the innovations they were being asked to implement. Video recordings of these meetings were transcribed using Otter.ai. Transcripts from Week 1 and Week 4 discussions were analyzed to understand teachers' readiness signals at the start and end of the PD. The themes of Weeks 1 and 4 were different. Week 1 focused on introductions, relationship building and exploration of new teaching goals, classroom interaction norms, and instructional activities. Week 4 focused on curriculum development, feedback, revision, reflection and integrating these new goals, norms, and activities into their classrooms.

Procedures

This study takes a deep dive into the details of the teachers' talk during the PD. It explores their reactions to the new ideas, pedagogies and practices associated with creating and implementing computational modeling lessons. The analytical procedures occurred in four steps.

Step 1. Codebook creation and code refinement

We began with a previous iteration of our framework (Jones & Swanson, 2020). To test and refine the framework, we used it to code readiness signals in the PD data. Utterances were determined by a change in speaker and each one was evaluated for instances of the nine specific readiness signals. The revised codebook is presented below (Table 1). The codebook operationalizes the theoretical framework by specifying the kinds of language associated with each of the nine signals.

Table 1
Readiness signals codebook

This table is meant to be used when the subject of a conversation is proposed innovations or change, and the teacher has communicated a reaction to it.	
Personal change signals—Check to see if the statements use personalized words like I, my, we, us, or ours.	
BP	**Belief**, Does the person convey interest, hope, belief, doubt, or disbelief about doing something?
AP	**Ability**, Does the person provide some indication that they are able or not able to do something?
MP	**Motivation**, Does the person provide some indication that they are overwhelmed, hesitant, or stressed?
School change signals—Check to see if the statements discuss students or school personnel. *School* includes students, staff, and administration.	
BS	**Belief**, Does the person indicate that students or school personnel convey disinterest, disbelief, or doubt about doing something?
AS	**Ability**, Does the person indicate that students or school personnel are able or not able to do something?
MS	**Motivation**, Does the person indicate students' or school personnel's willingness to do something?
Education system change signals—Check to see if the statements discuss something like standards, expectations, time, or requirements. The education *system* includes state legislators, district leaders and principal.	
BE	**Belief**, Does the person indicate that the system supports or makes it difficult to do something?
AE	**Ability**, Does the person indicate that the system is able to accommodate to these changes?
ME	**Motivation**, Does the person indicate that the system will adapt to allow them to do something?
Positive or negative - Are the statements communicating a predominantly positive or negative sentiment?	

Step 2. Establish inter-rater agreement and code data

To check for bias in the coding, we trained a person not associated with the research using 3.3% of the data. Codebook revisions, coding practice, comparison and discussion were conducted to reach the desired interrater reliability with a Cohen's kappa of 0.65. The first author coded the remaining data using the revised codebook. Each turn of talk was evaluated according to the nine questions and whether the readiness signals had positive or negative sentiments.

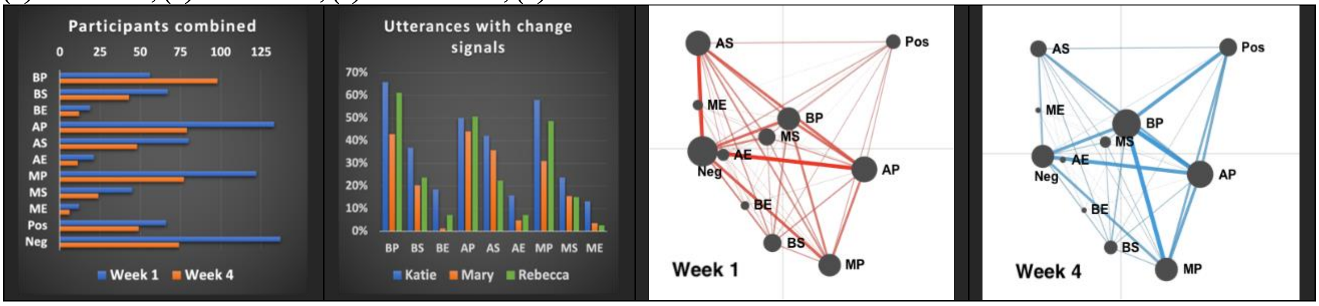
Step 3. Understand shifts in readiness signals

We used Epistemic Network Analysis (ENA) to quantify the readiness signals in teachers' language and illuminate their co-connections for each week. ENA uniquely provides the ability to visualize multiple readiness signals communicated by the teachers, the occurrence frequency (line thickness), and number of connections being made (network density) (Shaffer & Ruis, 2017). By visualizing a teacher's network of readiness signals at different points in time, ENA provides a way to detect subtle shifts in change aptitude.

Findings

What readiness signals do teachers communicate with respect to proposed innovations, when engaging in professional development around NGSS? To answer these questions, we counted all instances of readiness signals demonstrated by each teacher for Weeks 1 and 4. We counted positive and negative remarks for each week to see if teacher's aptitude for change shifted from the first to the fourth week of PD. From the combined participants chart (Figure 1), we can see that eight readiness signals dropped in number, but personal belief (BP) increased. We can see that even though the number of negative change signals dropped greatly, negative signals still outnumber positive signals by about 30%. In Figure 2, which shows utterances featuring readiness signals, we can see that all three personal signals -- belief (BP), ability (AP), motivation (MP), and ability school (AS) -- appeared in a higher percentage of the spoken utterances than the other change signals in both weeks.

Figure 1
(a) Combined, (b) Utterances, (c) ENA Week 1, (d) ENA Week 4



Do teachers' change aptitudes shift after participating in the PD? Comparing Figures 3 and 4 shows some shifts in positive connections. The network density from the positive node in Week 4 has decreased yet the strength of the connections co-occurring with all three personal signals (BP, AP, and MP) has increased. An aptitude shift is happening but not across all signals. The negative node maintains dense connections in Week 4, yet some of the links have decreased in frequency. These co-occurrences tell us that teachers continue to evaluate and communicate the challenges they face in adopting these new teaching practices. Readiness for change in the areas of personal belief, ability and motivation have a stronger presence in the conversations.

Limitations

The limitations of this work recommend areas of focus for future work. First, there might exist interpretation bias with a small number of coders. Future studies could follow up with participants, discuss the readiness signals, and address misinterpretations. Second, since the sample size is small, we did not check statistical significance in the analyses and could not validate patterns in readiness signal shifts.

Discussion and conclusion

We have taken an in-depth look at the discussions that occurred during the first and last weeks of a month-long NGSS-based PD that urged three educators to radically transform the way they teach science. We illustrate the feasibility of using our theoretical framework to explore potential tensions in teachers' adoption of curricular innovations. The readiness signals framework helped us see the complexity of teachers' thinking and decision making when introduced to innovative educational approaches. These readiness signals can indicate teachers' feelings towards proposed innovations. The data show an increase in positive readiness signals from the first to final week of a PD. Still, a significant number of negative signals suggest lingering concerns regarding the incorporation of these new norms and practices into their classrooms.

This work provides a framework for assisting those involved in educational innovation. The framework directs attention to readiness signals that communicate teachers' hesitance with adopting change. We have shown that our signals of readiness for change framework is a useful tool for uncovering the kinds of things teachers are considering when faced with the request to innovate in their classrooms. Our investigation of readiness signals can assist innovation leaders in better seeing their group's own readiness for change. Our data reveal that teachers are concerned about changing roles (i.e., teacher to facilitator), gaining new skills, leading learning experiences without seeing exemplars, and facing unknown outcomes that may not work. Teachers experience confusion around the meanings of different standards and their priorities. They struggle to choose what to spend time on and how much time to give each topic. It is our hope that discussions across all dimensions in this framework can help us move science education forward in new and productive ways.

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How Kinetically-Held Gestures Support Collaborative Problem Solving in Physics

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Abstract: Embodied forms of communication like gesture are essential for problem solving, but we know little about how they are used in group interactions. Drawing on ethnomethodology and conversation analysis (EMCA), we examine how undergraduate physics students use the *temporality* of gesture to orchestrate productive interactions: Using *kinetically-held* (frozen in place) *gestures,* students (1) recruit attention, (2) mobilize responses, (3) weather interruptions, and (4) facilitate extended consideration of elaborated and clarified ideas.

Introduction & theoretical approach

Collaborative problem solving in STEM engages students in productive disciplinary practices and knowledge building (e.g., Engle & Conant, 2002; Roschelle, 1992), but learning outcomes of groups are contingent on the quality of their interactional processes (Barron, 2003; Roschelle, 1992). The learning sciences have documented many interactional resources students use to coordinate interactions during collaborative STEM problem solving, including strategies for releasing tension (Sohr et al., 2018), managing uncertainty (Conlin & Scherr, 2018), and navigating off-task behavior (Langer-Osuna et al., 2020). While we know much about productive forms of *talk* that are conducive to generative collaboration, less is known about how gesture helps orchestrate productive group interactions. In this study, we examine how undergraduate students use the *temporality* of gesture to coordinate collaborative physics problem solving. In particular, we show how students use *kinetically-held gestures* (Kendon, 2004) – suspended representational gestures – to support productive group interactions.

Detailed, mechanistic examinations of interaction are crucial to understand sources of variability in collaboration and how outcomes emerge (Barron, 2003; Koschmann & Zemel, 2009; Roschelle, 1992). Roschelle (1992) illustrated how students must carefully monitor and repair shared understandings in group work: collaborators must not move on from proposals until they have sufficient evidence of shared understanding. Barron (2003) discovered another key interactional characteristic: based on how *responsive* students were to each other's verbally shared proposals, equally competent groups performed dramatically differently on problem solving tasks. Unsuccessful groups ignored, interrupted, and rejected (correct and incorrect) proposals before they were elaborated or clarified. We ask, how might representational gestures shape these interactional processes?

Representational gestures, which illustrate objects and processes (Kendon, 2004), are especially useful for collaborative STEM work because students use their hands and bodies to work out, model, and make sense of scientific and mathematical phenomena together (e.g., Alibali & Nathan, 2012; Roth & Lawless, 2002; Scherr, 2008; Singer et al., 2008; Walkington et al., 2019). An understudied affordance of representational gestures is their temporality. Participants can control how a gesture evolves *over time*. Representational gestures have distinct phases: (a) a *preparation* where the hands leave a resting position, (b) one or more *strokes* that carry semantic information, and (c) a *retraction* where the hands resume rest. A *gesture hold* occurs when, after a stroke is completed, the hands *do not* return to a rest position but remain frozen for a period of time (Kendon, 2004). Holds both illustrate content and project information about participation or turn-taking. They are used to mark turns-in-progress that speakers intend to resume after speech disfluency (e.g., a pause to find the right words), interruptions, or because a speaker struggles to gain attention (Park-Doob, 2010; Sikveland & Ogden, 2012). Holds can also be used to mobilize responses from participants, e.g., by demonstrating the speaker's expectation that a listener should supply an answer to a pending question (Kendon, 2004).

Study context, methods, and findings

We examined 11 groups of 3-4 students completing 4 problems from the Collaborative Learning through Active Sense-Making in Physics curriculum (Potter et al., 2014) in an undergraduate physics class (25 hours of video). We identified 100 instances of group members' use of representational gestures where representational gestures were held for more that 1.0 second. All groups used holds. We selected a single interactional sequence to present representative examples of *each* of the different interactional functions of kinetically-held gestures in group work we observed in our collection. Our EMCA-inspired microanalysis traces the temporality of representational gestures, including their preparations, strokes, holds, and retractions to reveal how holds are coordinated with other semiotic resources to organize interaction. Our transcripts adapt (1) Jefferson's conventions for talk*;* (2) Mondada's conventions for gaze, facial expression, and body movement: -- *extended duration,* --> *action continues;* and (3) Kendon's conventions to annotate gesture preparation, strokes, holds, and retractions:

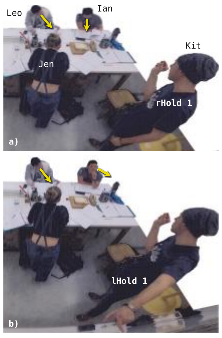
preparation phases ~~~, *strokes* ^^^, *held gestures* ***, and *retractions* -.-.; *beginning and end of phases* are denoted with |. Symbol sequences illustrate the timing of gesture phases, aligned with co-occurring speech syllables and other semiotic activity. Each gray box shows a set of vertically aligned co-occurring semiotic resources, and speech tracks are aligned horizontally to show sequential turns. Gesture is marked in blue, speech in black, and other activity in gray.

Kit, Leo, Ian, and Jen are working on a problem that requires them to model a toy car launcher with a spring inside that gets compressed by the same distance each time a car is loaded. This distance indicates the amount of energy stored in the spring. When the car is launched, the spring decompresses. The energy in the spring is converted to kinetic energy of the car, which is released with a certain initial velocity. Students are asked if *all* cars will have the same launch speed. Kit turns to the group with a proposal: The initial distance should be *greater* than zero, and the *final* distance should be zero because the spring is initially compressed and must return to its relaxed state as the car is being accelerated. Kit's proposal is consistent with the convention that the energy in a spring is zero when it is not compressed or stretched.

Figure 1

Using a representational gesture hold to recruit attention

```
01  kgestrh: ~~~~~~~~~~~~~~~~~~~~~~|^^^^^^^^^^^^^^|********
                    rPrep              rStroke     rHold 1
02  gaze:    Ian, Jen, & Leo looking at their notebooks-->
03  KIT:     SO::-
04                 (0.2)
05  IAN:                °What’s ou┌r thing for a ┌spring?°
06  KIT:                          └ACTually      └no:-
07  kgestrh: ***********************************
                           rHold 1
08  igaze:   @Ian’s notebook------------------>
09  KIT:     (..0.4..) With the spring the fir-
10  kgestrh: ********************************************
                               rHold 1
11  kgestlh: |~~~~~~~~~~~~~~~~~~|*************************
                   lPrep                     lHold 1
12  igaze:   @Ian’s notebook-------------------->looks up
13  KIT:     the initial should be greater than zero.
14  kgestrh: ***************************************
                             rHold 1
15  kgestlh: ***************************************
                             lHold 1
16  igaze:   @Kit---------------------------------->
17  KIT:     It's not at equilibrium. (....0.6....)
```



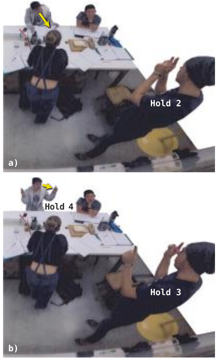
Barron (2003) observed that unsuccessful groups often have issues with *recruiting* each other's *attention* to joint problem spaces (Roschelle, 1992). Making sure a proposal will be adequately considered and understood means ensuring that it is not ignored. Kit turns from the board to his group, making a bid to share a proposal. He begins with "So-" (E1.03) and pauses (E1.04) while moving his right arm out toward the group (r**Prep**, E1.01). Leo, Ian, and Jen are all gazing at their notebooks (E1.02). Without looking up, Ian asks a question about the spring (E1.05). Kit restarts his turn (E1.06) and makes a shrinking pinch shape with his right thumb and index finger (r**Stroke**, E1.01), evoking the image of a spring contracting. He then starts to hold this pinch shape (r**Hold 1**, E1.01; **E1.a**). As the group maintains gaze on their notebooks, Kit starts a third attempted turn in E1.09 and also cuts it off but continues holding his pinch gesture (E1.07). He points to the board with his left hand (l**Hold 1**, E1.11; **E1.b**). With both arms outstretched (r**Hold 1**, E1.10; l**Hold 1**, E1.11), he starts a fourth time, now making a complete proposal: "The initial should be greater than zero" (E1.13). Ian raises his head to look up at Kit (E1.12). With Ian's attention secured and still holding his gesture (E1.14-16), Kit elaborates his proposal, providing additional evidence: "It's not at equilibrium" (E1.17). By deploying several cut-off phrases and false starts, accompanied by a visible gesture held out towards the group, Kit succeeds in not having his proposal be ignored. Speech restarts are an effective tactic for recruiting visual attention as a speaker when trying to take a turn (Goodwin, 2018). However, Kit also deploys a *gesture hold* to *recruit attention:* Continuing to hold his hand outstretched (E1.01-14), he displays he has something to share that requires their attention.

Even when shared attention has been achieved, groups may not acknowledge a proposal (Barron, 2003). An important interactional strategy is to *mobilize a response* (Stivers & Rossano, 2010) when proposals have been shared. After successfully gaining Ian's attention (E1.16 in Figure 1), Kit releases his first gesture hold in Figure 2 and produces a new representational gesture that he holds (**Hold 2**, E2.18; **E2.a**) as he provides additional support for his assertion that the spring is not at equilibrium (E1.17): He says, "you see it's bent right here" (E2.20), bringing both index fingers together vertically and evoking an image of a compressed spring (**Hold 2**, E2.18; **E2.a**). He holds this gesture (E2.18,24) as he gazes at Ian. Ian, still looking at Kit, replies, "Yeah" (E2.22). Kit directs attention to the gesture ("you see," E2.20) and, by not immediately releasing the hold, demonstrates he expects a response: Hold and talk solicit an *assessment* of his assertion made in speech and illustrated in gesture. Making sure they agree that the spring is compressed is useful to re-calibrate their shared understanding of the situation. Kit's utterance and hold *mobilize a response* from Ian who accepts the premise (E2.22). This is key for gathering consensus and moving forward, even though they still disagree about the significance of the premise.

Figure 2

Using a representational gesture hold to mobilize a response and weather an interruption

```
18  kgest:  *************|~~~~~~~~~~|********************************
                Hold 1        Prep                Hold 2
19  lgaze:   @Leo's notebook------------------------------------------>
20  KIT:     You see it's bent right here.
21                                          (...0.5...)
22  IAN:                                                Yeah.
23                                                           (.0.3.)
24  kgest:   *******************|^^^^^^^^^^^|*********************
                  Hold 2            Stroke            Hold 3
25  lgest:          |~~~~~~~~~~~~~~|^^^^|~~~~~~~~~~~~~~~~~~~~~~~~~~|
                         Prep        Stroke         Prep
26  lgaze:-->looks up@Kit------------------------------------------->
27  KIT:     ┌And then            ┌wh-
28  LEO:     └>>The initial<<'s   └zero. (0.1) And then (0.1)   ┌you=
29  IAN:                                                      Ye└ah.
30  kgest:   **************************************************
                                Hold 3
31  lgest:   |^^^^^^|***********************************|-.-.-.
              Stroke               Hold 4               Retract
32  lgaze:   @Kit--------------------------------------------->
33  LEO:    =let go ┌of it.
34  IAN:            └Initial's zero for sure.
35  LEO:                                      Right.
36                                                   (.0.3.)
```

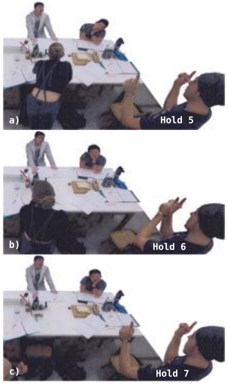


Barron (2003) also observed frequent interruptions in unsuccessful groups, where proposals were cut off and abandoned. Kit uses a third hold to *weather an interruption*: After securing acceptance from Ian, he begins a second part to his proposal in E2.27, saying "and then wh-", as he sweeps his vertical index fingers apart, evoking the image of the spring expanding (**Stroke**, E2.24). Leo, who has been gazing at his notebook, looks up (E2.26) and interrupts with a counterproposal (E2.28,33). Kit *verbally* abandons his turn (E2.27) but keeps his hands suspended in the air (**Hold 3**, E2.24,30; **E2.b**). This displays to the group that he considers his turn incomplete and projects that he will resume it. Notably, Leo also produces representational gestures (E2.25,31) and a gesture hold (**Hold 4**, E2.31; **E2.b**) as he interrupts. He repeats Kit's pinch-shaped "compressed spring" gesture (**Stroke**, E2.25), and he also moves apart his vertical index fingers to repeat Kit's "expanding spring" gesture (**Stroke**, E2.31). Both Leo and Kit hold the same two-handed vertical index finger gesture at the same time (**Hold 3**, E2.30; **Hold 4**, E2.31). Leo holds his gesture past the boundary of his spoken turn, mobilizing an assessment from the group. He successfully solicits a strong agreement from Ian (E2.34). After obtaining acceptance of the counterproposal from Ian, Leo releases his hold (**Retract**, E2.31). All the while, Kit has maintained *his* hold (**Hold 3**, E2.24,30) to *weather the interruption*: Although Leo interrupts with his counterproposal, Kit's maintenance of his turn with the gesture hold in Figure 2 provides a new opportunity for more discussion in Figure 3.

Figure 3

Using gesture holds to allow for elaboration, clarification, and extended consideration

```
37  kgest:  ******|^^^^^^^^^^^^^^^^^^^^^^^^|*********************
            Hold 3          Stroke                  Hold 5
38  KIT:    and then:: >>when it goes<< back, it goes back to zero
39  kgest:  *********************************
                          Hold 5
40  KIT:    to its equilibrium. (....0.6....)
41  lface:                    ((furrows brow->))
42  lhead:                    ((throws head back->))
43  kgest:  ************************************|^^^^|
                           Hold 5               Stroke
44  KIT:    That's what it's saying.
45                                   (...0.5...)
46  LEO:                                        Hmm.
47  kgest:  |***********************************|
                           Hold 6
48  KIT:    THIS (....0.6....) i::s >>not zero:<<
49  kgest:  ^^^^^^^^^^^^^^^|***********************|-.-.-.-.-.-.-.-.-.
                Stroke              Hold 7                 Retract
50  KIT:    (.0.2.) this is zero.
51                               (.0.3.)
52  LEO:                                  Huh. (..0.4..) O:kay:?
53  lhead:                              ((nods up))      ((nods down))
54                                                              (0.1)
```



The ultimate consequence of nonengagement with proposals is not having time or space to adequately consider them before prematurely rejecting them and moving on (Barron, 2003). Kit produces another series of holds as he *elaborates* and *clarifies* his proposal, providing new information to the group. The holds both support Kit to make the overall proposal more detailed and explicit, and they make space for the *group's extended consideration* to think about and assess each new piece of information. Kit is still holding his gesture from Figure 2 and has not been able to fully lay out his proposal. He restarts, repeating "and then" (E3.38), and reperforms the "expanding spring" gesture (**Stroke**, E3.37). As he continues talking, he maintains his hands frozen in this position (**Hold 5**, E3.37; **E3.a**) while providing two new important details about the uncompressed state of the spring: When released, the spring "goes back to zero" (E3.38), and *this* is returning "to its equilibrium" (E3.40). Holding the gesture throughout his explanation, Kit *elaborates* his proposal by illustrating the *final position* of the free end of the spring after it is released and has returned to its relaxed state, asserting the *value* of this final position, and establishing that this final, relaxed, position (and *not* the compressed position) should be considered *equilibrium*. In response, Leo leans backwards and furrows his brow (E3.41,42), in a silent but visible display of "doing thinking" (Goodwin, 2018). While still holding the gesture and providing a space for the *extended consideration* of these additional details, Kit elaborates further, claiming he is supported by the lab manual (E3.44). Leo provides a "hmm" (E3.46), displaying his continuing consideration of the proposal. Kit treats Leo's response as an absence of acceptance and understanding, and continues his explanation, using it as an occasion to *clarify*. He speaks with marked emphasis and repeats his gestures, using two holds to illustrate that "This is not zero" (E3.48; **Hold 6**, E3.47; **E3.b**) and "this is zero" (E3.50; **Hold 7**, E3.49; **E3.c**). In these turns, Kit takes the time to make each part of the proposal even more explicit. His holds are now what McNeill (1992) calls *catchments:* repeated images that help bring continuity and coherence through complex explanations. As Kit holds the last gesture (**Hold 7**, E3.49), Leo provides another display of his ongoing consideration ("Huh," E3.52), and then upgrades his acknowledgment of Kit's proposal to an acceptance and claim of understanding ("Okay," E3.52).

Concluding remarks

Our analysis demonstrates how *kinetically-held* gestures can play a role in ensuring proposals are taken up and explored by groups. Holds can provide an interactional antidote against pitfalls that Barron (2003) observed: Kinetically-held gestures can (1) recruit attention to proposals and ideas, (2) mobilize responses to proposals, (3) weather interruptions so proposals can be resumed, and (4) allow for extended consideration of proposals. Our investigation adds to previous studies in STEM education that illustrate how representational gestures are essential tools for learning when students try to make sense of complex phenomena together (e.g., Alibali & Nathan, 2012; Singer et al., 2008; Walkington et al., 2019). We explored the *temporality* of representational gestures and were able to identify and characterize new ways representational gestures contribute to problem solving by organizing and coordinating participation and turn-taking. Our study contributes to broader definitions of competence in collaborative work in STEM: By focusing on uncovering the fine details of the interactional practices students use to build, repair, and maintain a sense of shared meanings in interactions, we were able to recognize more of the assets students bring to STEM work and problem solving.

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Navigating Emergent Divisions in a Coalition for an Antiracist School

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Abstract: Disagreement often leads to polarization and division in activist groups. Here, we examine relationships between learning and conflict in a coalition working toward building an antiracist school community, which included staff and parents at one elementary school and their university partners (including three authors of this study). We analyze a key conflict in the group regarding whether our efforts should focus exclusively on Black students and families or take a more racially and ethnically inclusive approach. We then explore how members of our coalition positioned one another throughout these discussions. We find that participants positioned themselves and one another dichotomously, as either right or wrong, not only conceptually but also morally. This disrupted learning opportunities and eroded trust within the coalition—yet as we show, it was reasonable given multiple layers of context. We conclude by offering implications for design to support transformative learning in groups working toward antiracist change.

Purpose

Even as they advocate for a more just and inclusive society, socially progressive and radical groups may engage in divisive and exclusionary internal politics. This phenomenon has been rampant among justice-oriented groups in recent years (Grim, 2022). In this paper, we explore dynamics within a coalition that aimed to build an antiracist learning community at one elementary school. With our analysis, we seek to contribute to understandings of the kinds of ideas that divide members of school-based antiracist coalitions in the current moment, how members position others whose ideas they perceive as conflicting with their own, and the implications of these dynamics for learning within these coalitions.

Prior research

Intra-organizational conflict has been a rich area of study in research on social movements. Scholars have examined factors that contribute to such conflict, stages in the development of factions, and the consequences of factionalism (Kretschmer, 2013). Generally, however, this literature has not examined relationships between conflict and learning. In contrast, many studies within the learning sciences have, converging on the conclusion that learning is hindered by a competitive ethos but enhanced by a collaborative approach to disagreement (e.g., Barron, 2003; Chiu, 2008). But these latter studies focus on conceptual disagreements in classrooms, in which participants are likely less invested in the outcome than participants in activist groups are.

The present study attempts to bring these disparate literatures together to investigate how division may emerge within groups whose members share a commitment to social justice—a commitment that other studies of collaborative learning suggest should produce a “safe haven” (e.g., Picower, 2011)—and the implications for learning. In doing so, we also attempt to coordinate attention to broad social context and moment-to-moment interaction. We thus build on growing efforts in the learning sciences to link what we know about learning and design with studies of activism and social change (e.g., Pham & Philip, 2021).

Theoretical perspective

Building on Kendi (2019), we take antiracism to be a set of actions that counter ideas, practices, and structures that perpetuate hierarchies based on race and intersecting systems of oppression, and actively work toward equality. Making sense of precisely what this means in any given moment requires ongoing negotiation because the contours of racism and antiracism are specific to time and place, shaped by both local and extralocal contexts. Further, White supremacist ideologies are extremely powerful in shaping our unconscious assumptions about what is good, what is natural, and what makes sense (Louie, 2018; Philip, 2011). Thus, rather than assume that antiracism is a static state, we argue that antiracism requires ongoing, intentional, and communal negotiation and critical reflexivity—rigorously and continually examining the ways that we participate in and reproduce racism and intersecting systems of oppression, despite our conscious intentions.

Heterogeneity is a vital resource for this negotiation of meaning (Bang & Vossoughi, 2016). Racism impacts and is hence perceptible to different people in different ways, all of which must be understood in order to enable collective antiracist transformations. While embracing heterogeneity requires that we seek to understand ideas that are offered in good faith, it does not mean embracing every idea as if it were sound, humanizing, or just. Nor does it necessarily mean leveraging diverse views to reach a tidy conclusion. Rather, it can mean holding competing ideas in tension and grappling with them as a means of generating new knowledge. This contrasts with the dichotomous thinking that often arises from conflict (Wood & Petriglieri, 2005), which frames two differing positions as mutually exclusive; privileges one position as inherently better than the other; and eliminates possibilities for coexistence or other positions beyond the binary (Prokhovnik, 2001).

Methods

This study centers on a coalition of university researchers (the first, second, and fourth authors and three others) and faculty, staff, and parents at Eastwood Elementary.[1] In 2019, 90% of the Eastwood staff was white, 25% of students were Latino/a/x, 25% were Black, 18% were multiracial, 17% were white, and 8% were Asian (primarily Hmong). The school had a stated equity vision, but racism and racist acts persisted throughout the school, targeting multilingual students, Asian American students, and Black educators. At the request of the school, the university researchers partnered with the school to work towards building an antiracist school community. We met for a year and a half, including bi-monthly meetings with the school-based leadership team, and 6- and 5-day summer retreats for learning in 2019 and 2020 (on Zoom in 2020 due to Covid-19).

For the present analysis, we focus on two episodes from the 2020 summer retreat, one from a debrief meeting with the school leadership after Retreat Day 1 and one involving the whole coalition on Day 2. Both discussions took up the topic of whether the coalition should focus on Black students and families exclusively or take a more inclusive approach to antiracism. These conversations were rife with conflict and thus afforded a window onto the group's divisions. The debrief meeting included the Eastwood principal Amy (a White woman), assistant principal Keith (a Black man), and the teacher who initiated our partnership, Malik (a Black man). Five university faculty members were present: Carl (a Black man), Leema (a White woman), Mariana (a Chicana woman), Nicole (a Chinese American woman, and Kat (a White woman), as well as graduate student Laura (a White woman). We did not record this meeting but took extensive field notes. The meeting of the whole coalition on Day 2 involved 21 Eastwood teachers and staff and four mothers from the Eastwood community—one Black, one Hmong, one Latina, and one White. One particularly vocal participant in the episode we analyze was David, a White social worker. We recorded this Zoom session.

We analyzed the episodes to characterize (a) what speakers seemed to be advocating (b) and how we positioned ourselves and one another. We examined our own participation in the coalition in the same way as our partners', seeking to simultaneously reveal what made our actions reasonable and how these actions may have been problematic. Focusing on individual utterances helped us (somewhat) to distance ourselves from our own opinions, recollections, and experiences. Additionally, Amanda—who was not part of the Eastwood antiracist coalition—joined us for data analysis and writing and provided an additional check against our biases. After analyzing each episode individually and in pairs, all four authors compared and discussed our analyses. Our different characterizations were complementary and mutually supportive, bolstering our sense of the validity of our interpretations. Preliminary findings are based on our consensus account.

Preliminary findings

Three themes emerged from our preliminary analysis: (1) concern that some members were approaching antiracism in ways that allowed antiblackness and poor outcomes for Black students to persist, (2) concern that some members were espousing ideas and practices that dehumanized people of color, and (3) concern that some members were not willing, or able, to take concrete steps to confront racism in any form. Due to space limitations, we focus on selected aspects of the first and second themes.

Allowing antiblackness to persist

A concern voiced by some members of the coalition was that others' approach to antiracism was insufficient to address deep-seated antiblackness. For example, in the Day 1 debrief, the school principal, Amy, expressed her dissatisfaction with how the full meeting had gone, saying, 'I don't want to veer from talking about Black students in particular. … They are the most affected.' Similarly, on Day 2, David said, "Our Black boys and Black girls at [Eastwood] are the ones most frequently not accessing things in the classroom, are kicked out of the classroom, are getting referrals." Amy and Malik also argued that Eastwood teachers 'don't know how to teach Black students' (Amy) and 'seem to be inadequately trained' to work with Black students (Malik). Given limited time, Amy, Malik, David, and Keith argued that focusing on the area of greatest need was strategic. They contended that 'aiming too wide' (i.e., taking a more inclusive approach to antiracism) would allow teachers to 'shuffle around and not dig into the work they need to do' (Keith), more specifically to 'not engage with their thinking regarding Black students because this requires particularly hard discussions' (Amy).

Amy, Malik, and David's concerns were sensible given local, national, and global mobilization in the spring of 2020 demanding racial equity for Black people. Just weeks before the retreat, George Floyd was murdered by the antiblackness endemic to the United States (as argued by kihana ross (2020) in a *New York Times* op-ed that the coalition read). Moreover, a few years earlier, a report had shown that Eastwood's county produced some of the largest Black/White achievement gaps in the nation, and throughout the coalition's duration, various pro-Black initiatives were ongoing in Eastwood's district and highly salient for school staff.

Dividing and excluding

Several coalition members voiced concerns about focusing strictly on Black students, to the exclusion of Eastwood's Latina/o/x, Hmong, and multiracial students and families. For example, Carl compared ignoring 'Hmong, Latinos, … everyone who are of color' to 'go[ing] into a school that is on fire and bring[ing] only the Black kids out.' Nicole said she could not 'be part of an antiracist coalition that erases Hmong and Latinx students,' and Mariana stated she would 'resign and not be part of this group' if the coalition was going to engage in the explicit 'exclusion of Latino students.' Similarly, on Retreat Day 2, Nicole stated that "it is literally impossible to have a caring, inclusive, antiracist community that is caring, inclusive, and antiracist for only some people."

The concerns expressed by Carl, Nicole, and Mariana were responsive to the multilingual, multicultural, and multiracial demographic context in which they were situated. National discourses had long focused on a Black/White binary, erasing the contributions of Latinas/os/xs and Asian Americans as well as the racism their communities faced. This was mirrored by Eastwood's district, where there were no parallels to pro-Black initiatives for Latina/o/x or Hmong students, despite comparable levels of academic achievement (as measured by standardized tests), and in the case of Latina/o/x students, an equal or larger population at many schools (including Eastwood. Further, in visits to Eastwood, university partners documented that Latina/o/x and Asian American students were ignored in classrooms even as their most basic learning needs went unmet. Moreover, a Hmong mother had shared on Retreat Day 1 that she did not feel "welcome" at Eastwood, saying, "I have to sacrifice my culture to teach my kids to make it in this school." Additionally, for Mariana and Nicole, their own racial identities (as Chicana and Asian American, respectively) made the erasure and exclusion of Latina/o/x and Asian American students and families from the coalition deeply personal.

Positioning those with conflicting ideas

Participants positioned those whose ideas they perceived as threatening their own in a variety of ways, which we group here under two major themes: positioning each other as morally compromised or worse, and positioning each other as aligned. Under the first theme, our preliminary analyses indicate that participants positioned each other as dishonest, ignorant, hypocritical, complacent, and racist. For example, Nicole's and Mariana's statements about leaving the coalition suggested an unbridgeable chasm between themselves and the advocates of a strict and exclusive focus on Black students. Moreover, in objecting to how this focus 'erases Hmong and Latinx students' (Nicole) and arguing that 'if we're being honest and authentic,' the coalition should be re-named for its exclusive focus on Black students and 'not antiracist' (Mariana), they positioned advocates of this position as both racist and dishonest. Keith rejoined that the conversation had 'turned to All Lives Matter,' positioning Nicole and Mariana as both ignorant of 'our teachers' at Eastwood and as racist, grouping them with a movement opposed to Black Lives Matter. This positioning of one another as morally wrong is consistent with dichotomous thinking and inconsistent with valuing heterogeneity and critical reflexivity.

Almost every participant also made efforts to close distances between themselves and others, positioning everyone on the same side. Some of these efforts attended to others' feelings more than to the content of what they said (e.g., 'I hear you'). Other efforts cast contrasting views as complementary, not competing. During the Day 1 debrief, several university participants (Carl, Leema, Nicole, and Laura) attempted to leverage a focus on classroom practice to bridge gaps. Similarly, on Day 2, Leema summarized the different positions thus: "The actions need to be creating space for all cultures. … But what I hear David saying is that … we cannot accomplish that without doing some hard internal work about our internalized antiblackness." She then stated, "I don't see it as an either or. I see it as doing what Amber [another teacher] is asking for and also doing internal work simultaneously." However, none of these attempts were taken up in a way that advanced a shared understanding of antiracism or of the coalition's mission. One possible explanation is that participants could have been so caught up in the emotional experience of having their values threatened and 'attacked' (to use Keith's word) that conciliatory moves did not register very deeply. Or, efforts to resolve tensions may have been conceptually unsatisfactory to participants, insufficiently engaging with the details of their positions and the possibility that some tensions could not or should not be resolved.

Regardless of why the attempts to close gaps and construct alignment within the coalition were not taken up, their presence shows that the participants recognized the importance of trust, vulnerability, and positive relationships in the coalition. However, it seems that we perceive a conflict between tending to those relationships and other deeply held concerns and convictions—concerns and convictions that were informed not only by what happened in the immediate setting of the coalition but also by other contexts and our specific positions and identities in relation to those contexts.

Discussion and conclusion

It is clear that we missed opportunities to learn from one another throughout this retreat, particularly if we take learning to arise from "the coordination and dynamic coexistence of multiple ways of seeing and knowing" (Bang & Vossoughi, 2016, p. 184). Instead of coordinating, participants reiterated or further justified their positions without building on, inquiring into, or otherwise directly engaging the logic, evidence, or feelings beneath contrasting views. Further, no attempts to engage in critical reflexivity are evident. Working to coordinate our divergent perspectives and experiences could have resulted in a richer, more nuanced understanding of race, racism, and antiracism at Eastwood than any single person or faction could have developed alone. Failing to coordinate them produced flatter understandings, eroded trust, and foreclosed opportunities to develop a shared understanding.

It is easy to say that collaborative learning toward antiracism requires people to treat each other with trust and respect. But our case shows that this can be much harder to accomplish than studies of "safe havens" suggest. Indeed, trust and respect can break down because the same deeply felt commitments that bring participants to the table can lead them to perceive others' competing commitments as morally repugnant. This leaves participants with little room for mutual, shared learning. Better understanding the conditions under which this occurs is necessary to help antiracist learning communities to design for heterogeneity, curiosity, and critical reflexivity, and support groups to leverage contrasting ideas to generate better understandings of each other, themselves, and antiracism, as well as better plans for antiracist action.

Endnotes

(1) The three other members of the coalition from the university were Carl Grant, Kathleen Nichols, and Laura Roeker. "Eastwood" is a pseudonym, as are names for non-university participants throughout the paper.

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Who is Disabled? The Social Construction of Disabled Bodies in Embodied Activity

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Abstract: This exploratory review dissects the social and cultural construction of bodily ideals and 'disabled bodies' in embodied learning spaces by drawing on an interdisciplinary corpus of literature. First, this paper attends to the limitations of current embodied learning scholarship and explores notions of the many sociocultural and institutional pressures that shape youth's bodies in the habitus of both modern-day schooling with attention to how learning environments 'disable' and 'enable' students whose bodies fit the hegemonic bodily ideal.

Introduction

Within the embodied learning literature, the human body is positioned as a resource for engaging in negotiating and constructing meanings within the social and physical world (Nathan, 2021). Equity-oriented scholars have further proposed embodiment as in-motion, focusing on the dynamic relationships that bodies have with places, movements, and times (Warren et al., 2020). Yet, by nature, embodied activities constrain what forms of embodiment are 'counted' in design and carry a set of implicit assumptions around learners' ability and willingness to physically and visibly perform in a particular context (Mathayas et al., 2022). For the 'ideal' learner, the body is considered yet another tool that can be leveraged in instructional design to pursue learning objectives. But by neglecting to consider the needs of learners who do not fit into the model of this 'ideal' body in embodied activity design, we pressure learners to either conform to some developmental norm (Annamma & Booker, 2020), tolerate the denial of learning pathways and resources (Nasir et al., 2020), or 'push them as they are' through an environment custom-built and optimized with another user in mind (Uttamchandani, 2020). This functionally dehumanizes, coerces, and denies dignity to learners.

Learners engage in external processes of *becoming* (Nasir, 2002), self-formation, and discovery as they navigate the various possibilities for bodies (Wolputte, 2004). Thus, the nature of bodies is inherently multiplicitous, fluid, and indeterminate while remaining subject to the same cultural and social processes. While this review will not be comprehensive in its discussion of how each of these domains has historically conceptualized body normativity, I offer a narrative that holistically considers bodies as a product at the intersection of multiple social and cultural axes. I adopt a critical approach to *intersectionality* that attends to how individuals experience and are confronted by multiple co-occurring systemic and institutional oppressions. By identifying these vectors of oppression, we can name and understand the multiple interwoven marginalizations that people experience (Annamma & Booker, 2020; Gillborn, 2015) as learners engage in learning processes.

Defining the 'ideal' body

Learners are constantly subject to a set of socially-constructed bodily ideals that dictate how and whether their bodies are worthy of attention, practice, and social capital (Fitzgerald, 2005). These ideals furthermore feed into a system that stratifies youth based on culturally constructed ideological and material systems for determining one's 'goodness' and 'smartness.' Particularly in the United States, these conceptions of youth as inherently 'good' or 'bad' are discursively and institutionally intertwined with aspects of race, class, and gender; 'good' bodies are those which conform, assimilate, and subjugate themselves to those who represent the 'ideal' white, able-bodied, male standard. (Broderick & Leonardo, 2016)

Annamma and Booker (2020) discuss the normative standard of being as the determining force through which one attains access to power; access increases as one becomes more closely perceived as the norm. Expressions of difference from the norm become the grounds through which institutions and social structures work to shame and correct individuals' appearances and behaviors for the sake of developmental likeness (Annamma & Booker, 2020). Interpersonally, these expressions of difference fail to activate the same level of social capital within peer groups (Fitzgerald, 2005) and are perceived, treated, and punished as acts of noncompliance by authority figures/instructors (Goodwin, 2020).

Communities have long designed systems of social organization around the definition of the "other" defined as and by opposition to those in power. "Othering" functions to delegitimize, demonize and eventually erase non-dominant ways of being to maintain and enable social, cultural, and institutional dominance over those 'others' (Lee et al., 2020). Within the United States context, this "othering" is rooted in the practices and logic of settler-colonialism through which western white settlers establish a society founded on the commodification, dehumanization, and domination of non-white bodies. It is these histories and the establishment of racist, cis-heteropatriarchal, and ableist systems designed to ensure the stratification and erasure of bodies classified as existing too far from the white, masculine, able bodily idea through the denial of access to opportunities, resources, and power. These systemic denials of power and resources function to deny people that which makes them human, then reinforce and sustain beliefs and narratives which stigmatize, and stereotype social groups ultimately determining the criteria of who is and is not considered ‘human’ (Lee et al., 2020; Nasir et al., 2020, Rogers et al., 2020).

Physical education spaces as sites of dehumanization

Bodies and minds perceived as disabled have historically been perceived as a threat to society instigating the use of social and institutional efforts of erasure (Stiker, 2019; Lester, personal communication, April 22, 2022). Educational settings in particular affirm a normative presence in the facilitation of activities that require that bodies perform and be assessed according to how their body demonstrates mesomorphic, masculine, and motor-competent traits. While this includes learners with known physical, cognitive, and/or social disabilities, stigma built around bodily ability is also inexplicably tied to issues of gender, race, sexuality, and body size.

The assignment and possession of social capital and its relationship to the understanding of bodies as particularly salient within the disability studies literature pertaining to physical education and athletics contexts. In these spaces, attention, and value are given to technique-based athletic performance within a strict range of abilities and skills (Nyberg et al., 2020). This phenomenon is further exacerbated when physical education spaces take on a competitive, aggressive, and masculine atmosphere further deterring participation for those who do not perform ‘appropriate masculinity’ (Wellard, 2006). These pressures and values associated with athletic participation can additionally be fueled by community attitudes toward and perceptions of athletics: elite and high-socioeconomic often consider athletic achievement and participation as integral to the schools' image, reputation, and in-school identity (Wright & Burrows, 2006). Consequently, youth experience multidimensional pressures for their bodies to adequately perform at risk of being perceived as lacking effort, worth ethic, or some inherent capacity to ‘do’ physical activity (Wright & Burrows, 2006).

Thus, we create a system where social, embodied, and cultural capital is prescribed on the basis of achievement in activities designed to ensure that only a limited proportion of the population can excel (Penney et al., 2018). This inequitable distribution of social capital within physical education spaces leads to the deterrence of, avoidance by, and outright exclusion of youth from such activities (Allender et al., 2006; Fitzgerald, 2005; Penney et al., 2018; Wright & Burrows, 2006). This dilemma has prompted researchers to combat the stigmatization of these bodies and minds through the reconceptualization and re-mediation of educational activities and spaces requiring physicality (Fitzgerald, 2005; Maher & Fitzgerald, 2020; Nyberg et al., 2020; Penney et al., 2018; Pocock & Miyahara, 2018; Qi & Ha, 2012). Such work provides insight into what oppressive and disabling characteristics of physical education may be present in embodied learning environments and how we might adapt our activity designs to be more inclusive of learners who have been deemed ‘disabled.

Conclusion

Fitzgerald (2005) reminds us that the normative ideals that (re)enforce these barriers for students are deep-seated in the habitus of modern-day schooling and thus cannot be resolved exclusively with such instructional “superficial remedies.” Yet, if we are to engage in ethical and dignity-affirming educational practice (Booker et al., 2014; Curnow et al., 2019), we must also acknowledge how our bodies carry a multitude of presentations, histories, and experiences that are under repression and control (Vossoughi et al., 2020) and are imbued with historical, axiological, and epistemological orientations of the world (Marin & Bang, 2018).

I posit that embodiment scholarship must come to (1) recognize unwelcome, coerced, or dehumanizing actions in situ, (2) understand the consequences of these interactions for learners’ psychological and physiological well beings, and (3) design to proactively subdue dignity-denying processes by enabling learners to exercise their bodily autonomy. If we as educators are to ‘do no harm,’ it is vital that we consider the invisible oppressions embedded in our activity designs and the consequences of disregarding the lived experiences youth’s bodies carry such that no body falls through the cracks.

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“Growing as a Person”: Authoring Identity Across Formal CS Education and Everyday Computing Contexts

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Abstract: To understand how learners develop identities in computer science (CS), we must investigate learners’ experiences with computing throughout their lives. Drawing from a theory of learning as participation in communities of practice, we analyze interviews with high school students at the end of their time in a 2-year, constructionist CS course to better understand how these students’ CS education affected their experiences with computing in their everyday lives. We identify moments where students begin to “re-see” technology which offer insight into how students author their computational identities. However, our analysis reveals that re-seeing does not inevitably align with a positive trajectory of participation in CS. Instead, we discuss how the nuances of students’ “re-seeing” experiences combine with various social factors to influence students’ computational identity authorship.

Introduction

As computer science (CS) education expands in K12 education around the world, there is a growing opportunity– and a growing urgency–to design for CS learning experiences which positively influence learners, their communities, and the world. Traditional measures of content learning will not be enough to ensure that CS learning experiences have a positive influence; we cannot simply ask, “Are students learning CS?” Instead, we must focus on what learners need in order to participate in a world where computation plays an increasingly significant role. In addition to supporting participation in computing, CS education must prepare learners to decide *whether* and *how* to participate in our increasingly computationally-mediated world (Vakil, 2020; Ryoo et al., 2020). As a practice which helps learners recognize, make sense of, and solve computational problems, Wing’s (2006) Computational Thinking (CT) has become the most common way to describe how CS might help learners solve real-world problems. While early work largely understood CT as an individual cognitive phenomenon, more recent frameworks also recognize CT as a social practice embedded within systems of power (Kafai et al. 2020). In these framings, learning is understood in terms of participation in communities of CS practice. Identity is a central construct which models the processes by which learners show up and act in a community of practice. If CS education is to prepare youth to participate in and help shape our computational futures, we need a better understanding of how learning environments support learners in developing computational identities (Penuel and O’Connor, 2018; Kafai 2016; Tissenbaum et al. 2019; Dindler, et al., 2020). Because learners’ computational identities extend throughout their lives, we must investigate this construct across formal CS education and everyday computing contexts. Such an investigation can help us understand the roles that formal CS education can play in learners’ broader lives and help us provide resources to learners as they negotiate their computational identities. In this paper, we present a phenomenographic analysis of beginner high school CS students’ experiences negotiating their computational identities. In analyzing these experiences, we highlight the ways students feel their CS education contributes to this experience, supporting or constraining them in their use of technology. In doing so, we contribute to an understanding of computational identity that spans both formal CS education and everyday computing contexts.

Background

Our definition of computational identity begins with the understanding that learning happens through participation in communities of practice (Wenger, 1999). In order to characterize learning as a process of social participation, this framework outlines four components of learning: (1) doing, (2) belonging (3) experiencing, and (4) becoming. In this framework, the process of becoming is interconnected with the processes of doing, belonging, and experiencing. We are constantly developing identities (both our own and others') through our actions, which are in turn dependent on our positions and experiences within the community. How we position ourselves relative to others in a community of practice allows us to author our identities (Holland et al., 1998). At the same time, identity authorship is also restricted by the ways other members of a community of practice recognize (or don’t recognize) our participation. This development of identity through practice is rarely linear, instead consisting of many fluctuating moments where learners feel stronger or weaker identities relative to a field. Applying this framework to the work of a CS course helps us to see that course as situated within many different community contexts including the classroom, learners' home environments, and even digital spaces like StackOverflow. Identity development in CS has been charted as learners experience success and failure (Dahn and DiLiema, 2020), join or get excluded from communities of practice (Shaw et al., 2021; Margolis et al., 2008), and face stereotypes about who can be successful in the field (Love et al., 2021). This development is not always ultimately positive. Learners' participation in computing communities of practice can create distance in their computational identities, either because they feel incapable or uninterested in participating (Kang et al. 2019) or because the computing communities of practice are exclusionary (Nasir and Vakil, 2017).

Learners' experiences in communities of CS practice, both positive or negative, contribute to their trajectories of participation in the field of CS (Drier 1999). These trajectories of participation take into account learners' positions in communities of practice as well as the ways they navigate between different communities of practice. As learners have experiences in these communities, they develop expectations (of the discipline and of themselves) that determine what they see as possible and appropriate forms of participation in computing communities of practice. Rather than being deterministic, trajectories of participation should be seen as the resources and constraints that influence learners' perspective on what are possible forms of participation in their communities of practice. To investigate the process of identity authorship through participation, we are particularly interested in moments where learners feel their perspectives are shifting–moments where learners are "re-seeing" their computational worlds and their place in them (Silver, 2014). To paint a full picture, we must understand this re-seeing in formal computing settings and across multiple everyday uses of computational tools and ideas (Shaw and Kafai, 2020). With this in mind, we are interested in the following questions:

1. How do the ways learners use or feel about technology change as they learn CS?
2. Is there a relationship between these changes and how learners author their computational identities?

Methods

This study was conducted at a private bilingual K-12 school in Hong Kong, where twenty-eight ninth graders participated in a two-year curriculum. In this cohort, thirteen consented to participate in this research (14-16 years; three girls, ten boys). The central goal of the course is to "create a rich, diverse community of people making things with code, through which they can develop personal relationships with powerful ideas" (Proctor et al. 2020). The course was composed of six units (e.g. computational art, data science, web development, etc.); for each unit, students completed an open-ended project that applied skills and concepts from that unit.

At the end of the program in May 2021, three researchers who were also teachers conducted a semi-structured exit interview with each student. We asked students to reflect on formative moments with technology throughout their lives as well as changes in their relationship with various technologies (such as the internet and their computers) over the course of the two years. With these interviews, we extend Wilkerson et al.'s (2020) methodology for locating computational thinking in everyday spaces of learning to identify "locally constructed definitions" for identity in CS (p. 269). To analyze the data for this paper, three of the authors conducted a thematic analysis and identified students' reflections about the computational world and their place in it. One author then re-coded the interviews to identify all instances of "re-seeing" the computational world, drawing from students' own language to create the category. In this paper, we seek to capture the experience of our students as individuals rather than summarize across the class. We contribute these select perspectives to the literature on identity in CS education while laying the foundation for future work to explore broader categories of perspectives in our class and other populations. Students' names have been changed for anonymity.

Findings

Re-seeing the computational world

Though they had a wealth of experience with technologies from gaming PCs to learning management systems prior to the course, students frequently reported a change in their interactions with technologies during their exit interviews. Reflecting on watching a music video on a Virtual Reality platform, one student, Tina, said:

> "It made me think more about what I was using and what I was doing. And like the interaction between person and digital device, that kind of relationship. . . Like, "oh," if I click on this button, there's a whole bunch of code behind the color of this button and the depth to make it look like a button. And this button links with some other page. And it's like a whole process of coding and effort for me to just click on a button to get to a new page."

In total, we found that in ten of the thirteen student interviews we analyzed (77%), students discussed an experience where they used technology differently or felt differently about technology compared to their experiences before the course. Many, like Tina quoted above, described a realization of the many layers through which their interactions with technology flowed, unveiling servers behind web pages and file systems behind graphical user interfaces.

Re-seeing and computational identity authorship

Along with their shifting perspectives, some students described enacting this perspective as part of their computational identity authorship. During the data science unit, one student, Noa, chose to find her own datasets to answer a question about her experiences as a competitive athlete in a water-based sport. This experience was a critical moment in Noa's trajectory as a computer scientist. After completing the project, she went on to do a variety of data analysis projects that were connected to her interests in the ocean and in sustainability. In her final interview, she connected all of these experiences back to the data science project, saying, "the data science [project] actually helped [her] develop as a person," and "doing data [science] led [her] on to give [her] the opportunity to do [a conference publication] and many other projects developed after that." Reflecting on these experiences and how she developed over the two years of the course, Noa said:

> "I think a lot of it was character development, me growing as a person and as I mature, I feel I'm being more aware of the people around me, and the events happening around me... I'm actually doing more service. I want to do more for the world."

Though many students, like Noa, shared ways that their re-seeing experiences were connected to positive trajectories of participation in CS, students also shared examples of the ways their experiences affected their trajectories in negative ways, making them feel less confident and less excited to continue learning CS. For example, Tina noted that she respected people in CS "because it's very difficult" and described how in the first year of the course she began thinking that she "might not be built for computer science." This feeling extended through her final project of the class in the web applications unit. Looking around at the other projects, Tina felt like other students were progressing more quickly than her and her partner. For Tina, CS is "an interesting topic, but [she is] not necessarily enthusiastic about it compared to other people." In contrast with Noa's experiences, Tina's comments highlight the ways that she feels separated from others practicing CS.

Discussion and future work

Our findings highlight the cognitive shifts that occur when our students "re-see technology" in their everyday interactions. However, considering how changing perspectives affect students' identity, we interpret the act of "re-seeing" as a series of social negotiations that ultimately affect trajectories of participation in CS. Indeed, students' perspectives of technology were always changing within their communities of practice; they were "re-seeing" as they were doing, becoming, experiencing, and belonging (Wenger, 1999).

For students like Noa, their changing perspective on CS promoted a positive trajectory of participation in CS. However, this was not always the case. Even while developing a new perspective in CS, some learners' experiences were connected to a negative trajectory of participation. Tina's experiences offer a particularly interesting case study. Like many other students, Tina described the ways her CS education helped her see new features of technology. However, for Tina, this complexity still represented something she felt she would never understand. Tina's comments about feeling like "she wasn't built for CS" based on her perceptions of the field and on her experiences in the class align with research showing how stereotypes that students and educators hold about CS can limit learners' participation in the field (Love et al., 2021). At the same time, Tina's comments that CS is "an interesting topic, but [she is] not necessarily enthusiastic about it" do not seem flippant. Throughout her interview, Tina described ways that she imagined her CS education could serve her in the future and even sent a follow-up email to her interviewer clarifying that she felt her CS education had positively "changed [her] thinking about learning." This leads to another reading of Tina's experience: that given what she knows about CS and about herself, Tina decides to limit her engagement with the field. Though her formal CS education has not (yet) culminated in a positive trajectory of participation in CS, Tina is still negotiating her computational identity by refusing further engagement with CS education. While these two readings of Tina's negative trajectory are different, we believe that both are necessary to make sense of Tina's computational identity. We are critical of the ways the course community of practice contributed to Tina's sense of exclusion, *and* we recognize the agency Tina exhibits in refusing to participate further.

While Noa's and Tina's examples represent different trajectories of participation in CS, they both describe kinds of computational identities assumed by students, the experience of these identities in students' lives, and the CS education resources that influenced students to take on these identities. However, these examples represent just two of many in our data. In future research, we plan to use these insights as a foundation for further exploring how students' experiences with computing shift as they learn CS and for determining how specific experiences with CS education influence students' computational identity authorship. As technology increasingly intersects with problems in our world, this research is essential for designing CS education that prepares learners to participate in the world with the intention and ability to use computing as a force for good.

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Comparing Teacher Educator and Novice Teachers' Frames in Making Sense of Feedback During Rehearsals

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Abstract: In this study, we compared the frames that a teacher educator (TE) and preservice novice teachers (NTs) within a math teaching course used to interpret feedback that the TE provided during rehearsals. We conducted video-elicited interviews with the TE and two NTs in which they watched excerpts of TE feedback from a rehearsal video to understand: a) how the TE and the NTs described the problems of practice (PoP) that the TE feedback focused on and b) the frames the TE and the NTs used to interpret those PoP. We present two major differences in the types of frames that participants drew upon to describe the PoP. Our results highlight the importance of considering the frames that NTs may bring to rehearsals.

Introduction

Researchers have long sought to understand how to better support teachers to bridge theory and practice (Ball & Cohen, 1999). Several teacher education programs have implemented opportunities for pre-service teachers (NTs) to connect theoretical understandings from their courses to the enactment of teaching practice through rehearsals of teaching (e.g., Lampert et al., 2013). In a rehearsal, an NT practices teaching a lesson to their peers, who act as students, with a teacher educator (TE) serving as a coach. A key aspect of rehearsals is that the NT or the TE can interject (pause the teaching) to provide feedback related to problems of practice (PoP) that arise (Lampert et al. 2013). Feedback provided during rehearsal interjections may be evaluative (i.e., judging an action), and/or directive (i.e., suggesting a next step) and can take different forms (e.g., questions, comments) (Lampert et al., 2013). Such feedback can provide *potential* opportunities to learn pedagogical content knowledge (Ghousseini, 2017) and adaptive expertise (Ghousseini et al., 2015). Yet, the way that feedback is interpreted may depend on NTs' *frames* – that is, the lens they use to make sense of an event (Goffman, 1976). Frames have been shown to shape how in-service teachers interpret PoP (Vedder-Weiss et al., 2018). However, research is lacking about the frames that pre-service teachers use to interpret PoP, particularly within rehearsal feedback. Accordingly, we asked: 1) How do NTs and the TE describe the PoP that prompted the rehearsal feedback? 2) What frames do the TE and NTs use when they interpret those PoP? Our aim is to understand if and how NTs' frames may alter their interpretation of a TE's feedback. This is important, as feedback may be less effective when teachers fail to understand it (Sanyal, 2017).

Theoretical perspectives

We drew on two theoretical perspectives. First, we drew on Greeno's (2011) *situative perspective of learning*, which suggests that understanding and learning are social in nature, situated within contexts, and constructed through interactions. This means that NT and TE interpretations of feedback are shaped by their interactions with tools and people within the rehearsal. Rehearsals are often designed around two tools: (a) NTs teach an instructional activity with a routine structure that can be adapted to different content and ages (Lampert et al., 2013). (b) NTs may also be asked to focus their learning on a set of core teaching principles (e.g., children are sensemakers) and practices (e.g., eliciting student thinking) (Lampert et al., 2013) that provide a common framework for analysis of PoP (Ghousseini et al., 2015). Second, we drew on Goffman's (1974) notion of frames. Frames "provide interpretive contexts that support participants in a given situation to understand what kind of task they are engaged in, what kinds of knowledge are relevant or valuable, and what sort of behavior they and others are expected or entitled to engage in" (Louie et al., 2021, p. 97). Frames are rooted in people's experiences and beliefs (Alvidrez et al., 2022). The action of using a frame to make sense of a situation is called *framing* (Goffman, 1974). When frames are applied to interpret a problem, it is referred to as problem framing (Bannister, 2015). Problem framing can allow teachers to unpack and reflect on pedagogical practices and interactions (Vedder-Weiss et al., 2018). Therefore, NTs and TEs may collectively learn as they engage in problem framing during rehearsal interjections. Teachers may use different frames when problem framing, including epistemological and positional frames. Epistemological frames are about how knowledge is perceived to be created (Alvidrez et al., 2022). Positional frames are about the role of the participants in an activity. When engaging in positional framing, participants interpret their own and others' positions and the relationship between them (e.g., students-as-capable of tackling errors and students-as-incapable of addressing errors) (Alvidrez et al., 2022). When used to interpret a problem, epistemological and positional framing can take two different forms: *Diagnostic framing* is about how people identify a problem and its cause, while *prognostic framing* is about what people propose as solutions to a diagnosed problem (Bannister, 2015). Feedback provided during rehearsal interjections may be interpreted using either diagnostic or prognostic frames or both.

Methods

This study took place in a mandatory elementary math teaching methods course offered in the second year of a teacher education program in Eastern Canada. The course aimed to support NTs to learn about knowledge and practices for teaching number and arithmetic. Most NTs had limited in-class teaching experience. As part of the course, each NT participated in one rehearsal in a group of 2-3. NTs selected one instructional activity (quick images or strings) and were provided a lesson plan to use. To prepare for the rehearsals, NTs were introduced to a set of core principles (e.g., children are sensemakers) and practices (e.g., pressing on student thinking) (Lampert et al., 2013). Participants included three TEs (each teaching a separate section) and NTs enrolled in the course. We use gender-neutral pronouns (they/them) to refer to participants. For this paper, we selected one of the TEs (TE-1) and two NTs enrolled in TE-1's class (NT-1 and NT-2). We selected TE-1 as a case because they were experienced with providing feedback during rehearsal interjections. We selected NT-1 and NT-2 as cases because we had observed that their responses differed and might allow us to see a greater range of frames.

We conducted 60-minute semi-structured interviews with TEs and NTs in which they watched video-recordings of rehearsal interjections. For this initial analysis, we focused on the first interview (out of 2-3) conducted with participants. Participants viewed the same rehearsal video, selected based on three criteria: a) there had to be at least three interjections, b) interactions were typical (e.g., in terms of participation), and c) there was consent from all who participated in the rehearsal to have the video used in the interview. NTs did not necessarily watch their own rehearsal as their presence in class was sufficient to interpret and reflect on their TE's feedback, and we were interested in what NTs might learn from all rehearsals, regardless of their role. TE-1 was asked two sets of questions. One set was asked after viewing 30-seconds of the video before an interjection in the rehearsal: 1) You are about to pause. Why did you pause here in the rehearsal? 2) What did you notice that caused you to pause? The other set was asked after viewing the interjection: 1) What did you want the NTs in your class to understand there? 2) Why do you want the NTs to understand that? 3) How do you think your comments/questions help support NTs' learning? NTs watched the 30-seconds prior to the interjection and the interjection that followed and then were asked: 1) Explain in your own words what you think [TE-1] was saying or trying to say. 2) What do you think that [TE-1] wanted you and the other future teachers to understand? 3) Why do you think that [TE-1] wanted you and the other future teachers to understand that?

To understand the ways that participants framed PoP during rehearsals, we conducted a frame analysis (Goffman, 1974), drawing upon methods of discourse analysis to understand how participants conveyed significance, positions in activity, connections between actions and ideas, and perceived values and norms (Gee, 1999). First, all interview videos were transcribed and then parsed into episodes. Episodes started when the interviewer started to play the rehearsal video and ended when the interviewee finished answering the questions for that clip. We numbered the episodes in each interview to correspond with the same interjection in the rehearsal. This resulted in a total of 10 episodes. We then analyzed the transcripts iteratively using a set of analytic questions based on literature and refined through our discussions of the data. To identify PoP, we asked: How does the participant describe what the TE said and why the TE paused during the rehearsal? To identify frames, we asked: How does the participant justify the solution of the PoP and/or why the PoP is problematic? Through this process, we identified several categories of frames to further analyze the data. Examples include: a) formal course principles and practices of teaching (when participants used the exact terms in the course core principles and practices), b) informal course principles and practices of teaching (description of the core principles and practices using other language), c) perspectives on learning (general ideas about how students learn), and d) positional (how students are positioned as learners and teachers as educators). Finally, we compared episodes to identify commonalities and differences in how participants framed problems.

Findings

We describe two major distinctions in the types of frames that participants used to make sense of the PoP in the rehearsal. These frames impacted how problems were described. To illustrate our findings, we will draw upon Episode 5 from the participants' interviews because they used different frames to interpret PoP. In this episode, the participants watched two consecutive video clips from a quick images rehearsal taught by another NT in the class (not NT-1 or NT-2), who we refer to as the rehearsing-NT (R-NT). Quick images is an activity in which students are quickly shown images of dots and asked to determine how many dots there are. In the rehearsal, the R-NT presented the quick image in two ten frames (grids composed of 10 rectangles). In Episode 5, the R-NT had asked a student to share their strategy for finding the number of dots in the quick image. The student explained that they had imagined moving the dots from the left card to the right card to fill in the empty cells. The R-NT then revoiced the student strategy and asked whether any other students had another strategy to share. TE-1 paused the rehearsal and asked, “How do you know [the answer is] ten?” The interjection then ended.

Formal vs. informal frames

Unlike the NTs, the TE more frequently drew upon the formal course principles and practices to frame PoP. For example, in Episode 5, TE-1 explained the pause by drawing upon three different course practices: “I want [R-NT] to understand that [they] missed the opportunity to press to reach [their] goal. [They] just assume[d]. I said, ‘How [does] it makes ten?’ Because [the student] said, ‘I put those four [dots] and I put them.’ Okay, but how do you know it’s ten?...There's no pressing on students’ thinking. [They] just revoice[d].” Here, TE-1 used three formal course principles and practice as frames to make sense of the PoP: pressing on students’ thinking, teaching toward an instructional goal, and revoicing students’ thinking. The practice of revoicing students’ thinking provided a diagnostic frame to make sense of what the R-NT had been doing that TE-1 saw as problematic. The other two practices provided a prognostic frame for understanding what the R-NT could have done instead.

In contrast, NT-2 sometimes drew upon core principles and practices but often used different language to describe those principles and practices. For example, when watching the same rehearsal moment, NT-2 said, “[TE-1] was asking [student]...where you get that ten from since [R-NT] did not make that clear...So [R-NT] didn't ask [student] to explain [their] answer. So just make sure that us as future teachers continue to engage students and to represent their thinking and explain their thinking.” When asked what they meant by representing, NT-2 explained, “So as [student] did on the board, [they] showed [their] work, representing, and then explaining it afterwards which is important to make sure that all the other students in the class to understand [their] way of thinking, how [they] solved that problem.” Here, NT-2 also drew upon a similar prognostic frame to what TE-1 described as “pressing” but used different language: “explain their thinking.” However, NT-2 drew upon another formal course frame, representing students’ thinking, yet used it in a different way from how it was defined in the course: as the student representing on the board (instead of the teacher representing). This frame focused NT-2’s attention on the student’s action of writing on the board instead of the teachers’ action of revoicing and targeting an instructional goal (that TE-1 had focused on), and thus led to slightly different framings of the problem.

Student vs. teacher positional frames

All three participants drew upon positional frames in many episodes but did so in different ways. TE-1 often simultaneously drew upon a mix of positional frames that positioned students as capable and teachers as facilitators of students’ learning and often connected these positional frames to the math of the lesson. In contrast, NT-2 tended to only draw upon positional frames that suggested students were capable of learning on their own. NT-2’s positional frames were often coupled with frames about perspectives of learning. For example, in Episode 5, when NT-2 was asked to explain why it was important to have students explain their thinking, they responded: “To make sure that your students are gaining from other students’ knowledge. ...if the student doesn't explain how they thought of it, all the other students in the classroom will not gain from how the original student thought of it, and the teacher will not gauge how much the student like compr- like understands it.” Here, NT-2 drew upon a frame that learning is social (a perspective on learning). In addition, by viewing students’ explanations as important for each others’ learning, NT-2 also used a positional frame that placed students as capable.

NT-1 tended to use positional frames about teachers’ authority roles in the classroom. In doing so, they sometimes positioned students as less capable. For example, after watching the same video clip in Episode 5, NT-1 described what the TE said as, “[TE-1] said [they] understood that- if we filled the whole cell [of the ten frame], that's a full cell, but [TE-1] said [they] didn't understand how it made 10.” NT-1 then explained, “[TE-1 wants future teachers to understand that] you're not going to have everyone following because it's information we said, it's been a long time since [the teacher said it]. If we have a complete cell [in the ten frame], it gives 10 boxes and so we should have written it next to it.” When asked why this was important, NT-1 explained that primary school students “are not going to have the same abilities as us, so we must not take for granted they are following everything we do and that they will have the same ability to remember things.” In this excerpt, NT-1 drew upon two positional frames: (a) the teacher’s role is to clarify ideas for the students and (b) adults are different in their abilities to remember and understand. The NTs’ differing positional frames may have partly been due to their perceptions of the TE’s role in the rehearsal. NT-1 revealed that they understood the TE to be acting as an elementary student asking a question to the teacher. Because of this perception, NT-1 framed the problem as a *student* issue: that students may not be following what is happening because the information was said a while ago. In contrast, NT-2 understood the TE to be modeling a question for the rehearsing NT to ask, thus framing the problem as a *teacher* issue: that the teacher did not ask students to explain their thinking.

Discussion

In this paper, we have illustrated how different frames from NTs and the TE can shape how they interpret PoP in the rehearsal. Our findings highlight the affordances and limitations of learning through rehearsals of teaching. Both NTs were able to provide interpretations for all episodes, suggesting that they engaged with the feedback to some level. On the other hand, their understandings of the feedback often differed from what the TE intended. Our results also show that NTs constructed pedagogical concepts – connections between lived concepts (e.g., particular examples of questions teachers can ask) and formal concepts (general principles or theories about teaching and/or learning) (Horn et al., 2017). In many episodes, participants similarly described what TE-1 said and the actions that occurred in the rehearsal that prompted the interjection (the lived concepts). However, even with this alignment, they still often generalized the problem into a formal concept differently depending on the frames they used. This was evident in Episode 5: Both TE-1 and NT-2 described how the R-NT had failed to ask the student to explain his thinking, yet TE-1 generalized the problem as an issue related to targeting the instructional goal of the lesson. Although subtle, such connections may alter how NTs reason about and respond to future pedagogical situations. Our results also show how the complexities of the rehearsal context shifted which frames NTs drew upon. In particular, in Episode 5, their interpretation of the role of the TE changed how they drew upon and prioritized frames about teachers and teaching or frames about students. Thus, our results suggest that TEs and NTs need to have greater awareness of the frames that they bring to their collective inquiry of PoP.

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STEM Enrichment and Career Development: Analysis of NSF's Young Scholars Program

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Abstract: This paper examines data collected from in-depth interviews with 20 participants of the Young Scholars Program (YSP), a STEM enrichment initiative for middle and high school students in the U.S. that was funded by the National Science Foundation from 1988 to 1996. Using social cognitive career theory (SCCT) as the guiding framework, the analysis considers how the students' motivation, self-efficacy and sense of identity may have been influenced by the YSP experience and how these constructs may have been connected to the development of their careers. Applying epistemic network analysis (ENA) to the data, it was found that greater levels of STEM motivation, identity and opportunities were central to the career development of individuals who ultimately remained in STEM-related professions.

Introduction

Various STEM enrichment programs in K-12 settings have been implemented over the years to increase student knowledge, skills and interest in STEM topics and subjects. A key aim of such programs, particularly those funded through public resources, has been to support and encourage the entry of individuals into STEM-related academic disciplines and ultimately into the STEM workforce. However, whether a young participant eventually decides to pursue and sustain a career in a STEM-related field has been difficult to evaluate. The long-term retrospective study of the Young Scholars Program (YSP) is an effort to address this challenge. The YSP was a federally-funded STEM enrichment initiative that was carried out across the U.S. between 1988 and 1996. Designed for middle and high school students, the YSP sought to: (1) enhance participants' knowledge of and exposure to STEM fields; (2) foster interest in STEM education and research; (3) increase awareness of academic for STEM careers; (4) gain familiarity with universities and research institutions; and (5) enhance confidence in making career-related decisions (National Science Foundation, 1993). With more than twenty-five years having elapsed since the end of the program, the current age of YSP participants range from late 30s to early 50s. Through surveys and interviews of the YSP participants, the retrospective study seeks to examine the impact that the YSP may have had in the subsequent academic and professional trajectories of the young students.

In this context, this paper examines data collected from in-depth interviews with 20 YSP participants. Guided by social cognitive career theory (SCCT), this paper considers how the students' motivation, self-efficacy and sense of identity may have been influenced by the YSP experience as well as how these constructs may have been connected to the development of their careers. Building on Bandura's (1986) social cognitive theory, SCCT focuses on the role of self-efficacy and outcome expectation in mediating interests and goals that lead to choice behavior (Lent et al., 1994). It provides a framework for understanding the relationship and interactions among constructs affect career-related decision-making processes (Lent, Brown, & Hackett, 1994). SCCT also accounts for environmental factors and individual learning experiences in addition to personal attributes, such predispositions and demographic information (Lent et al., 2000). Through the notion of an iterative and dynamic feedback loop, SCCT recognizes the effect that previous career-related actions can have in subsequent decisions (Lent et al., 1994). While not an explicit component of SCCT, the importance of identity formation in career development has been emphasized, particularly in adolescents. In the process of identity formation, adolescents seek to gain a deeper understanding of their own beliefs, values and emotions as well as a sense of their interests and abilities (Gushue et al., 2006). A key component of this process is career exploration, whereby students begin to develop their own vocational or career identity (Macht Jantzer et al., 2009).

Methods

This paper analyzes data collected from semi-structured interviews of 20 YSP participants. Convenience sampling was utilized, as comprehensive lists of participant names and contact information were not retained for many of the YSP projects. The professional fields of YSP participants included in this analysis were split evenly between roles that are STEM-related and those that were not (see Table 1). Both groups of interviewees consisted of individuals from diverse demographic backgrounds.

Table 1

Summary of participants by professional field, gender and race/ethnicity

	Current Professional Field	
	STEM Field	**Non-STEM Field**
Gender		
- Female	5	8
- Male	5	1
- Non-binary	0	1
Race/Ethnicity		
- American Indian/Native American	0	1
- Asian	1	1
- Black/African American	2	2
- Hispanic/Latinx	1	1
- Pacific Islander	1	0
- White/Caucasian	5	3
- Other/Not specified	0	2
Total	**10**	**10**
Sample Professional Roles	Research Scientist / Administrator, Science Teacher, Professor (STEM), Aerospace Engineer, Computer Network Engineer	Artist/Writer, Designer, Judge, Professor (Non-STEM), Business Executive, Higher Education Administrator

Interviews were carried out using an online video conferencing platform. The first part of the interview focused on the experiences of participants during their involvement in the YSP while the subsequent portion concentrated on the development of their academic and professional careers and the influence of YSP in this process. The recorded interviews were transcribed and segmented by sentence. The data was coded independently by two raters using a codebook comprising a total of 13 codes organized around four categories: (a) topic/field; (b) self-reflective constructs; (c) description of YSP experience; and (d) career-related factors (see Table 2). Codes in categories a and b were applied to both sections of the interview data; codes in categories c and d were each applied to interview sections one and two, respectively. For each dataset, two coders reached agreement on the final coding through a process of social moderation (Herrenkohl & Cornelius, 2013).

Epistemic network analysis (ENA) was then used to model the connections between the codes present in the interview data. ENA is a tool in quantitative ethnography, applies statistical and visualization techniques to identify patterns in discourse (Shaffer, 2017). Specifically, connections among codes are modeled in ENA by quantifying their co-occurrences in the recent temporal context (Siebert-Evenstone et al., 2017). The unit of analysis was defined as a participant and a conversation was specified to be the set of lines contained within a section of an interview. A moving window of size 4 was used to model the co-occurrences of codes between a given line and three preceding lines in the same conversation. For each section of the data, subtracted ENA networks were created to compare the patterns of discourse in the reflections of YSP participants currently in STEM-related professional fields and those working in other sectors.

Table 2

Codebook of constructs included in the analysis

Category	Code	Description
Topic/Field	STEM	Direct reference to a STEM-related discipline, field, area or topic
	Non-STEM	Direct reference to a discipline, field, area or topic that is not STEM-related
Self-reflective constructs	Motivation	Gaining interest, desire or intent to pursue further action toward a goal; setting goals/expectations (to propel forward) or a having a sense of direction for the future
	Self-efficacy	Confidence, pride or sense of accomplishment in themselves; belief in one's own ability to complete a task, achieve a goal or succeed; expectation of positive change in their abilities
	Identity	Reference to sense of self, sense of independence or a sense of belonging; reference to permanent or long-term characteristic, ability or state the participant attributed to self
Description of YSP experience	Knowledge Acquisition	Gaining of knowledge or skills by the speaker; description of learning processes in which the speaker took part
	New Experiences	Reference to a new or eye-opening experience for the speaker; description of experiences that enabled the speaker to broaden their perspective

	Peer Interaction	Interactions, exchanges or relationships with peers in social and academic contexts; references to the development of interpersonal/social skills with other participants
	Engagement	Reference to active participation and involvement in an task, project or activity
	Positive Affect	Experience described through explicit expressions of joy, fun, excitement, positive regard
	Negative Affect	Experience described through explicit expressions of stress, sadness, anxiety, regret
Career-related factors	Career Opportunities	Reference to opportunities offered to the speaker for academic and professional development or advancement
	Career Challenges	Reference to academic, professional and personal challenges confronted by the speaker (challenges can refer to obstacles, loss of opportunities, failures, etc. that hinder advancement or development in a particular field, area or career path)

Results

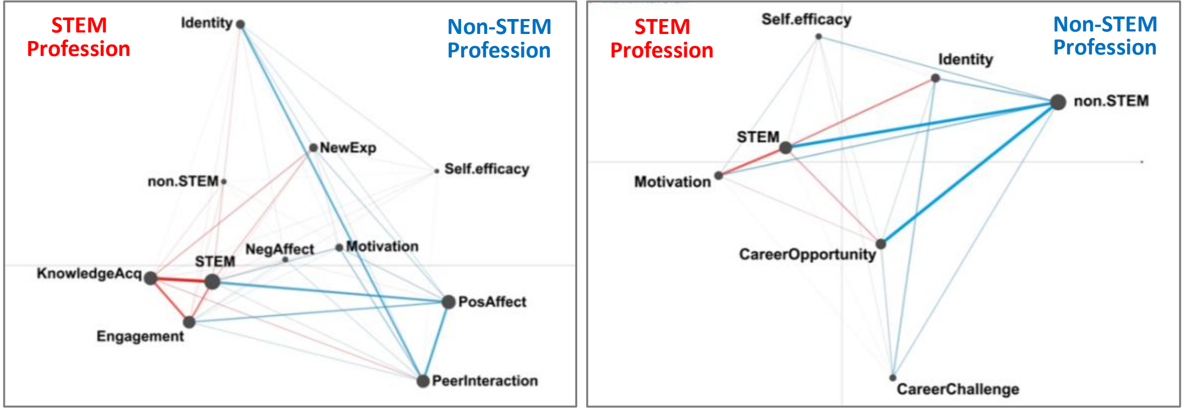
Reflections of YSP experiences

The first analysis explored the differences in the reflections of participants about their YSP experiences (see Figure 1a). For participants who are currently STEM professional fields, their discourse patterns exhibited relatively stronger connections among STEM, Knowledge Acquisition and Engagement. This suggests that the active involvement in the learning of STEM content during the YSP left a strong imprint in their minds. As one participant in this group noted: "…prior to the program, I had just a basic, most basic, rudimentary understanding of what science, engineering and math meant in the real world and this very much concretized my ideas, expanded my ideas" (Participant 13).

On the other hand, stronger associations between Positive Affect and both Peer Interaction and STEM as well as between Peer Interaction and Identity can be observed for participants in non-STEM professional fields. This points to the emphasis given to the sense of enjoyment and belonging that these students felt while being with each other and working on STEM-related activities. This connection was articulated in the following manner by a participant in this group: "Yeah, for me, it was just a sense of belonging and that what might have made a person cool or popular or approachable at school didn't really need to cross over into that particular space because we all knew that we were nerds like that. That was kind of like, you know, the baseline. So it's like, we [are] good…we don't have to compete" (Participant 2).

Figure 1

Subtracted ENA models for the discourse patterns of YSP participants in STEM and non-STEM professional fields: (a) reflections of YSP experiences; (b) reflections on career development and YSP influence



(a) (b)

Reflections on career development and YSP influence

Examining the differences in the reflections about career develop and the impact of the YSP, participants working in STEM-related fields displayed relatively stronger connections between STEM and the constructs of Motivation, Identity and Career Opportunity (see Figure 1b). This is indicative of the mutually reinforcing nature of gaining interest, finding opportunities and enhancing one's sense of belonging within the STEM domain. The linkages between STEM topics, identity, motivation and self-efficacy were captured in the comments by a participant in this group: "I think that having YSP and along with some of the other STEM programs that I participated in, I think all contributed to my love... I mean, number one, my love of science, but number two, that I could do it" (Participant 16).

For individuals who ultimately pursued other professional fields, the reflections placed greater emphasis on the connections between NON-STEM and CAREER OPPORTUNITY as well as between NON-STEM and STEM. The first association is likely to be indicative of the opportunities garnered from other fields that may have eventually led them to their current profession. At times, it was being in the right place at the right time. Reflecting on the shift that he had been asked to make at his company, one participant in this group reflected: "They didn't have somebody to head up product management and brand management and market management. So they asked me to kind of create and manage and develop a team for all of that globally. So I'm now over the product management and brand teams…" (Participant 11). Second, scientific thinking and reasoning continues to benefit participants despite their transition from STEM-related fields. Another participant described how she was able to apply scientific approaches to her first job: "I started that job a week after I graduated college, but there was something about again being thrown into, like this is how STEM is in the real world that I think just helped me be like…well, just take it one step at a time. You know, like, have a hypothesis" (Participant 6).

Discussion

This analysis focused on the interlinkages among motivation, self-efficacy and sense of identity contained in the reflections of YSP participants. Examination of key differences in the reflections of participants currently in STEM-related versus other professions revealed some interesting findings. First, participants working in STEM fields placed greater emphasis on the depth of STEM learning during the YSP, which was followed by higher levels of STEM motivation, STEM identity and STEM opportunities in the development of their careers. This may be reflective of the iterative feedback loop described in SCCT (Lent et al., 1994), whereby their YSP participation may have served as the first career-related action toward a STEM profession. Second, participants in non-STEM fields highlighted the role of peer interactions in enhancing their sense of identity and enjoyment with STEM topics during the YSP. Although they were drawn to other sectors by various opportunities, they nevertheless maintained a connection to the scientific approaches they had learned. Building on this preliminary analysis, further work should seek to investigate the how the three social cognitive constructs relate to career development at the individual level.

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Learning Scientists' Perceptions of Their Impact on Teacher Education Programs

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Abstract: Informing teacher education programs and impacting teaching practices has long been a stated goal of learning sciences research. As a first step in understanding the reality of this impact, we conducted a survey of individuals who identify as learning scientists from 39 different higher education institutions distributed internationally. Survey questions asked these learning scientists to describe both current engagement with teacher education programs at their institution and aspirations for future engagement. Results indicate that learning scientists see their current overall impact on teacher education as low-to-moderate, but they also perceive a high potential for stronger impact in the future. Barriers to successful engagement and specific ideas for how to build bridges with teacher education programs are detailed.

Introduction

From its origins, the learning sciences has coupled an investigation into the processes of learning with attempts to shape those processes in real world educational contexts such as classrooms. In the inaugural issue of the *Journal of the Learning Sciences* (JLS), editor Janet Kolodner states that the objective of the journal is "to foster new ways of thinking about learning and teaching that will allow the cognitive sciences to have an impact on the practice of education" (Kolodner, 1991, p. 1). Over the last three decades, JLS has become a top tier educational research journal, and the community of learning scientists continues to grow. However, the field's "impact on the practice of education" is difficult to assess. While there have been several papers and volumes that have described how research findings from the learning sciences can be used to inform the practice of teaching (e.g., Jurow et al., 2012; van Aalst et al. 2017), there is no simple metric with which to evaluate the extent to which these ideas are being taken up in schools. One place that may offer a partial picture of this impact is the interface between learning scientists and teacher education programs at higher education institutions that have both.

To conduct this investigation, we administered a survey to learning scientists and asked them several questions about their involvement with teacher education at their institutions. We took a similar approach as the "What Do Learning Scientists Do?" study (Yoon & Hmelo-Silver, 2017) which also surveyed learning scientists, though the unit of analysis in this study was institutions that had both learning sciences researchers and teacher education programs. We sought to collect survey responses from one learning scientist at as many institutions worldwide that we could reach, and we report on our initial findings from this survey below. We readily acknowledge that to get a more complete picture of the impact the field is having on teaching would require much more extensive engagement with pre-service and in-service teachers who are in teacher education programs, and perhaps also with students and to observe classrooms where these teachers are putting their training into action. However, we believe that a reasonable place to start this inquiry is to examine what activities learning scientists are currently involved in with their teacher education programs and what ideas they have for future involvement.

Survey

The impetus of this survey came from members of the International Society of the Learning Sciences (ISLS) Education Committee. The authors of this paper are a subgroup of the committee that was charged with developing and administering a survey that would inform future engagement efforts with teacher education programs.

Study recruitment and respondents

The aim of our survey was to get the broadest sense possible for how learning scientists are engaging with teacher education programs at institutions with a learning sciences presence. Because some institutions may have multiple learning scientists who interact in some way with teacher education and may share similar perceptions and experiences, our goal was to get a response from one person at each institution. Our purposive sampling method began by sending an email to the contact person identified for each institution in the Network of Academic Programs in the Learning Sciences (NAPLeS). This list, which is hosted by the ISLS website, currently includes 39 institutions with a learning sciences program. We identified additional institutions with learning scientists through contact recommendations from the ISLS Education Committee, the ISLS leadership team and Board of

Directors, and survey respondents. In total we sent survey invitations to individuals identified as learning scientists at 66 universities. We received responses from individuals at 39 different universities, resulting in an institutional response rate of 59%. Of the 39 survey responses we received, 25 were from US or Canadian institutions, 8 from Europe or the UK, 5 from Asia or Australia, and 1 from South America.

Survey framing

The survey was administered using Qualtrics and participants accessed the survey using a weblink that was sent to identified learning scientists at each institution. After completing a consent form, participants were taken to an introductory screen that explained the intent of the survey and why they were being invited to participate. Part of this framing text states: "*We have asked you to take this survey because you have been identified as a learning sciences researcher who has significant interaction with, or significant knowledge about, the teacher education programs at your institution.*" To ensure clarity, we defined teacher education programs as "*the instruction, mentoring, and training that aims to prepare individuals to teach in formal education contexts."* Although survey respondents self-identified as learning scientists, we still felt it important to establish a shared definition that participants could refer to when giving their responses, and so we stated the definition of the learning sciences given by ISLS: "*the interdisciplinary empirical investigation of learning as it exists in real-world settings and to how learning may be facilitated both with and without technology.*"

Structure and items

There were 28 total items on the survey comprising a mix of short answer, closed-list selections, and open-ended responses. It took most participants between 15 and 30 minutes to complete the survey. The first six items asked basic institution and contact information (respondent's name, title, email, institution name, department or unit name, and a brief 1-2 sentence description of any unique characteristics or emphases of the learning sciences program at their institution). The overall approach for our substantive questions was to inquire about both the *current state* of the interface between learning sciences and teacher education programs at their institution, as well as what they see as the *potential* for interaction in the future. For example, the first question from the body of the survey was "*On a scale of 1-7, with 1 being very low and 7 being very high, how much does learning sciences research influence teacher education programs at your institution* ***currently****?*" This question was immediately followed by the question "*How much potential do you believe there is for learning sciences research to influence teacher education programs at your institution* ***in the future****?*" The body of the survey was grouped into 4 primary topic areas: 1) **General** questions about the relationship between learning sciences and teacher education programs, 2) **People**, 3) **Courses**, and 4) **Outreach and Informal Activities**. For each of these topic areas there were questions that asked the respondent to rate the current and future impact/engagement of the learning sciences with teacher education programs (e.g., "*How much do you believe the* ***teacher education courses*** *at your institution draw upon the learning sciences?*"). These questions were followed by a closed list question that allowed participants to select the specific areas or activities where the engagement was manifest.

Each topic also included 1-2 open-ended questions seeking institution specific details about the engagement activities. For example, the survey asked the respondent to list the names of courses "*that explicitly incorporate learning sciences theories and empirical research*." The survey also asked for respondents' ideas for how learning scientists could engage teacher education programs in the future. Under the topic of Outreach and Informal Activities, for example, the survey asks: *Briefly list some of the ideas you have for how learning sciences theories and empirical research could be applied to* ***outreach and informal learning*** *opportunities for teachers at your institution (but do not currently).* The survey was also asked about perceived challenges to having a successful impact on teacher education programs.

Survey findings

Because we explicitly sought the perceptions of learning scientists, two of the 39 respondents were removed from the sample because they rated themselves a 3 or lower, out of 7, on the "identifies as a learning scientist" item.

Quantitative results

Table 1 shows the average rating to five survey questions that asked participants to respond on a 1 to 7 scale, with 1 being very low and 7 being very high. Except for the two respondents removed from the dataset, the individuals who completed this survey generally reported a strong identification with the learning sciences (mean of 6.1, *SD*=1.1). This suggests that we were overall successful in directing this survey to individuals who saw themselves as learning scientists.

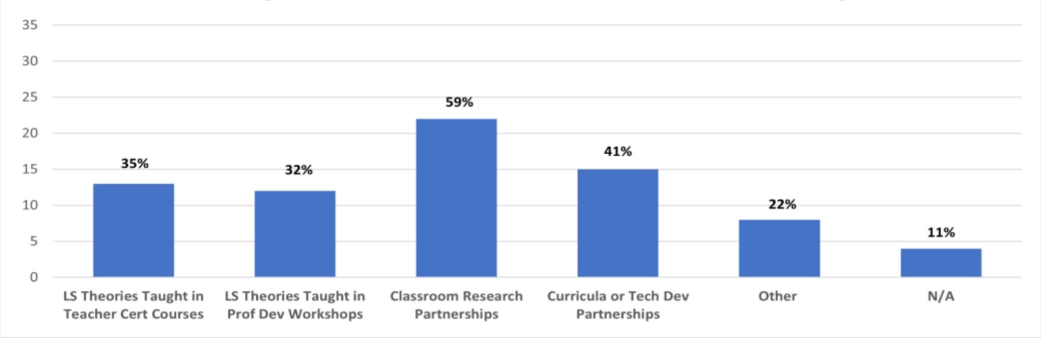
Table 1
Average survey responses on scale of 1 to 7.

Survey Item	Average Rating	SD
How much do you identify as being a Learning Scientist?	6.1	1.1
How much does Learning Sciences research influence Teacher Education programs at your institution *currently*?	3.2	1.4
How much potential do you believe there is for Learning Sciences research to influence Teacher Education programs at your institution *in the future*?	5.2	1.4
How much do you believe the Teacher Education courses at your institution draw upon the Learning Sciences?	3.1	1.4
How much do you believe the outreach and informal learning opportunities for teachers at your institution are influenced by the Learning Sciences?	3.4	1.7

On average, survey respondents rated the impact of learning sciences research on teacher education programs at their institution as 3.2 (*SD*=1.4). This suggests that learning scientists see their impact on teacher education as low-to-moderate. However, when asked about the *potential impact*, respondents gave an average rating of 5.2 (*SD*=1.4), a full 2-point average difference compared to the current impact. Perceptions of impact from learning sciences research on courses in the teacher education program (3.1, *SD*=1.4) and on informal learning opportunities for teachers in teacher education programs (3.4, *SD*=1.7) were also in the low-to-moderate range.

When asked about specific activities where learning sciences research intersected teacher education programs at their institution, many respondents reported that multiple different activities were occurring (Figure 1). For example, over half of the 37 respondents (22) indicated that teachers in the program were being exposed to the learning sciences through classroom research partnerships, and 41% of respondents (15) reported teacher involvement in curriculum or technology development projects influenced by the learning sciences. About a third of respondents (13) indicated that learning sciences theories were explicitly taught in teacher certification courses. Only 11% of the survey participants (4) indicated that none of the listed activities involving learning sciences research were occurring. Eight of the respondents selected “Other” and listed some additional activities such as “*Learning Sciences researchers run workshops that student teachers are invited to*.”

Figure 1
Number of responses (and percentage of 37 total respondents) for each answer to the question: “What are some of the ways Learning Sciences research influences Teacher Education programs at your institution currently?”



Qualitative results

The authors adopted an emergent coding approach (Charmaz, 2008) to analyze the open-response questions on the survey. We each individually read the responses, made notes about the emerging categories, and then we engaged in synthesis conversations about the important themes that came from the surveys.

Several respondents described a ***perceived lack of awareness of the learning sciences*** at their institutions, both within specific departments and across disciplines that may ordinarily be considered linked to the learning sciences. For example, when asked to describe the barriers to engaging with teacher education programs, one person stated, "*A barrier might be that other faculty that are involved in Teacher Education at my university do not have a clear picture of what the 'Learning Sciences' actually is.*" This perception that academics outside of the learning sciences are not familiar with the field seemed to contribute to the overall low-to-moderate impact assessment that respondents conveyed.

While some survey respondents cited ideological differences or definitional issues with integrating learning sciences into teacher education programs, it was more common for them to refer to **structural and pragmatic challenges**. In most institutions learning scientists are situated in different departments than teacher education programs, meaning that any attempts to collaborate or exert influence was susceptible to typical issues of academic siloing and associated resistance to cross-disciplinary work.

The learning scientists who took this survey generally acknowledged that their field was seen as **more focused on long term research goals**, such as contribution to theory, and **less on the application of that theory to practice in the classroom**. While many felt that learning sciences theory and findings have much to offer to teacher education and teachers, there has not been enough translational work and application to provide an immediate value-add. As one respondent put it "*most LS research does not speak to the reality of teaching or student learning in an accessible way*."

Finally, respondents felt that **publication pressures and metrics associated with promotion** were barriers to engaging more formally with teacher education programs. Multiple respondents referred to a "*perceived lower prestige of teacher education*" as a possible reason why more learning scientists do not choose to engage. A couple of people noted that there seemed to be a lack of bidirectionality in the work that learning scientists carry out in the field of teacher education; there is a sense that the learning sciences only informs teacher education and not the other way around.

Strategies to build bridges and concluding remarks

The most frequent suggestion was for there to be co-development of funded research projects with teachers as research partners or co-investigators, rather than cultivating a perception of teacher education programs as "testbeds" for learning scientists to conduct their research. In addition to increasing the amount of research done with teachers as part of teacher education programs, it was also suggested to adjust the focus of research to make it more relevant and timelier to teachers. For example, a number of respondents suggested more emphasis on equity considerations in research with teachers, where these considerations are front and center to their practice. It was widely stated that co-planning teacher education programs would provide the best opportunity to address challenges perceived by the learning scientists who took this survey. It was believed that meaningful partnerships would provide a pathway for a more nuanced integration of learning sciences theory into the curriculum that might then translate into teaching practice.

A reasonable next step would be to extend this inquiry into a survey or interview with select teacher educators and teacher education students who are participants in the programs captured in this survey. Asking these individuals about their perceptions of the learning sciences–either by name or by relevant theories and ideas–could be one component to understanding how effective learning scientists are in engaging with these programs.

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What Influences Epistemic Actions on Social Media?

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Abstract: Social media have permeated people's lives and have become spaces where people retrieve and engage with information. Social media offer opportunities for epistemic engagement with information, which may be demonstrated by people's goal-oriented epistemic actions during information evaluation. This study examined whether epistemic actions are influenced by individual or contextual characteristics. Adults (n=242) were presented with a Twitter post focused on the impact of meat consumption on climate change, using different rhetorical appeals and were asked to decide on the actions they would take on the post. Findings indicate that while the type of rhetorical appeal did not directly influence epistemic actions, personal characteristics – demographics, epistemic beliefs– did. Implications for learning and future research directions are discussed.

Introduction and theoretical framework

In 2022, 4.59 billion people were reported to use social media platforms, worldwide, and the number is projected to reach six billion by 2027 (Statista Search Department, 2022). Yet, social media as spaces for informal learning is still an under-explored area (Greenhow & Lewin, 2016). The use of social media for learning has been mostly investigated in higher education settings, with the goal of making classes more engaging and participatory (Evans, 2014). In a review of K-12 teachers' use of social media for teaching or for professional development between 2004-2017, yielded only five studies reporting on learning and, of these, only one study discussed student learning (Greenhow, Galvin, Brandon & Askari, 2020). While researchers have argued that social media can help bridge formal and informal learning, others argue that social media practices do not portray advanced forms of learning (Greenhow & Lewin, 2016). The present study is motivated by the overwhelming presence of social media in our everyday activities and the scant attention that this engagement has received so far in learning sciences research. Coupled with reports about the pitfalls of using social media and the risks of being exposed to and influenced by misinformation, we aimed to understand which personal or contextual characteristics might mediate laypeople's epistemic engagement with a social media post. We take a situated view of epistemic engagement, contextualized in the actions laypersons take on posts encountered on social media; epistemic actions indicate information exploration and aim to enhance understanding or further knowledge.

Epistemic engagement on social media may be influenced by the affordances and constraints of the social media platform and by the message characteristics. In this study we examined epistemic engagement on the same simulated social media platform but varied the message design by using three Aristotelian rhetorical appeals for creating persuasive messages (Cope & Sandys, 2010): logos, ethos and pathos. *Logos* refers to the rational aspect of discourse, and specifically to fact-oriented argumentation; *Ethos* refers to qualities that may convey credibility or reliability; and *Pathos* refers to emotional appeals during communication that may lead to the experience of emotions. Appeals to reason (logos) may include claims, warrants, evidence and conclusions; appeals to credibility (ethos) may include references to one's professional expertise or experience and appeals to emotion (pathos) may include emotionally charged language or outline a positive or negative scenario. Aristotle argued that communication is persuasive when all three rhetorical appeals are employed by the speaker. However, on social media, where persuasive information may be short in length by design, there is a restriction on the number of appeals that a speaker can rely on. Hills (2019) coded Twitter posts around politicized issues and found that only 5 out of 300 posts relied on all three appeals; the majority of posts relied on appeals to credibility (ethos). In an analysis of misinformation strategies used in over 26,000 misinformation posts on social media, Chen et al. (2021) found that the rhetorical strategy mostly employed was appeal to negatively-valenced emotions.

Personal characteristics may also influence one's epistemic actions on social media. Cano (2005) reported differences between secondary school girls' and boys' epistemological beliefs, suggesting that it might be worthwhile to explore the impact of gender on the participants' epistemic actions. Finally, capacity for self-directed actions, goal setting and beliefs are formed over one's life and may differ depending on lived experience. Therefore, in this study we explored whether the participants' epistemic actions differed due to demographic characteristics, such as age and stage of life.

Research questions

Based on prior work and the review of the literature, we, therefore, asked the following research questions:

a) Can a short (about 280 characters) post on a controversial issue on social media elicit epistemic actions? b) Does the design of the message of the post have an effect on the participants' epistemic actions? c) Did epistemological beliefs and climate change attitudes influence intent to take action in response to a post? And d) What is the relationship between beliefs, intentions, trust and epistemic actions?

Methods

Intervention and participants

We collected data from 242 adults (male:126; female:115; prefer not to say:1) using a representative sample through an online panel in Cyprus. Participants were randomly assigned to one of four rhetorical appeal stimulus conditions (Ethos: 59, Logos: 61, Pathos: 61, Combination: 62) and were matched on age, gender, education, field of education and vegetarian status across all conditions. Participants in each condition were asked to indicate the extent to which they trusted the post using a Likert scale of 1-10 and explain why. They were then asked to what extent they would take any of the following seven actions: (a) like, (b) share the post with others, (c) add a comment, (d) search for additional information, (e) save the post for future examination, (f) follow the profile of the user to receive updates on new posts, and (g) search for other posts by the same user. Finally, participants were asked to indicate if the post persuaded them to reduce meat consumption and whether they would take any other actions. The intervention used four variations of a Twitter-like post on the controversial issue of the climate impact of red meat consumption. Each condition used a different rhetorical appeal: Ethos (C1), Logos (C2), Passion (C3), and a combination of all Ethos, Logos, and Passion (C4). *Ethos* named a scientist, an academic institution and a journal, *Logos* used argumentation to illustrate a logical argument, *Pathos* used emotional language and second-person pronouns for personal appeal, and *Combination*, combined elements of all three.

Data collection and analysis

The participants' science epistemology beliefs and climate change beliefs and intentions were collected at the end of the intervention through two validated surveys: the Scientific Epistemological Beliefs Instrument -SEBI- (Lin & Tsai, 2017) and the Climate Change Attitude Survey -CCAS- (Christensen & Knezek, 2015). Demographic data on age, gender, educational background, use of social media and vegetarian status were also collected. The quantitative data were analysed using SPSS 26.0 and Mplus 7.3. To examine the differences among versions of stimuli, we conducted a MANCOVA analysis, having stimulus condition (C1, C2, C3, C4), age, gender (male, female, prefer not to say), and vegetarian status (yes, no) as independent variables. The level of trust and the various actions (a-g) the participants could take were set as the dependent variables, while the factors of the SEBI and CCAS questionnaires were set as covariates. After this analysis, a path model using Mplus was performed, to test the relationships between beliefs, level of trust, and willingness to take various actions. Correlations between the continuous variables in the study were also run, along with linear regression analyses to examine whether actions could be significantly predicted by epistemological beliefs and climate change beliefs.

Findings

Did the social media post elicit epistemic actions?

Participants viewed the post on a screen and were then asked to indicate if they would take an action in response to the post they viewed using a Likert scale of 1-10. Regardless the rhetorical appeal condition, most participants indicated higher tendencies for intention to act for the same two actions: a) search for additional information, and b) review the author's profile to examine other posts they have shared. Therefore, we can assert that, even if the post is short, social media can also provide space for activating epistemic engagement.

Did the design of the post have an effect on the participants' epistemic actions?

The Aristotelian rhetorical appeals (ethos, logos, pathos) are still used as strategies to create persuasive texts. In our analyses we examined whether any of these appeals, or their combination, could have a differential effect on how persuasive the post was and on one's intent for epistemic engagement. A MANCOVA examined the unique and interaction effects of the independent variables (stimulus condition, age, gender, vegetarian status) on the dependent variables (level of trust in provided information, various actions), when controlling for their beliefs and intentions about climate change and their science epistemological beliefs. It was found that the stimulus condition did not have an independent effect on the dependent variables, when controlling for the beliefs and intentions about climate change and the participants' science epistemological beliefs, with Λ=.82, F=1.27, p= .16, $\eta_p^2 = .07$. Age, gender, and vegetarian status all had significant unique effects on the dependent variables, with Λ=.74, F=1.87, p= .004, $\eta_p^2 = .09$, Λ=.83, F=1.78, p= .022, $\eta_p^2 = .09$ and Λ=.87, F=2.58, p= .006, $\eta_p^2 = .13$, respectively.

Further exploration showed that males (M= 6.30) who were in the *ethos condition* had higher levels of trust compared to females (M=4.66; p= .003) but had lower levels of trust compared to females when they were in the other three conditions and especially when they were in the *logos condition*. Similarly, males from the ethos condition were less likely to perform any actions on the post compared to females (M=1.94, M=1.96, whereas in all other conditions females were less likely to perform any actions on the post compared to males (logos: M= 1.52, M=1.80, pathos: M=1.76, M=1.90, combination: M=1.83, M= 1.95).

Relationship between beliefs and epistemic actions

Beliefs about climate change and intentions about climate change did not have independent effects on the level of trust or on the willingness to take actions about the presented information, with Λ=.94, F=1.24, p= .27, $\eta_p^2 = .07$ and Λ=.95, F=1.04, p= .42, $\eta_p^2 = .05$, respectively. Between-subject effects showed that beliefs about climate change had a significant effect on the level of trust (F=6.34, p= .013) and on sharing the post (F=4.10, p= .044), whereas intentions towards climate change had a significant effect on commenting on a post (F=4.85, p=.029). Multiplicity and uncertainty of knowledge had a significant unique effect on the dependent variables, with Λ=.89, F=2.14, p= .02, $\eta_p^2 = .11$, but the other two factors — development and justification of knowledge and purpose of knowing and knowledge — did not, with Λ=.99, F=0.27, p= .99, $\eta_p^2 = .02$ and Λ=.94, F=1.06, p= .40, $\eta_p^2 = .06$, respectively. Linear regression analyses of whether *actions* could be significantly predicted by epistemological beliefs and climate change beliefs, regardless of the stimulus condition showed that the model was significant with F(1, 240)= 14.62, p< .001 and could predict 6% of the variance of trust. Believing that climate is changing predicted increased trust in the posts. The regression model for *liking the post* was significant with F(1,240)= 11.11, p= .001 and could predict 4% of the variance of liking the post. The only independent variable that could significantly predict this action was Multiplicity and uncertainty of knowledge, with b= -.21, t= -3.33, p= .001. That is, believing that knowledge is retrieved from multiple sources and is uncertain predicted less likes of a post. The regression model for sharing a post was significant with F(1, 240)= 18.33, p< .001 and could predict 8% of the total variance of this action. The variables that could predict *sharing a post* was Multiplicity and uncertainty of knowledge, with b= -.27, t= -4.28, p<.001 and beliefs about climate change, with b= .13, t= 2.04, p= .04. That is, believing that knowledge is retrieved by multiple sources and is uncertain predicted less shares of the post and believing that climate is changing predicted more shares of the post. The only independent variable that could significantly predict this action was purpose of knowing and knowledge, with b= .13, t= 1.99, p= .047. That is, believing that there is a purpose in knowing and in knowledge predicted more checks of the profile who did the post. The regression model for reducing meat consumption was significant with F(1,240)= 24.80, p< .001 and could predict 12% of the variance of meat reduction. Reducing meat consumption was predicted by Multiplicity and uncertainty of knowledge, with b= -.31, t= -4.98, p< .001 and beliefs about climate change, with b= .17, t= 2.77, p= .006. That is, believing that knowledge is retrieved by multiple sources and is uncertain predicted lower reduction in meat consumption and believing that climate is changing predicted higher reductions.

Effect of age and gender on trust and intent to act

Younger participants were less likely to comment on the post (M= 2.86, p< .001) or share the post (M= 3.14, p= .017) compared to older participants (M= 5.33 and M= 4.60, respectively). Also, older participants (50-64: M=5.33, p= .003 and 65+: M= 5.69, p< .001) were more likely to report that they would reduce their meat consumption after reading the posts, compared to the younger participants (18-29: M= 3.57).

Relationships between beliefs, intentions, level of trust and epistemic actions

The interactions between the continuous variables of the study were also examined using a path model in Mplus to identify any causal relations. The variables inserted were level of trust, actions on the post, beliefs about climate change, intentions towards climate change, Multiplicity and uncertainty of knowledge, development and justification of knowledge, purpose of knowing and knowledge. The path model showed that believing that the climate is changing predicted higher levels of trust of the participants on the posts. Then, higher levels of trust predicted more willingness of the participants to act on the post with various actions. However, actions that needed more effort (i.e., commenting on the post, following account, reducing meat consumption) were also predicted by lower levels of Multiplicity and uncertainty of knowledge. Believing that scientific knowledge is constructed by self-acquired knowledge from multiple sources and that knowledge is certain resulted in participants reporting that it was more likely to comment on the post, follow account or reduce meat consumption.

Discussion

This study investigated adult laypeople's responses to a controversial statement on a social media post, seeking to understand the epistemic actions the participants wished to take, but also which factors might influence their epistemic engagement. As laypeople's epistemic engagement on social media is an under-examined area of study (Greenhow & Lewin, 2016) we asked the question of whether such encounters with short social media posts have the capacity to elicit or activate epistemic actions. We then asked which individual or contextual characteristics might be influencing epistemic engagement and explored relationships between them. The first finding is that social media posts can activate one's curiosity and interest to search for additional information on a controversial issue as indicated by their intention to take knowledge-driven actions. This is promising, as it shows that laypeople can activate resources to approach even a short social media post from a critical point of view. Nonetheless, we do not know if they would do so without the prompting of this experimental setup. A second main finding was that even though a short post on social media can elicit epistemic actions, analyses show that there was no straight-forward relation that explained what influenced which action. Rather, epistemic engagement appears to resemble a complex system "composed of a number of constituent components" (Mercer, 2011, p. 435). In this study, we examined whether the persuasive characteristics of a social media post might influence participants' epistemic actions. We also explored the possibility that other factors, such as demographics and beliefs might be influencing one's intent to epistemically engage with the information on social media. Results suggest mediation effects, as also suggested by the path analysis model and the regression analyses. Findings reinforce that people notice different aspects of a message and this has implications for educational and instructional practices. Adopting a virtue responsibilism approach, which "characterises intellectual virtues as acquired or learned cognitive character traits such as curiosity, intellectual autonomy and open-mindedness" (Heersmink, 2018, p.2), we would like to argue that differences, and interactions, such as the one identified in this study can alert the teacher or designer of learning scenaria that they need to support learners' understanding of persuasion strategies used in the design of social media posts. Our study was short in duration and was limited to the participants' sharing of their intended actions. Epistemic engagement is more than intentions though. This study has identified several open questions that we believe should be explored in future studies through more in-depth qualitative work.

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What Can Students Learn From Their Own Data? Data Literacy With Student-Facing Learning Analytics

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Abstract: With the increasing need to make sense of the ever-growing quantity of data originated from digital interactions, data literacy skills become a basic requirement to navigate everyday tasks. In the field of education, data has gained wide attention, especially with the introduction of analytics from teaching and learning data. Current trends of research on data literacy in learning sciences focus on educators' needs of specific training and knowledge about how to make data-driven decisions that benefit students' progress. Despite little research at the intersection of developing learning analytics (LA) for students and developing their data literacy skills, we argue that student-facing learning analytics (SFLA) can be leveraged for strengthening students' data knowledge and skills. Based on an integrative review of existing literature, we briefly discuss several important considerations that will benefit future implementations at the intersection of SFLA and data literacy.

Introduction

The growing availability of data and, more importantly the need to make sense of them, in technology-mediated societies has caused the rise of data literacy (DL) as one the key skills for the 21st century. D'Ignazio (2017) refers to DL as the knowledge about "how to collect, find, analyse, and communicate with data" (p. 6) and adds to its benefits the emancipatory power that comes with a critical inquiry supported by data. DL gains relevance in the knowledge society, as social, economic, and civic participations rely more on data-mediated interactions. Therefore, critical perspective on how data systems interact with the world, and the role humans play in how data is collected, analysed, and used, is crucial given the ubiquity of artificial intelligence (AI) in everyday situations (Markham, 2020).

The increase in data availability has permeated various fields, with teaching and learning being no exception (Lang et al., 2022). Particularly, this concerns the field of Learning Analytics (LA), which relies on data collection, analysis, and interpretation for understanding learning (Lang et al., 2022) and informing teaching and learning practices (Hernández-de Menéndez et al. 2022). Research recognises two main skills demanded for the success of the LA-enabled classroom, namely 1) data literacy, for being able to interpret data; and 2) connecting data to pedagogic knowledge, for being able to adapt teaching and learning practices based on information provided by the data (Papamitsiou et al., 2021).

While some LA-tools are designed for teachers, student-facing learning analytics (SFLA) are directed exclusively for students. SFLA track behaviours of students in online learning environments and report such data as feedback back to the students (Galaige et al., 2022). SFLA has the premise to promote student agency and involvement, and thus, students' autonomy in their own learning (Bodily & Verbert, 2017; Hu et al., 2022). SFLA is expected to empower learners to take responsibility for their own learning, improving learning experiences and outcomes (Galaige et al., 2022; Lang et al., 2022) by offering authentic learning experiences.

Despite the need of DL for LA is often mentioned as a prerequisite for successful LA implementations (Papamitsiou et al, 2021, Wolff et al. 2016), students' data understanding and practices are often forgotten in research (Xing & Wang, 2021). In studies with SFLA, students are expected to benefit from monitoring their own learning behaviours progress with LA tools. However, this has been found to be overwhelming for most students (van Leeuwen et al., 2022). Given that current research relies on the assumption that students are capable of understanding the information that is presented to them in SFLA, it also becomes crucial to address DL skills in the same context. Therefore, we are interested in unveiling whether and how students can acquire data skills by interacting with LA tools that are directed for them.

In this study, we aim to provide preliminary answers to how recent research has studied the relationship between students' DL and SFLA, and illuminate if this interaction can provide an authentic learning environment that may naturally benefit students' DL. We conducted an integrative literature review (Torraco, 2016) to synthesise representative perspectives of emerging discussions and practices at the intersection of these topics. In the rest of this paper, we first introduce the methods used to investigate the literature, and then present the synthesis of the literature review results followed by a discussion of the findings.

Method

We conducted an integrative review of the literature (Torraco, 2016) to investigate the relationship between data literacy (DL) and student-facing learning analytics (SFLA) in current research. An integrative approach for reviewing the literature is suited for emerging topics that have not been yet reviewed comprehensibly and helps establish a preliminary conceptualisation of the topic of interest (Torraco, 2016). For defining the search strategy, we started from the premise that SFLA can be adopted for leveraging DL skills among students, and defined search queries that include specific keywords such as "learning analytics", "data literacy," and "student-facing learning analytics." We searched for potentially relevant articles using three major databases: Web of Science, Scopus, and the Association for Computing Machine Digital Library (ACM-DL). The queries matched title, abstract, and keywords in all databases, and we did not impose restrictions for language or publication year.

After deleting duplicates, the total number of records identified by the search is *N*=85, including records published between 2012 and 2022. By far, the most popular venue for publications about these topics is the International Conference on Learning Analytics and Knowledge (LAK), and other venues include conferences and journals related to human-computer interaction and educational technology. The results contained *N*=6 conference proceedings and workshops, *N*=10 review articles, *N*=1 article in Spanish, and *N*=1 not in the field of LA (addressing DL in the field clinical neuroscience research) which were excluded from the review. After this elimination, *N*=67 papers were considered for further evaluation. Relevance of each article was assessed based on their inclusion of DL within the context of LA/SFLA, or vice versa. We include all empirical and theoretical studies that are published in English, and that discuss explicitly the relationship between DL and LA or SFLA; and articles that do not include students in these discussions were excluded. All articles were screened based on title and abstract. First, we filtered out articles that exclusively focus on technical development or advancements of LA tools or guidelines, or that do not focus on students as the primary beneficiary group of DL or LA (*N*=41 excluded). Nonetheless, some of these articles were also read to find other ways in which DL and LA research has been conducted so far; for example, among teachers. Then, we aimed to identify within the remaining articles (*N*=26) those that either address the relationship between DL and LA/SFLA, or studies that evaluate how DL and LA/SFLA impact students' outcomes.

We identified the emerging themes from the literature based on iterative reading of the pool of articles. Because the purpose of the review is to provide integrative synthesis of the existing literature and explore perspectives that might have not been fully explored, we first identified the main concepts developed in each of the articles, and then synthetise the emerging ideas in themes that encompass related concepts (Torraco, 2016). We grouped ideas in two themes that are presented in the following section.

Preliminary results

From the reviewed literature, we identified *N*=26 articles that include DL and LA/SFLA within the same discussion, and *N*=11 of them focus specifically on students. From these studies, we identify two major themes: 1) Reiterating the need for data literacy: Studies that identify the need for DL for adequate design, implementation, and widespread adoption of LA/SFLA, or that aim to assess the factors that play a significant role in this process; and 2) Gaming the system: Studies that have implemented practices to develop data skills with SFLA use.

The need for data literacy

Researchers are not oblivious of the critical need for DL to grow the development and adoption of LA systems across different educational levels and stakeholders. *N*=16 of the articles reviewed include explicit remarks on the lack of DL skills and why it is important to increase their presence for effective LA implementations. Only *N*=4 of them addressed this need specifically for students. Yet, none of them elaborate on strategies to promote DL among students in the setting of LA-mediated learning. All the studies discuss the topic in the higher education context. Some studies (*N*=2) find statistically significant support for DL as a critical mediator of the acceptance, usage, and perceived usefulness of LA systems. Xing and Wang (2021) found that university students' data literacy significantly influences the perceived data autonomy, digital identity, and reflectiveness, and students' data practices are culturally mediated. Similarly, teachers' pedagogic competence for teaching technology-related topics is strongly related to students' data literacy as identified by Lin et al. (2022).

On the other hand, frameworks and guidelines emerging from practical implementations or a series of interviews or workshops to identify needs and usability of SFLA designs, often remark that the complexity of information presented to the students requires contextualisation and pedagogical support to interpret the analytics (Chen et al. 2018). Wise (2014) identifies that effective design of SFLA tools should not only consider that students are provided with the relevant information about their learning but that they can interpret such information leading to satisfactory performance. Interpretation of information conveyed through SFLA might be scaffolded with the acquisition of DL skills.

Wasson and colleagues (2016) are more specific on their requirements for data literacy and use for learning. They recognise the need for assessing various configurations of SFLA tools and their impact on data generation, and thus, the competences required for interpreting the results. Reflections arising from their findings on data literacy use for teaching serve to pose questions about what kind of data is representative of students' learning, how to present this information to students, and what students need to know about LA, self-reflection, planning, or self-directed learning to make sense of the information and being able to learn with it. Conclusions from their research emphasise the need for a framework that addresses these concerns while advocating for ethics, privacy, and protection of data.

To game or not to game the system?

One of the most common fears that researchers and teachers might face when introducing SFLA to learners is that they gain sufficient knowledge about how the system works and will try to obtain the desired performance without *really* learning nor achieving learning outcomes. In this review, we identified practices (N=2) that resemble the intuition behind trying to *game the system*, but that actually benefit understanding of how data is collected, processed, analysed, and presented, and offer students an opportunity for learning through critique. Shibani et al. (2022) promote critical engagement with automated feedback in a writing analytics tool. Essays written by students are analysed automatically by the system, and then students must answer whether they agree on the output and argue why. With this critical posture, students should annotate the feedback and adjust their writing if they consider it necessary. While this approach is effective for promoting awareness that data systems could be wrong, there is no explicit scaffolding for students to make sense of the information received, and the learning is focused on their writing skills.

Kitto et al. (2018) take this intuition one step further. They propose "Active Learning^2 (squared; AL^2)," a framework to motivate DL through ill-performing machine learning (ML) models. In their implementation, students learning task is to post comments on a discussion forum, from which their performance is classified and presented back to the students. Later, students learn how text classification works and what their behaviour profile looks like; then, they are required to challenge the classifications that they think are wrong. In this way, the learning is two-fold (AL^2): This re-labelling is used by the system to improve algorithmic performance, while students are exposed to an open reflection of how ML models work, and more importantly, how they can produce a wrong output.

We identify two driving factors in the interventions described: 1) pedagogic design that allows students to interact with SFLA and not simply blindly rely on the output, and 2) the possibility of imperfect ML models driving the results. In this scenario, DL is an enabler and a side learning outcome that empowers learners to be critically aware and escape the repetition of patterns often encouraged by some designs of LA systems. As if they were trying to *game the* system, students are required to learn how the system produces its outputs and try to beat it, but they must reflect on whether the output could be incorrect, why, and how to make it better. This pedagogic approach with SFLA does not attempt to group or rank students but takes advantage of the imperfections of the system to actively engage them in a critique process that also benefits disciplinary learning outcomes. The critical posture adopted by students incites to liberate learning from algorithmic bias and alight data usage and transparency issues that usually accompany data-based systems (D'Ignazio, 2017).

Finishing remarks

The study of data literacy (DL) and learning analytics (LA) has shown their importance for improving learning and, more importantly, their interdependence. Current literature has noted the close relationship between DL and LA but is dominated by one way of the relationship: DL is essential for the development and implementation of LA. Nonetheless, how LA supports the improvement of DL among its users has not been widely discussed yet. In this review we aimed at identifying current discussions and practices around the use of student-facing LA (SFLA) for improving DL among students.

This review revealed the fact that the research at the intersection of these two topics is scarce, yet the potential of SFLA as precursor for DL has started to be studied and offers attractive paths for new research. We identified innovative and promising practices that serve this purpose, yet none of the studies attempted to measure the effect of LA/SFLA usage over DL. Empirical interventions aimed at this objective should benefit our understanding of how students learn about data in an authentic learning environment. Learning supported in this premise should include designs with sound theoretical and pedagogical backgrounds that encourage students' reflections on their analytics and cultivate critical practices around data, including ethical considerations that comprise the whole process.

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Arts as Critical Transdisciplinary Pedagogy: Awakening Relationality Through the Anti-Oppressive Facilitation of Soil Painting on the Land

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Abstract: Mobilizing the power of arts in and through inquiries within the field of learning sciences can forge a new space for learning. Our paper highlights how arts-based methods inaugurate spaces for critical transdisciplinary understanding of soil with refugee children who participated in our multimodal land-based learning program. Refugee children's artwork and dialogic interactions were examined in social and scientific contexts through the conceptual framework of arts integration and critical pedagogy to elucidate relationality through land-based learning experiences. Careful planning and composition of soil portraiture offered insight into soil as a living entity and medium which fostered co-creation and unearthing of sociopolitical awareness surrounding body consciousness and (de)colonial relations with the land.

Backgrounds: Toward critical conceptualization of arts and transdisciplinarity

Evoking the power of arts in and through inquiries within the field of learning sciences can open a new space and opportunity for learning. As Lee (2001) powerfully demonstrated, engaging Black youth in historically salient, rich literature by Black authors can open spaces for their intellectual reasoning to shine. Gutiérrez (2008) showed how migrant youth poetically and poignantly tell their lived histories, *testimonio*, inspired by artistic scholarly texts such as Paulo Freire's (1970) *Pedagogy of the Oppressed*. More recently, arts in the learning sciences have been brought to attention of the field, as Halverson and Sawyer (2022) maintain that arts in the learning sciences research have received relatively little attention, or arts have been reduced to tools to learn more hegemonic disciplines such as Science, Technology, Engineering, and Mathematics (STEM). Our paper highlights how integration of arts created otherwise impossible learning opportunities through the intentional pedagogical design of the Soil Camp (Takeuchi et al., 2021). In this paper, we pay attention to the power of arts to show and deepen racially and linguistically minoritized refugee learners' understanding of disciplinary concepts in STEM, which is entangled with their understanding of "life" (their lives and other lives in intertwined manners). Recognizing that the Western education paradigm has perpetuated oppressive, colonial ways of knowing (Battiste, 2013; Poitras Pratt et al., 2018), the theoretical framework of this research positions arts-based pedagogy as a form of resistance with transformative potential. Decolonial Indigenous frameworks (Battiste, 2013) together with anti-colonial land-based approaches to art education with refugee youth (Bae-Dimitriadis, 2020) inform the research design and interpretations of findings.

These critical ways of seeing arts can challenge underlying disciplinary norms and colonial formation of disciplines, especially in the disciplines of STEM that has historical entanglement of explicit and implicit militaristic and colonial agenda (Philip et al., 2018; Takeuchi & Marin, 2022). As Strong et al. (2016) have demonstrated in their enactment of critical transdisciplinary pedagogy, youth can mobilize the power of arts to invite snapshots of their lives (that is often neglected in school contexts) and their community expertise into STEM disciplines. Arts in embodied forms for youth (e.g., choreography and dance movement developed among Black communities) could be seen as funds of knowledge for learning physics, which has been historically treated as a school discipline removed from youth's lives (Solomon et al., 2022).

Our ways of seeing learning is fundamentally sociocultural and historical. Sociocultural theories of learning helped us to design the learning ecology that could break disciplinary silos between home, community, and school (Gutiérrez, 2008; Lee, 2001). Sociocultural theory of learning sees arts as a medium to bring "horizontal forms of learning, the movement" (Gutiérrez, 2008, p. 150) into disciplinary learning. Our analysis will shine a light on children's sense-making of *the soil as living*, seen through the process of artworks generated by children.

Methodology

Our approach was grounded in social design research methodology (Gutiérrez & Jurow, 2016) that centers historicity, diversity, equity, and ecological resilience as design principles and aims to co-design just practices and futures in partnership with a range of communities. Soil Camp pedagogical design was led and facilitated by preservice teachers, educators, researchers, and various community partners with 85 refugee children and youth (Takeuchi et al., 2021). Child participants hail from Syria, Northern Iraq, Kurdistan, New Guinea, Pakistan, South Sudan, Ethiopia, and Eritrea, having resettled in Canada within the last five years. Eighteen teachers and teacher candidates (who are mainly racialized multilinguals) joined as facilitators of Soil Camp. The participants engaged in numerous environmental justice workshops and were invited to learn more deeply about land stewardship from Indigenous perspectives through the relationships with Indigenous Elders and Knowledge Keepers who storied the land by bringing forward animacy and spirit through circular epistemology (Poitras Pratt et al., 2018, p.5) that centers the importance of multidimensional understandings of our interconnectivity with plants, animals, and the soil. The focus activity of "soil painting" discussed in this paper was nested within these ethos, as a sensory-imbued activity that involves painting with soil pigments and painting about the soil. The pigments were created by mixing a variety of fine soil sediments with an acrylic medium and a few drops of water. The soil samples were crushed with a mortar and pestle or sifted with handmade and professional soil sieves by the children. There was immense variability in the texture, tones, and overall quality of the soil pigments created by the children.

Data and analysis

A team of researchers collected video data, interviews, fieldnotes over two years since 2021. Drawing from the participatory design research framework (Bang & Vossoughi, 2016), our research team invited the participants to engage with us in the documentation of learning and help us highlight telling moments and observations. For this paper, we closely analyzed video data amounting to 157.69 minutes collected during the soil painting activity facilitated by Anita who has disciplinary backgrounds in arts and art histories, and the artworks created by the children and youth. On-site interviews with the participants were conducted to elicit the participants' backgrounds, their sensory experiences on the land (what they see, feel, smell, and hear), and their developing sense of soil and understanding of the land. Individual artworks were then selected based on iterative analysis of video and transcripts, reflecting the pertinent influence of Marin & Bang's (2015) framework of nature-culture relations. The research team analyzed 53 soil paintings made by the children and youth, through the lens of Lawrence-Lightfoot's (2005) notion of portraiture as a method of inquiry to document, analyze, identify, and narrate recurring patterns and themes. In our analysis, we saw arts as a critical tool that provided an opportunity for children to engage in sense-making while glimpsing into their emerging understanding and worldview (Hickey-Moody, 2021). Instead of focusing on pre-set STEM concepts, our analysis focused on the ideas constructed and communicated through children's artworks and conversations, on their terms. The research question that guided our analysis was: how did children deepen their corporeal relationality with and through soil during the transdisciplinary arts integrated experience of creating soil portraiture?

Findings

The children's paintings were a direct reflection of land-based learning interactions and their lived experiences on the land. Through their paintings, the children were able to present macro and micro visions of soil and ecosystems. Paintings of the landscape contained depictions of the visible and familiar elements above the ground such as the sun, soil, plants, trees, grass, flowers, and mushrooms. Below the soil surface, children depicted their interpretation of invisible components such as bacteria and other microbes based on their abstract and emerging understanding. We saw expanded visions of soil in how children chose to depict earth's matter on watercolour paper: macro, micro, introspective, and relationally focused compositions. The invisible complexity of soil ignited the reflexive imagination of our participants and ushered in a network of connections encircling themes of cognizant socio-emotional understanding, cycles in ecosystems (that include human as a part of the ecosystem), and body politics (with a particular focus on human reproduction and soil fertility). For example, one of the children remarked that the microscopic view of soil "looks like the inside of someone's body." Similarly, another child, Aly (children's names are pseudonyms) drew parallels between soil ecosystems and the female reproductive system. As shown in Figure 1, her artwork was composed with a light wash of soil paint and a sketch of roots in the soil which she also exemplified as fallopian tubes, veins, and blood. This network also resembles mycelium (fungal threads) found underground that was showcased in Driver's (2021) interactive video that the participants watched. Aly spent the majority of time sketching this network of intersecting lines with careful precision while engaging in a conversation with other children at the table (see Table 1). Exposure of the children's shared understanding and interpretive reflections during the artistic process transformed the space into a site where children could engage in critical dialogue to make sense of their world and the world in which soil invisibly cooperates and exists.

As the children were sketching and painting, the facilitator walked around the table to support and assist them. Meanwhile, the children engaged in conversations while simultaneously working on their art. One such conversation as shown in Table 1, unfolded in the absence of the facilitator as Aly was sketching. A lighthearted conversation that began as making fun of each other led to a moment of critical sense-making as some of the girl-identified children began to unpack their understanding of women's abortion rights (utterance 6 to 9 in Table 1). While the children were somewhat familiar with the sociopolitical issue through media and lived experiences, they did not take a specific stance or engage in a debate, instead, Lily (utterance 8) and Rita (utterance 9) presented two sides of the argument. This dialogic interaction unraveled naturally and was prompted within several interrelated contexts for ideologies in learning (Philip et al., 2018). Participants shared analogies of the fertile landscape soil exhibits with the female reproductive system and noted similarities and comparisons between root systems and the network of blood and veins that run through human bodies. The last week of Soil Camp occurred in early July 2022 directly after the U.S. Supreme Court's June 2022 Ruling to overturn Roe v. Wade — the decision that had guaranteed a constitutional right to abortion for nearly 50 years. This highlights an intersectional inquiry process that takes place on the land as a response to changing climates, whether they are ecological or sociopolitical.

Figure 1
Aly's Painting Analogy between Soil Fertility and the Female Reproductive System.

Table 1

	Time Stamp	Speaker	Utterances
1	#00:02:45-2#	Aly	When mom made you, she said, oh gosh, I'm not ever having any more kids ↑
2	#00:02:55-3#	Sherry	When mom made you, she said, ah not another one
3	#00:02:59-3#	Aly	Then why did she keep going on?
4	#00:03:03-8#	Sherry	She had no choice
5	#00:03:05-0#	Habiba	Wait! But how'd you know, she's older than you!
6	#00:03:09-6#	Lily	I'm confused about the abortion thing, is it in Canada too?
7	#00:03:14-2#	Lily	You know how there's women's rights for abortion or something?
8	#00:03:23-1#	Lily	I don't think it should be a thing, you're killing babies
9	#00:03:33-2#	Rita	Yeah, it's tight, it's not your choice. Before the [embryo develops, you can actually kill it. Before it turns into an actual human. So, it doesn't matter

Discussion

Through an arts-integrated approach, soil painting provided an opportunity for transformative and liberating learning to occur by establishing a safe space for semiotic expression, embodied communication, and affirmation of identity. By touching, feeling, smelling, observing, and interacting with soil as a whole environment containing millions of living organisms, participants activated interpersonal cognizance by questioning the role soil plays in our own ecosystems and how it contributes to abundance in life. As demonstrated in our findings, a deep sense of belonging to a community can be in essence established by fostering artistic agency with epistemological exploration achievable through artistic engagement and can lead to emancipation and critical awareness (Freire, 1970). A seed for ideological expansion (Philip et al., 2018) was planted in and through these learnings mediated by the participants' intertwined sense-making of the soil and human body. The explicit deepening of collective knowledge at Soil Camp is reflected in our presented case in findings as a direct result of the artmaking *process*, demonstrating how children obtain obscure information about the life of soil and parallel ideologies surrounding human reproduction and soil fertility. The children's desire to understand the current and complex sociopolitical milieu illustrates art as a method of communication for heterogeneous understanding of life in and around the soil. Critical transdisciplinary relationality emerged through dialogue on soil paintings and acts of artmaking, where children and youth explored themes of identity, community, belonging, social values, and human rights. The examination of entangled lived experiences through soil painting offers rich perspectives of curiosity, inquiry, and bodily autonomy through critical awareness curated by means of material agency on the land where children actively created and composed extensive life cycles to creatively question, challenge, and disrupt mainstream narratives by breaking the silos between STEM concepts and realities of refugee children (Strong et al., 2016; Takeuchi & Marin, 2022). By expressing feelings visually using lines, shapes, forms, tones, colours, and textures of soil paint, the children emerged as soil advocates or those who value, appreciate, and protect the soil for future generations to heal present day iterations of colonialism.

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Harnessing Student-Generated Questions as a Learning Strategy

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Abstract: The use of student-generated questions (SGQ) is a relatively novel educational strategy that can result in learning gains across diverse student populations and educational settings. This paper examines the effectiveness of three conditions (generation, retrieval, and re-reading) against two categories of question (factual and applied) through a between-subjects study design. After completing one of the three learning conditions: student-generated questions (generation or SGQ) with simultaneous access to content, practiced free recall of the learnt content (retrieval), and re-reading of the study material (re-reading), content learning was evaluated through a final test. Results demonstrate the learning potential of generation and hint at an association between question type and condition, suggesting that SGQ is an effective strategy to boost student learning, with potentially stronger results in specific contexts.

Purpose

Many educators and researchers continue to investigate new modes of active learning to engage learners more deeply than traditional lecture methods. A variety of approaches have been reported that highlight the benefits of adopting a learner-centered approach (Brindley et al., 2009; Conrad & Openo, 2018; Kearns, 2012). One method that has gained recent traction within e-learning literature is that of student-generated questions (SGQ) (Belanich et al., 2003; Ebersbach et al., 2020; Mishra & Iyer, 2015; Shakurnia et al., 2018; Su & Chen, 2018; Yu & Liu, 2009; Yu & Wu, 2012). SGQ is a method that begins a shift to more student-centered learning by enabling students to generate their own questions based on to-be-tested content. Ample empirical literature has shown that student-generated questions (SGQ) can increase learning gains for diverse student populations, across a variety of platforms and learning domains (Belanich et al., 2003; Ebersbach et al., 2020; Mishra & Iyer, 2015; Shakurnia et al., 2018; Su & Chen, 2018; Yu & Liu, 2009; Yu & Wu, 2012). However, evaluating SGQ against other robust and common learning strategies, such as retrieval and re-reading practices, requires further experimentation. The underlying cognitive mechanisms which differentiate these techniques also require further insight. In addition to differentiating the potential cognitive understanding between different active learning mechanisms, the present experiment contrasts the effectiveness of SGQ to other learning strategies and question styles in order to better understand its educational potential.

Literature review

A range of research explores the perception and effectiveness of SGQ within educational contexts. Research by Su & Chen (2018) indicated that SGQ positively facilitated learner motivation, attitude, and engagement within flipped classrooms. Shakurnia et al. (2018) found that students within a medical education environment benefitted from using SGQ, though the technique was unpopular and unfamiliar. Yu & Wu (2012) implemented survey research methodology within an undergraduate course to uncover cognitive mechanisms behind SGQ and perceived value for learners; ultimately, their data analysis established that students who adopted SGQ engaged in deeper learning.

Cognitive accounts of SGQ have been offered, suggesting that SGG is a rendition of the "generation effect" (Slamecka & Graf, 1978), defined as enhanced learning due to the generation of novel content. Generation is an active form of learning that likely allows for deeper level processing, with the offset of increasing cognitive load. Despite this theoretical derivation in the 1970s, literature on this effect provides contrasting results. Arguably, this stems from an erroneous utilization and understanding of the word generation. Research by Slamecka & Graf (1978) and Karpicke & Zaromb (2010) incorporates generation through various word-pair associations. While this technique was standard methodology due to the high level of control it allowed researchers, Karpicke & Zaromb (2010) criticized word-pairs and aptly re-named them "incidental recall". Modified generation methodologies have since been explored and tested (Berthold et al., 2007; Schwamborn et al., 2010). Though they offer less control and more in-depth data analysis, many free generation techniques (like SGQ) have exhibited stronger learning effects than incidental recall activities (Berthold et al., 2007; Karpicke & Zaromb, 2010; Schwamborn et al., 2010; Slamecka & Graf, 1978).

Other established student learning strategies include retrieval and re-studying approaches. Retrieval practice is a well-known cognitive effect, heavily supported within educational literature (Carrier and Pashler, 1992; Roediger & Butler, 2011; Karpicke, Lehman, & Aue, 2014). Unlike the popular (and considerably less effective) method of re-reading content to study, retrieval practice is an active form of learning that involves variations of free recall. Despite the robust effects of retrieval practice, students are not keen to adopt this practice within their study routines. Theoretically, retrieval is proposed to have two key mechanisms: context and retrieval strength (Carpenter, 2009; Karpicke & Blunt, 2011; McDaniel & Fisher, 1991). Context refers to the ability of environmental cues to elicit memories during retrieval practice (McDaniel & Fisher, 1991). On the other hand, retrieval strength refers to the potency of the association between any cue and a memory (Karpicke & Blunt, 2011). During retrieval practice, one or both of these mechanisms may be contributing to learning.

Materials & methods

145 first-year Introductory Psychology students completed this online study in person, within a laboratory setting, under the supervision of a trained facilitator. There were approximately 47 students in each of the 3 conditions: generation (SGQ), retrieval and re-read (control). An online survey tool known as LimeSurvey was utilized to conduct this experiment. A four-paragraph reading passage about mirror neurons was utilized as the target learning content. The passage was specifically simplified for experimentation, though traditionally it is studied in upper- year Neuroscience courses. Thus, it was reasoned that most students would be unfamiliar with this content because *Introductory Psychology* is a prerequisite to these upper year courses.

All participant completed the following phases of the study: a timed reading phase, followed by a timed, condition-based study phase, two brief distractor tasks, and a final testing phase. A pilot study with less than 20 participants was conducted in order to determine the length of time sufficient for a full reading of the passage, the time required to generate MCQ questions, and to rectify any digital shortcomings. Each participant completed the reading phase for 10 minutes, read the corresponding condition-dependent instruction page, and completed the randomly assigned condition-based study phase. In the re-read condition study phase, there was renewed access to the passage for another 16 minutes. In contrast, the retrieval condition consisted of a free recall period for 8 minutes, allowing participants to transcribe as much of their learnt content onto a blank online page accordingly. This was followed by access to the full passage for another 8 minutes, to restudy and remedy any previous retrieval errors. Participants in the generation condition were provided consecutive access to one of four paragraphs in the passage for 4 minutes each, for a total of 16 minutes. Within this 4-minute timeframe, participants were provided a sample of a good MCQ and then asked to generate one MCQ with one correct answer and three distractors based on the content of the available paragraph. Final testing phase consisted of 24 MCQ, a randomized mix of 12 factual MCQ and 12 applied MCQ. Factual MCQ were derived verbatim from the reading passage into question format, a standard testing strategy used within most undergraduate education. The 12 factual MCQ comprised of 3 MCQ from each of the four paragraphs to ensure evenly distributed testing of the passage. In contrast, applied MCQ comprised of detailed explanations of novel situations to assess deeper understanding as opposed to rote memorization.

The retrieval and generation conditions were consciously designed to prevent overlapping between possible mechanisms responsible for learning. The retrieval condition allowed students to practice free recall without access to the passage, but with a subsequent chance to correct any errors. In comparison, the generation condition solely examined whether the creation of novel content with parallel access to the passage, bypassing conflicts with possible retrieval mechanisms, had any effect on a final assessment of learning.

Results & conclusions

We conducted a general linear model analysis to examine the effects of the independent variables of question type (factual and applied) and condition (re-read, retrieval, and generation) against the dependent variable, final test performance. The between-subjects effects highlighted a significant main effect of condition on final test performance, $F(2, 142) = 20.998$, $p < .001$ with a moderate effect size of $\eta^2 = .228$. The within-subjects contrasts of question type on final test scores suggests a weaker connection between the two, $F(1, 142) = 3.607$, $p = .060$, $\eta^2 = .025$. Moreover, a significant yet small linear effect of the interaction between both independent variables was observed, $F(2, 142) = 3.998$, $p = .020$, $\eta^2 = .053$. This indicates the potential interaction of condition on question type for final test scores.

Subsequent pairwise comparisons revealed significant mean differences between all conditions: generation and retrieval conditions, $t(142) = .113$, $p < .001$, generation and re-read conditions, $t(142) = .242$, $p < .001$, and retrieval and re-read conditions, $t(142) = .126$, $p < .001$, respectively. Pairwise comparisons of factual MCQ scores against condition highlighted the non-significant mean difference of test performance between generation and retrieval conditions, $t(142) = .033$, $p < .372$. All other pairwise comparisons of factual test performance validated the study by displaying significant outperformance of the control condition: generation and re-read conditions, $t(142) = .158$, $p < .001$, and retrieval and re-read conditions, $t(142) = .124$, $p < .001$, respectively. Pairwise comparisons for applied question scores demonstrated significant mean differences against all conditions: generation and retrieval conditions, t(142) = .073, p < .021, generation and re-read conditions, t(142) = .200, p < .001, and retrieval and re-read conditions, t(142) = .128, p < .001, respectively. Overall, results are supportive of the hypothesis that SGQ (generation) is as effective a learning strategy when compared to the robust effects of retrieval practice. Interestingly, results also suggest a greater learning potential for applied contexts when implementing SGQ.

Scientific significance of the study

The present study may inform the analysis and further study of active cognitive learning mechanisms. Differences between factual and applied question performance for generation and retrieval conditions suggest similar mechanisms for factual recall and potentially different underlying mechanisms for applied scenarios. With equivalent performance for factual questions in the generation and retrieval conditions, both study strategies may utilise the cognitive mechanisms of increased retrieval strength and context. Greater retrieval strength would allow for stronger associations during learning for memory and cues whereas increased context would heighten the number of cues available for later recall (Carpenter, 2009; Karpicke & Blunt, 2011; McDaniel & Fisher, 1991). Either of these techniques would sufficiently enhance learning for factual questions. However, application questions test broader understanding which is semantically distinct from learnt content. In this instance neither retrieval mechanism would boost learning. In contrast, generation through the creation of SGQ may go beyond cognitive mechanisms of strength and context by promoting integration of learnings with prior knowledge. Nevertheless, the cognitive mechanisms of retrieval strength and context discussed above may still be present within generation. For instance, they may be enhancing neural activation and pathways like retrieval practice while still increasing novel connections to prior knowledge and improving overall retention of material. This principle of integration may be crucial for performance on applied questions which bypass rote memorization to evaluate student understanding through novel scenarios. Moreover, transfer-appropriate processing theory may also have a role in this study. Since the present experiment utilised only MCQ, there could be an increase in memory as a result of the similarity between the processes used to generate new material and the ones used when answering an application MCQ. More extensive research is required to determine the robustness of the generation effect and the learning potential of SGQ for application-based questions.

Our results and supporting comprehensive literature on SGQ suggest that SGQ can be effectively harnessed as another form of active learning in post-secondary education. While studies have validated the strength of SGQ within academic, online and flipped classroom learning contexts, this technique was often studied in isolation, as opposed to direct comparisons with other study techniques (Shakurnia et al., 2018; Su, & Chen, 2018; Yu, & Liu, 2009). However, Ebersbach et al. (2020) provide further insight into the potential of SGQ. Using developmental psychology as content, they tested the long-term recall effects of generation against the testing effect and restudy (control) conditions for factual and applied (transfer) questions. Results of their linear regression model revealed non-significant effects between generation and retrieval but positive significant effects when compared to the control condition for overall final test performance. Subsequent Bayesian analyses revealed smaller positive effects for factual and applied question scores for generation and testing conditions. Comparing our results to those of Ebersbach et al. (2020) hints at a slight increase in the generalizability of SGQ from MCQ to open-ended questions, and from neuroscience to developmental psychology content. The differences between both sets of results demonstrate the need for future studies to address potential cognitive differences of retrieval between the testing effect and free recall, and the similarities or differences when compared to generative learning strategies.

Despite its benefits, educational experts and students may be hesitant to embrace a generative approach to learning. One way to potentially encourage this practice could be in the integration of SGQ with new technologies and software. Many studies have tested this idea, providing strong results for the efficacies of such strategies within e-learning programs (Belanich et al., 2005; Yu & Lai, 2015; Kay et al., 2020). Furthermore, studies have also been conducted on the benefits of including certain features of these programs. For instance, Yu & Wu (2020) found that student feedback along with SGQ provided a noticeable benefit to student learning. Other potential features may include access to model questions and the ability to remain anonymous when generating questions. These features may be the key to encouraging students to use SGQ as a study method; Yu (2014) found that as more features were added, students' perception of the usefulness of SGQ software correspondingly improved. Moreover, implementation of SGQ within digital education platforms may serve to improve student engagement and retention of core content within applied contexts. Ultimately, SGQ has the potential to be an important active learning strategy, with the potential for implementation in various educational settings (online or in- person), and the ability to refocus attention on student-centric learning.

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Strategies for Supporting Epistemic Discourse About Ideals

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Abstract: Scientists construct, evaluate, and revise epistemic products collaboratively through epistemic discourse. Similarly, students need opportunities to engage in epistemic discourse towards collaboratively establishing epistemic norms and using them when engaging with epistemic products, such as models. Teachers have an important role in guiding this discourse. However, less is known about what strategies teachers can use towards that end. The data in this study are from one teacher’s implementation of a model-based inquiry curriculum in her middle school science class. I use the Apt-AIR framework to identify and explore several strategies that one teacher used to support her students’ discourse around epistemic criteria throughout the class discussion and while discussing particular criteria. The strategies identified in this research can support curriculum design and point to future directions.

Introduction

Science is a social practice. Scientists construct, evaluate, and revise epistemic products such as scientific models collaboratively. These collaborative processes happen through *epistemic discourse*—the varied discussions that communities—like science or classroom communities—have as they develop norms (Longino, 2002). Among these norms are *epistemic ideals*—or criteria—which scientists use to guide their engagement with epistemic products, such as models (Longino, 2002). Some epistemic ideals may include that a scientific model is good if it *aligns with the body of evidence*, or if it is *parsimonious*. These ideals are the shared criteria that scientists use as they evaluate, revise, or discard epistemic products, and ultimately ratify ideas into knowledge. Given their centrality in science practice and their inclusion into recent educational standards (e.g., NGSS Lead States, 2013), it is important to support students in understanding and developing facility using epistemic ideals.

Teachers have an important role in guiding students’ understanding and engagement with epistemic matters (e.g., Ke & Schwarz, 2021), including ideals. Several studies have looked at how teachers can support epistemic discourse about different scientific practices such as evidence construction (Manz & Renga, 2017) and argumentation (McNeill & Pimentel, 2009). Recent research has also shown that, with support, middle school students are able to use criteria when evaluating models and explanations (e.g., Ryu & Sandoval, 2012). However, less is known about the teacher strategies that can be used to support students in engaging in increasingly sophisticated epistemic discourse about epistemic criteria. In this paper I present a case taken from a larger study of a class discussion about evaluating scientific models to investigate *what instructional strategies does a teacher use to support student in engaging in more competent epistemic discourse around epistemic criteria?*

Theoretical framework

To characterize whether a teacher is guiding students towards greater competence in engaging in epistemic discourse I draw on the Apt-AIR framework (Barzilai & Chinn, 2018). The authors identify *apt epistemic performance* as an important educational goal. To unpack this goal, it is helpful to first look at the starting point of the framework, the AIR model of epistemic cognition (Chinn et al., 2011). This model lays out three components of epistemic cognition, a) epistemic Aims, which are the goals that someone has with respect to epistemic matters, such as *evaluating the quality of a scientific model* or *understanding an idea*, b) epistemic Ideals, the criteria used to determine whether epistemic aims have been met, as discussed above, and c) Reliable epistemic processes, the processes used to achieve epistemic aims, such a *synthesizing all the evidence* when evaluating a model. From these components, *apt epistemic performance* is successfully achieving one’s epistemic aims through competence—that is, through using reliable epistemic processes and epistemic ideals.

The Apt-AIR model outlines five aspects that characterize competent engagement with the three AIR components: a) *Cognitive engagement in epistemic performance*—engagement in cognitive processes that reliably achieve epistemic aims in accordance with epistemic ideals. In the case of teachers, this can often include directing students to engage in cognitive processes. e.g., When evaluating scientific models, the teacher could comment on qualities of a good model or explain features of the models. b) *Regulating and understanding epistemic performance*—having metacognitive knowledge about epistemic aims, ideals, and processes and using epistemic metacognitive skills to guide their usage. e.g., A teacher could help students monitor their understanding of ideals for evaluating models. This paper will be focusing on these two aspects. The latter three are c) *Adapting epistemic performance*—an ability to achieve epistemic aims in an adaptively across diverse situations, d) *Caring about and enjoying epistemic performance*—the dispositions to achieve valuable epistemic aims, and e) *Participating* *in epistemic performance with others*—achieving epistemic aims in varied *social* configurations. Using the Apt-AIR model it is possible to identify whether the ideals constructed and endorsed by science classroom communities are appropriate to the varied situations that the class encounters. In this study, I will be using Apt-AIR to characterize the strategies that the teacher used to support students' engagement with epistemic ideals.

Methods

Context, participants, and data

The data come from one teacher's implementation of a life-science, model-based inquiry curriculum over several months in one of her seventh grade classes (students: 12-13 years old), as part of the Promoting Reasoning And Conceptual Change In Science (PRACCIS) project. The teacher, Ms. Pisano (all names are pseudonymous), taught at a suburban school in the United States and maintained a high fidelity to the PRACCIS curriculum.

The focal discussion occurred while the class was engaging in a unit about cell membranes. The students were exploring the guiding question, "How do lead particles get into our cells?" The focal discussion occurred early in the unit, before students had seen most of the evidence. Earlier in the unit the students had received five models about the topic that were constructed by undergraduates and were chosen to highlight different possible strengths and weaknesses of models. Students individually evaluated and ranked the models and then discussed their rankings in small groups. The teacher then led a class discussion about the students' evaluations (focal discussion). To support their modeling practice, students had previously developed a class list of criteria for good models. Their list was publicly displayed in the classroom and referred to during discussions. One purpose of the focal discussion was to use students' evaluations to refine this criteria list. It thus provides an opportunity to investigate how the teacher supported students in engaging in more apt discourse about criteria.

Analysis

To get a broad look at the discussion, I first coded whether any ideals were being discussed in each utterance, and which. This included explicit mentions of the ideal, as well as descriptions of it or direct responses to other people's discussions of the ideal, such as agreement about a definition, or an elaboration. I also coded whether the teacher or a student had first brought up the ideal within a series of contiguous utterances about it (see Fig. 1).

Based on the findings, I identified four focal ideals. I then coded the instances of discussion of these focal ideals using a scheme that I developed based on the Apt-AIR framework (Barzilai & Chinn, 2018). I identified whether and how each of the five aspects in the framework was used. To further specify the continuum between cognitive and metacognitive engagement and the degree of metacognitive engagement, I drew from Av-Shalom et al.'s (2019) categories of metacognitive discourse. Two of these categories are outlined in Table 1. The analyses revealed several strategies for supporting students' discourse about ideals, which I discuss below.

Table 1
Degree of cognitive to metacognitive discourse within two categories

Expression of thought	**Applying understanding to particular topics**
Cognitive: statement has no expressions of thought	**None**
Borderline: statement includes qualifiers that could also just be elements of speech (e.g., "I think X"; "maybe it's Y")	**Applying**: speaker specifies that a particular ideal is relevant (e.g., "This model *is detailed*")
Monitoring-self (Mon-self): statement includes explicit expressions of what someone is thinking (e.g., "First I/our group thought X, but then I changed my/we changed our mind")	**Tailoring**: speaker explains why an ideal is relevant (e.g., "This model *is detailed because X*")
Monitoring-others (Mon-others): statement includes speculation about what other people *may* be thinking (e.g., "I think she might be confused"; "It seems like she thinks X")	**Refining**: speaker discusses a qualifier or boundary of the ideal (e.g., "so how about *we only need relevant or necessary details*" [refining ideal: "details"])

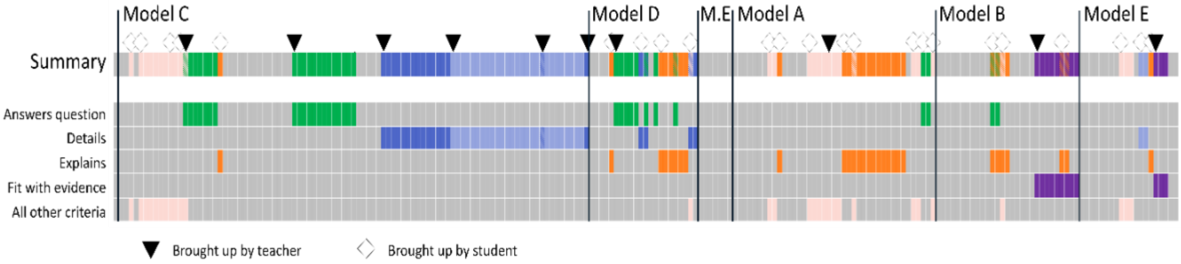
Findings and discussion

As the class discussed the five models, the students and teacher brought up many ideals (Fig. 1, summary line). However, Ms. Pisano guided the discourse towards only one or two focal ideals at a time. Only when students began to use the focal ideal(s) appropriately did she shift the focus to another ideal. At the beginning, Ms. Pisano raised and highlighted two ideals, that models are good if they *answer the question* (Fig. 1, green) and if they *are detailed* (Fig. 1, blue). Later in the discussion, the students began bringing up those ideals spontaneously and appropriately, demonstrating a growing understanding of and proficiency using them. These two ideals became less prominent in the discourse as Ms. Pisano shifted the focus towards a third ideal, that the model is good because it *explains well*. Unlike the first two ideals, "explains" was raised by the students, not the teacher. It first arose early in the discussion, but Ms. Pisano steered the students to other ideals. However, after the second time students raised it Ms. Pisano picked up on the ideal and supported students in discussing it further. Once students had discussed and refined "explains," Ms. Pisano repeated the process with a fourth ideal, fit with evidence.

Below I will discuss two contiguous excerpts that highlight two of the strategies that Ms. Pisano used to guide her students' discourse about ideals. Throughout the excerpts, we can also see a shift in the discourse from metacognitive to cognitive and back. The first excerpt begins with a metacognitive expression of thought (monitoring-others: "What question would you think they're answering?") and shifts to a cognitive articulation of the students' own goal. Later, it shifts again, this time to another category—not as an expression of thought (bolded in excerpts), but towards students applying their understanding to the model (underlined). In the second excerpt we see the discourse move from applying the ideal, to tailoring and then refining it, before shifting back to applying. This continual shifting happened throughout the discussions of the other ideals in the episode as well, and points to a more general strategy that Ms. Pisano may have been using across contexts.

Figure 1

Ideals brought up in utterances in a class discussion



Strategy: Introducing a metacognitive process: "backwards checking"

Early in the discussion, the students raised various critiques about Model C, saying that it was not descriptive, it "doesn't make sense," and that the pictures were "weird." Ms. Pisano acknowledged the students' contributions, but steered the discussion to a new ideal by asking them, "If you just saw this model, what question would you think they're answering? If you had no idea what question they answered … if you just read it, what would you think?" After a brief digression about whether Model C was really the worst of the five, Ms. Pisano circled back and explicitly re-introduced her query as a process for identifying whether the ideal had been met (line 1). Ms. Pisano them modeled how to use the process (lines 2-6) and guided a student to compare the questions (line 7).

1	Ms. P	**What question do you think this person's answering?** I think that's a good way to see if the model's on topic, is to look at the model and say, 'okay, if I had to guess what question they were answering this is what I would guess.'	**Mon-others** Tailoring
2	Mika	How does the lead get into-- how does the lead need to get into the cell?	
3	Ms. P	Okay, so how does it get maybe *to* the cell?	
4	Mika	Mhmm	
5	Ms. P	And **what's our question?**	**Cognitive**
6	Mika	How does the lead get *into* the cell?	
7	Ms. P	Okay, so does this, does this answer the question?	Applying

This is an example of a metacognitive process that Ms. Pisano would later in the year name "backwards checking" and which she and the students would continue to use. This is a sophisticated strategy for helping students understand and regulate their epistemic performance: answering the question might be a familiar ideal to students but they may struggle to identify whether it has been met. This strategy seemed to have helped students better understand the ideal, and they began raising it spontaneously when discussing subsequent models.

Engaging in metacognitive process: Refining ideals

Several times, Ms. Pisano supported students to refine the ideals they were using. Following the prior excerpt, the students were still divided about whether Model C answered the question (Line 8). Ms. Pisano responded to a student's explanation of how the model *did* answer the question (line 10) by refining the ideal (lines 11-13). She then s the students to engage with the newly refined ideal (line 13). Ms. Pisano went on to support students to refine other ideals as well, and these refined ideals became part of the students' revised class list of criteria for good models. In preliminary work from other episodes, this is a strategy that Ms. Pisano seems to have used often, even in discussions that were not explicitly aimed at identifying or engaging with criteria.

7	Ms. P	Okay, so does this, does this answer the question?	Applying
8	Various	No, yes	
9	Ms. P	Okay, Anna	
10	Anna	In one of them it says, like, the lead breaks down the membrane so it can enter into the cell.	Tailoring
11	Ms. P	Okay, so part of it does answer. Does the *whole* thing answer the question?	Refining
12	Various	--Students shake their heads no--	
13	Ms. P	Okay, so **I think something that we need to think about is**, does the entire model answer the question? [1] What parts maybe could you get rid of or change in this model to make it more on topic? [2]	**Mon-self** Refining [1] Applying [2]

Conclusion and future directions

This paper begins to identify different approaches that teachers can use to support students to engage in high quality epistemic discourse about ideals. The methods also show a demonstration of how two of the aspects of the Apt-AIR framework, cognitive engagement in epistemic performance and regulating and understanding epistemic performance, can be considered two sides of a spectrum, and can benefit from further specification. The analysis of these two aspects highlighted another interesting pattern—a continuous shift between degrees of cognitive and metacognitive engagement. In a larger study I am exploring how and when this occurs in other episodes of classroom discourse, and how this shifting may support students' understanding of and engagement with epistemic ideals, as well as with epistemic aims and processes. This research can give us insight about what strategies are possible as well as why, or towards what end, Ms. Pisano used the strategies that she did and what affordances and results they had within the discussion. This can provide a model for how teachers can engage in epistemic discourse towards supporting students in deepening their understanding of and engagement with epistemic ideals.

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Infrastructuring Pathways to Technology Learning for Older Adults in a Public Library

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Abstract: While gaps in older adults' technology use and learning are significant, they are often overlooked. This paper centers older adults' technology learning in public library contexts, with a focus on how interconnected infrastructures can serve to support their learning. Through an exemplary case study spanning several public library programs targeted at older adults, I ask: How did interconnected infrastructures support or fail to support pathways to technology learning for older adults in a public library setting? Through this study, I hope to contribute to knowledge that can support design and infrastructuring for meaningful technology learning for older adults in public library contexts.

Introduction

There continues to be a significant gap in technology use and proficiency for adults over the age of 65, despite technology being increasingly consequential for core life activities such as communication, accessing medical resources, and managing finances (Anderson et al., 2019). This leaves older adults at increased risk of isolation, as the COVID-19 pandemic has highlighted how much we rely on technology for social connection (Xie et al., 2020). Technology resources and learning opportunities through public libraries and library makerspaces are one promising avenue for addressing these gaps and vulnerabilities (American Library Association, 2007; Koh et al., 2018).

It is important to understand how older adults find and access these technology learning opportunities, and what motivates and deepens their engagement. While lifelong learning is upheld as a core value in the Learning Sciences, the study of how older adults access and participate in learning communities is rarely centered. Adult learning in public libraries has also been under-researched (Lee & Phillips, 2019). In this exemplary case study I hope to build on that knowledge by asking: How did interconnected infrastructures support or fail to support pathways to technology learning for older adults in a public library setting?

Theoretical framing

Infrastructures are the (often taken for granted) underlying structures that shape and inform activity in a particular place or system. In the context of learning environments they are important for understanding how educational innovations can be sustained, what constraints educators are working within, how learners can or can't access opportunities, and how learning is scaffolded (Ma & Hall, 2018; Penuel, 2019; Smirnov et al., 2018). Infrastructures are locally situated and relational, taking on meaning as interconnected pieces that both shape and are shaped by organizational and group practices within particular social and historical contexts (Penuel, 2019; Ruhleder & Star, 1996; Star, 1999). They are "big, layered, and complex", and embedded "inside of other structures and social arrangements" (Star, 1999, p.381).

In this study, I look at how infrastructures interact to influence older adults' technology learning pathways. For the purposes of this study I consider a learning pathway to consist of the process of a learner: (1) being brokered (i.e. connected with a learning opportunity or resource) (Ching et al., 2016) into a learning environment, (2) accessing the learning environment, and (3) having a learning experience there.

Methods and context

The study took place in a public library system in an affluent, predominantly white suburban neighborhood in the Mountain West region of the U.S. The site of this case study was chosen because the library's makerspace was very successful at engaging older adults, and the library and county at large had a robust infrastructure for engaging older adults in technology resources and arts and craft programs. The library hosted programming engaging older adults across several sites, including outreach at senior living facilities. I focused my analysis on the two sites that had the most robust programming: the library's makerspace (located in a separate building from the library), and the county's community center. The makerspace held all-ages drop-in hours several times a week, bi-monthly intergenerational project-based workshops on the weekends, and seniors-only hours Thursday mornings. At the community center, library staff hosted bi-weekly drop-in tech help and senior iPad classes, and monthly afternoon craft workshops. While the craft workshops and tech-help were not exclusively for seniors, the majority of participants were older adults.

Data collection spanned 3 months as part of a larger exploratory study on adult and intergenerational Science, Technology, Engineering, Arts, and Math learning programs in public libraries. Data included in this analysis consisted of observational fieldnotes of programs (*71 hours of observation for intergenerational programs, 17 hours for older adult programs*) and staff meetings (*11 hours*), notes from conversations with staff and program participants, and interviews with 5 staff members and two older adult makerspace volunteers.

In my analysis, I first did a round of descriptive coding across data sources to identify moments of older adult (adults confirmed or appearing to be over age 60) technology learning and talk of older adult technology learning and programs. This was followed by several iterative rounds of inductive and deductive coding (Miles et al., 2018). Deductive codes identified social, material, and procedural infrastructures. Inductive codes, drawn from data collection memos with further emergent coding during analysis, focused on moments of brokering and connection, and expressed identities, interests, and motivations. I also created relational maps of participants, the programs they participated in or moved between, and how they were introduced to them.

Findings

Significant infrastructures appeared at the organizational level and programs level, with *social*, *material*, and *procedural infrastructures* stretching across these. In this section, I describe how these infrastructures appeared to work together to support brokering, accessibility, and learning for older adults, and when breakdowns in these infrastructures occured. Because of the complex and relational nature of infrastructures, I will present them as such in my findings, rather than attempting to disentangle them into discrete infrastructural categories.

Infrastructure and brokering into and between programs

The community center where the library held drop-in technology help and iPad classes was an ideal location for outreach because of a combination of *social*, *material*, and *procedural infrastructures*. It already had a lot of programming for older adults and housed the offices of senior services staff. The county's social and cultural services existed under one umbrella, making it easier for library staff to coordinate library events at the community center. Based on my observations, older adults were often connected to the iPad workshops and tech-help through one of two *social infrastructures*: (1) through staff at a library circulation desks when they approached them to ask a tech related question, or (2) through senior services staff during participation in other activities at the community center. I regularly saw the same participants at multiple programs held at the community center, and based on conversations during tech programs, they seemed to be connected with a number of different programs and social groups based at the community center.

Friends and family members often introduced each other to the makerspace. Adult children sometimes brokered their parents into the space, and friends would invite each other to workshops or to come see the makerspace. The project-based workshops the makerspace hosted were another common way older adults were introduced to the makerspace. Regular sewing workshops were well attended by older adult women, and I commonly observed them return to the space; first to finish projects they started during the workshops, and later to work on new projects. Some primarily stuck to sewing. Others became interested in using different tools in the space (*material infrastructure*) that they saw others using (*social infrastructure*), like the vinyl cutter, or "egg bot", a robot that could be programmed to draw patterns onto eggs.

Library staff, a *social infrastructure* at the library, had an opportunity to broker connections to the makerspace for older adults who attended tech programs and craft workshops at the community center. This would have enabled participants who engaged in technology or craft learning to deepen their engagement with creative technology. However, I didn't observe library staff doing this. As a participant observer, there were several instances where I took on that role, successfully brokering older adults between these programs and the makerspace. In these instances I became a temporary element of the *social infrastructure*. On several occasions when staff observed me doing this, they expressed an interest in connecting people between the programs.

This disconnect flowed in the other direction as well. In an interview with an administrator who was instrumental to setting up the makerspace, she said that some adults would come in without a baseline of technology knowledge that would enable them to meaningfully engage with the tools in the space. This made it difficult for them to move from traditional crafting to using technology to create projects. When I asked her if they referred those people to drop-in technology help or technology basics classes facilitated by library staff at other locations, she said they didn't, but they should. I also didn't observe much brokering happening at craft workshops facilitated by library staff at senior living homes. Residents had varying degrees of independence in their living arrangements, and didn't always have access to transportation. A makerspace staffer planned to begin attending some of these outreach programs to make some of the makerspace's resources available off-site. However, this did not happen during the time of data collection.

The disconnect between programs seemed to result from elements of the *procedural*, *material*, and *social* infrastructure at the organizational level. Makerspace staff and other library staff organizing programs targeted to older adults had different supervisors, were located in separate buildings, and weren't able to meet frequently because of the timing of their respective work and program hours. During staff meetings, there was frequent discussion of how staff in different programming positions felt disconnected from what their colleagues were doing and wished there was more time or support built-in for collaboration or communication.

Infrastructure, accessibility, and participation

Older adults reported that consistent hands-on one-on-one support from library and makerspace staff (*social infrastructure*) was consequential for engagement with technology learning in both skill's based technology workshops and drop-in technology help, and makerspace open hours. As one participant said to a library staffer while receiving one-on-one assistance during tech help, "I love that I have people I can ask questions to and not feel stupid." During this same conversation the participant expressed getting comfort from knowing that support resource was available to them on an ongoing basis.

Weekly open hours for older-adults were important to many seniors who regularly participated at the makerspace. This was initiated by a makerspace staffer after open hours switched to afternoons and early evenings, and older-adults were vocal about missing morning hours. Some exclusively came to the morning hours, when it was quiet and they had more energy. In conversation with each other, attendees at older-adult open hours expressed their enjoyment of working on projects and being social with others of the same age.

All ages open hours were also important to older adults' participation in the makerspace. I frequently observed grandparents or other older family members or caregivers collaborating on projects with children. They often engaged with technology like the vinyl cutter and laser cutter to support youth in their projects, and some branched out to work on their own projects as well. In one example of this, a grandfather who had come in with his daughter and grandchildren was overheard on the phone excitedly telling someone about the "cool tools" they had at the makerspace. He later came back several times to use the laser cutter.

Volunteers, who were largely retirees, played an important role in facilitating both drop-in tech hours and makerspace programming. Volunteer opportunities were an important infrastructure for brokering some older adults into the makerspace and encouraging sustained participation. The majority of these volunteers were retired teachers or identified as educators in some way. While a handful of the older adults I spoke to and observed over the course of the study reported being retired technology professionals, or coming in with prior technology knowledge, most reported originally learning technology tools they used in the makerspace from younger makerspace staff. As they developed more proficiency with the technology in the space, they were able to teach and assist each other, as well as younger participants, moving the group collectively from primarily cross-generational learning to increasingly more intragenerational learning. This was true of both older adult volunteers and many of the most active makerspace participants.

While I saw volunteers who had more expertise in crafting deepen their knowledge of technology tools and softwares over time, there were also missed opportunities to deepen their expertise. In one instance during an e-textiles workshop, two of the regular volunteers helped people with craft-based things, like threading needles, poking LEDs through fabric, and transferring circuit patterns onto fabric. After the workshop they mentioned to makerspace staff that they felt like they couldn't help troubleshoot the circuits because they had not had the opportunity to make the project themselves before the workshop.

In closing interviews with makerspace staff, they reported that they had been getting increasingly busy, and anticipated having less and less capacity for one-on-one troubleshooting and teaching. This may have implications for the comfort of older adults newly participating in the makerspace in the future, and makes the tech learning of their peers who have been regular participants and volunteers even more consequential.

Discussion

By making infrastructures more visible, we can learn how to deliberately design for infrastructuring pathways for older adult technology learning in public libraries, as well as other community and informal contexts (Penuel, 2019; Ruhleder & Star, 1996; Smirnov et al., 2018). Social infrastructures within the library were supportive to older adult's technology learning pathways, as were their existing relationships and social networks. Infrastructuring can be done to support older adult's participation by leveraging the different types of social networks and relationships they have. Based on the study's findings, it may be important to infrastructure a mix of intergenerational and same-age affinity space for older adults to further participation and deepen their learning. For example, some older adults wanted to exclusively participate in quiet making time during morning hours. For others, bringing children to the makerspace and supporting them in their projects was their entry point to engaging with new technology tools. Supporting volunteering opportunities was also an important way to help older adults deepen their technology knowledge while engaging their desire to support others in their learning. As noted above, it also may be an important means of infrastructuring support for new learners who need hands-on assistance if makerspace staff are no longer able to provide that level of support on their own.

The lack of networking infrastructure between programs or departments was a pervasive issue, making it challenging to broker opportunities between internal programs, let alone outside of them. Staff were unaware of or struggled to remember and execute strategies for connecting with older adults at programs facilitated at other locations, in part due to the lack of infrastructure for communication between staff members who were physically located in different buildings. For example, one library staffer asked a regular makerspace participant to distribute flyers to her craft group, but hadn't thought to give flyers to her colleague who facilitated technology workshops for seniors at the community center. This points to a need for prioritizing time for staff collaboration across departments and locations.

A major limitation of this study is the primarily white and middle class participants. While the makerspace was very successful at engaging older adults, those older adults, like other age groups at the makerspace, were predominantly white. This study can not speak to the design of infrastructuring learning pathways that facilitate equitable and culturally relevant or sustaining participation for older adults with diverse racial and ethnic identities, or linguistic practices. Older adults will have different material and cultural needs dependent on their held identities, lived experience, and material realities. Further research should prioritize building knowledge that supports the needs of older adult learners with historically marginalized identities, or from under-resourced communities. Infrastructural issues identified in this study will likely be even more challenging for the many public libraries who are significantly less resourced than the one in this study. Further research is needed to understand the scope of infrastructure related challenges in these settings, as they will present differently in relationship to the resourcing and capacity of the organization, staff, and, patrons.

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Symposia

Building and Sustaining Research Practice Partnerships: Variations on Opportunities and Challenges

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Abstract: This symposium features four presentations that illustrate variations in the opportunities and challenges encountered in RPP work focused on educational improvement targeting teachers' learning to engage students in inquiry-based disciplinary learning. A coherent theme across these presentations is the variation and specificity within as well as across each of the projects. Nevertheless, across the projects, three principles/processes of RPP work stand out as critical to building productive communities of practice: (1) negotiation and re-negotiation of shared goals, (2) breaking through traditional roles and power dynamics to enable truly collaborative relationships among partnership participants; and (3) adaptation of partnership processes and indicators of progress to suit the specific contextualized circumstances of each partnership (Penuel, et al., 2020).

Introduction

Learning sciences research aimed at facilitating professional learning has increasingly trended toward research-practice partnerships (RPPs) that embrace the multi-leveled complex systems in which teaching and learning are embedded (Bronfenbrenner, 1994; Cobb et al., 2003; Coburn et al. 2021; Cohen et al., 1993). Classrooms are dynamic systems requiring that teachers be equipped to engage in principled adaptation of instructional practices (Penuel et al., 2022). Engaging in instruction as principled adaptation necessitates that teachers understand the underlying principles, important ideas, and authentic practices of the disciplines they teach; how to best support students' engagement with these; and the diversity of resources that students bring to learning situations. At the same time, classrooms are embedded in institutional, district, state, and national contexts that impact teachers' learning and what happens in classrooms (Goldman et al., 2022). Accordingly, instructional improvement work requires collaborations among the multiple stakeholders in educational systems and those based in learning and education sciences communities (Penuel, et al., 2020). Building such collaborations presents both opportunities and challenges for developing and sustaining RPPs.

The presentations in this symposium illustrate variations in the opportunities and challenges encountered in RPP work focused on educational improvement targeting teachers' learning to engage students in inquiry-based disciplinary learning. The theme across them is the contextual specificity of RPP work. The uniqueness of each RPP increases the criticality of attending to three principles/processes of RPP work if it is to result in building productive communities of practice: (1) negotiation and re-negotiation of shared goals; (2) breaking through traditional roles and power dynamics to enable truly collaborative relationships among partnership participants; and (3) adaptation of partnership processes and indicators of progress to suit the specific contextualized circumstances of each partnership (Penuel, et al.. 2020).

Specifically, Kavanagh et al. examine processes involved in enabling researchers and practitioners to cross the boundaries of their traditional roles and relationships to enable deeper understanding of the nuances of in-the-moment instructional decision making that enables adaptive teaching. Gibbons et al. illustrate how a detailed understanding of between-school differences in institutional contexts and teachers' prior experiences working with researchers was critical to establishing adaptive partnerships. Feng et al. investigate the impact of high school disciplinary department cultures and values on the negotiation of shared goals and evolution of partnership work, highlighting the importance of attending to the multiple institutional levels that impact teachers' learning and instructional practices. Castro Superfine and Superfine highlight the implications for measuring the impact of RPP work given differences among districts in the problems of practice that they prioritize.

Partnering in the black box: Breaking the Fourth Wall to take RPPs into instruction

Sarah S. Kavanagh, Hala Ghousseini, Elham Kazemi, & Elizabeth Dutro

Teacher-researcher collaborations involve the coming together of two communities that, while overlapping, are distinct in the roles individuals play, their day-to-day work, and organizational expectations and cultures. In such collaborations, scholars of research-practice partnerships (RPPs) argue it is productive to attend to how researchers and practitioners engage with each other in relation to these distinctions by conceptualizing collaboration within RPPs as occurring at boundaries of sociocultural difference (Akkerman & Baker, 2011; Penuel et al. 2015). Collaboration at the boundary can be a source of learning where individuals work to make sense of differences, understand their own and others' perspectives more clearly, and develop new practices that merge or transcend existing practices (Akkerman & Bakker, 2011; Engeström et al., 1995; Wenger, 1998). Such work holds potential for learning and design of innovations that take into account the complexity of educational change in classroom and school contexts. Existing studies examine how collaboration at the boundary between researchers and teachers supports the design of tasks, lessons, and assessments that deepen classroom teaching and learning (e.g., Penuel, et al., 2007). While designs that have been generated through RPPs can support teachers' enactment of instruction, existing research provides limited understanding of how researchers and teachers might collectively negotiate the moment-to-moment improvisational decisions teachers make during instruction.

In our most recent work (Ghousseini et al., 2022; Kavanagh et al., 2022), we have considered the potential for learning at one boundary that often exists between researchers and practitioners as they collaborate on instructional practice: the boundary between performing teaching and observing teaching. In this recent work, we argue that typically, even if researchers and teachers are closely collaborating before and after instruction, during instructional time when students are present, teachers perform and researchers observe. This boundary between performers and observers is what scholars in theater and film studies refer to as a fourth wall. The "fourth wall" is the invisible line that divides the stage (where the actors perform) from the house (where the audience observes). Our work has examined the potential mechanisms for learning (Akkerman & Bakker, 2011) that occur when researcher/practitioner teams acknowledge, interact with, cross, or break the fourth wall to collaborate with one another during instruction. In this presentation, we examine the *coordination* work (Akkerman & Bakker, 2011) that researcher/practitioner teams engaged in to make ongoing joint-work at the boundary of the instructional fourth wall possible. Specifically, our investigation is guided by the following question: What coordination efforts enabled researcher/practitioner teams to acknowledge, interact with, cross, or break the fourth wall that typically exists between performers-of-teaching and observers-of-teaching?

Theoretical background

In some Western theatrical traditions, artists choose to break the fourth wall for didactic purposes (Brecht, 1898–1956) to allow the performer to alternate between being in character and stepping out of character to bring the audience inside the complexity of a dramatic action. This form of boundary crossing opens possibilities for both performers and observers: the performer can engage in a dialectical relationship with their role and with the audience and the observers can get a more nuanced sense of the performance and have more agency in the unfolding of the drama. In their review of studies of boundary crossing across disciplines, Akkerman & Bakker (2011) identified four potential learning mechanisms that can occur in situations of boundary crossing: identification, coordination, reflection, and transformation. The mechanism of identification involves practices and norms of each community coming to light, requiring definition and articulation. Reflection involves both perspective taking and making as actors come "to realize and explicate differences between practices and thus to learn something new about their own and others' practices" (Akkerman & Bakker, 2011, p.145). The mechanism of transformation comes into play when cultural differences lead to joint-work and the emergence of in-between practices through the negotiation of shared problems. While our previous work has looked across these learning mechanisms, in this analysis, we focus specifically on the mechanism of coordination, which involves developing the means and procedures that diverse practitioners can use to engage in joint work at the boundary. Akkerman and Bakker (2011) identify four processes that researcher/practitioner teams use to coordinate boundary-crossing work: building communicative connections (through shared boundary objects), translating across communities (e.g., research results into applications), enhancing boundary permeability (so that actions and interactions run smoothly), and routinization (finding procedures by means of which coordination is becoming part of automatized or operational practice). We draw on these four processes as conceptual tools for understanding the various coordination efforts that researcher/practitioner teams used as they prepared to work together at the boundary of the fourth wall.

Context and methods

We focus our analysis on four researcher/practitioner teams working together in four K-8 schools with rich cultural, racial, and linguistic diversity. Over the course of two years, these four teams engaged in professional learning experiences that involved an established, ongoing routine for joint-work at the boundary of the instructional fourth wall through a professional development (PD) structure called Learning Labs (LL). In each LL, teachers engage in cycles (McDonald, et al., 2013) of professional inquiry focused on leading disciplinary discussions in mathematics and literacy. In LLs, teachers and teacher educators come together to co-plan lessons that they enact all together in one of the teachers' classrooms, at times 'passing the chalk' and at times pausing to discuss students' ideas and instructional next steps. In our previous work (Kavanagh et al., 2022), we have analyzed these pauses, which we colloquially called "Teacher Time Out" or TTO (Gibbons et al., 2017). In a TTO, researchers and teachers interact at the boundary of the fourth wall and work to collaboratively enact classroom instruction with students. They may jump into a performer role to ask students a question, pause instruction while teaching to ask for ideas about where to go next, or pause the flow of instruction to discuss and puzzle through the design of responsive instruction in the moment. In this work, we move away from analyzing TTOs directly and turn the clock back to understand how researcher/practitioner teams built their capacity to engage in this type of boundary-crossing work together during instruction.

We analyzed the first six labs at each site (a total of 24 labs) to provide a common data set across the varied sites. Because we were interested in how researcher/practitioner teams *prepared* to engage in boundary crossing during instruction, we focused on the preparation portion of labs during which teachers and researchers prepared to go into classrooms to teach together. To analyze the preparation portion of these 24 labs, we used Akkerman & Bakker's (2011) coordination processes as our primary codes to better understand what researcher/practitioner teams did to prepare to engage in boundary crossing at the fourth wall of instruction. For each of the 24 labs, we identified the work that teams did to (1) build communicative connections between diverse participants, (2) engage in translation across researcher and practitioner communities, (3) enhance the permeability of the fourth wall, and (4) develop routines for boundary crossing during instruction.

Results

Our analysis revealed examples of how researcher/practitioner teams engaged four different coordination processes that allowed them to acknowledge, cross, and break the fourth wall during instruction.

Building communicative connections: Other work on coordination at the boundary within RPPs has focused on how research/practitioner teams have used boundary objects that are shared by multiple parties to allow for the exchange of information across communities of practice (Christiansen & Varnes, 2007; Landa, 2008). Unsurprisingly the four researcher/practitioner teams in our study also used boundary objects to build communicative connections across participants during instruction. The most important of these was the lesson plan. At each site, participants built the lesson plan together and at many sites they printed enough copies for every participant prior to entering classrooms together and on the plans took pains to note how they would be working together. These plans became touchstones for participants in moments when they worked together at the instructional fourth wall.

Engaging in translation: Additional important coordination work involved identifying where researchers and practitioners held different understandings and working to engage in collective sensemaking across divergent understandings. For example, at one site, teachers and researchers spent significant time investigating their conceptualizations of the concept of "comprehension," a concept that was central to their work in classrooms, but that held different meanings for practitioners than it did for researchers. This proactive translation work then allowed researchers and practitioners to communicate at the instructional fourth wall in ways that would not have been available to them before.

Enhancing the permeability of the Fourth Wall: Prior to entering classrooms together, researcher/practitioner teams did considerable work to acknowledge the instructional fourth wall and to make plans for how they might engage with it when they visited classrooms together. Some teams decided on questions that they would address together at the boundary of the fourth wall and other teams role-played what it might sound like to cooperate across the fourth wall during instruction. This preparatory work made it possible to come together during instruction to consider knotty questions about children's thinking and content complexities.

Developing routines: As in other work on coordination at the boundaries within researcher/practitioner team (Lutters & Akkerman, 2007), we found that developing routines for boundary crossing was instrumental in preparing researcher/practitioner teams for collaboration at the fourth wall. The development of Teacher Time Out (TTO) as a routine, one that had a standard structure, but was still malleable in-the-moment, offered participants a pathway into collaboration during instruction. In early labs, before participants had a vision of this routine, collaboration was much more difficult.

Conclusion

Our previous work (Ghousseini et al., 2022; Kavanagh et al., 2022) suggested that there are things to be learned in RPPs that are best learned in "the rush of minute-to-minute practice" and that cannot be learned elsewhere, but preparing to cross boundaries during instruction is complex work. The findings of this analysis offer important insights into how researcher/practitioner teams can build their capacity to collaborate together during instruction. Acknowledging, crossing, and breaking the instructional fourth wall for the purpose of teacher learning is not only counter cultural, but also risky in a variety of ways. Without careful coordination work in researcher/practitioner teams, the potential of this kind of work is not likely to be met. This research begins to offer illustrative examples of how researcher/practitioner teams have prepared to do this kind of instructional boundary crossing. We hope that these examples might illuminate pathways forward for even deeper work at the boundary of the instructional fourth wall.

Examining institutional settings for teacher learning

Lynsey Gibbons, Anne Garrison Wilhelm, & Latrice Marianno

We are scholars who are committed to working alongside teachers and principals to conduct research that is guided by the priorities of both groups. In our current research-practice partnership work with elementary schools, we aim to support teachers to orchestrate productive classroom talk that positions students as capable sense-makers and supports deep disciplinary learning (Michaels & O'Connor 2015) as well as support school leaders to attend to teachers' development. The goal of our current partnerships is to work alongside educators to organize structures within their schools that support regular engagement in collective professional inquiry (Little, 2002), investigating issues related to supporting children's learning through deepening their classroom discussion practices.

When developing a partnership aimed at supporting teacher development, it is important to understand teachers' interpretations and understandings of their work, while simultaneously treating those interpretations and understandings as situated in and at least partially constituted by the institutional settings in which they work (Cobb et al., 2003). Individual's actions are shaped by but also produce, reinforce, and change the structural conditions in which individuals interact (Feldman & Orlikowski, 2011). We have proposed a theoretically-grounded approach for getting to know partner educators and the contexts in which their work is situated (Gibbons et al., 2022): (1) the broader backdrop – including local, state, national policies, and current events – within which each of the partner schools is situated; (2) existing supports and structures (as designed and enacted) that educators experience routinely; (3) teachers and school leaders' current expectations and the extent to which there is coherence between and among supports and expectations; and (4) the everyday practices of educators as they carry out their work. In this paper, we describe a comparative case study involving two elementary schools as we began partnering with them. We sought to understand what we learned about the educators and the settings in which they worked that informed the design of research and professional learning that was responsive to their current lived experiences and needs.

Context, data collection and analysis

This study is part of a larger project focused on understanding how elementary school teachers learn to facilitate classroom discussions. We partnered with two elementary schools in two neighboring districts to support teachers and school leaders to engage in a set of job-embedded, collective inquiry experiences using the Learning Labs (LL) structure (Kazemi et al., 2018). For this study, we leveraged data from interactions with teachers (14 at School A, and 9 at School B) and school leaders (2 at School A, and 2 at School B) that took place before the LLs commenced. Individual interviews with teachers (lasting 45-60 minutes) included questions regarding their' perceptions of classroom discussions, existing structures for collaboration, past professional learning supports, and expectations from leaders. Individual interviews with school leaders focused on their goals for learning and teaching, conceptions of teacher learning, instructional leadership, and district expectations. Researchers also attended 1-2 weekly grade-level team meetings to learn about teachers' interests and challenges. With information gathered from the educators, the team met to plan LLs and identify goals for teacher learning based on our understanding of teachers' needs. We continued to learn about the teachers and school leaders as we engaged in the LLs. Each LL was video-recorded and teachers completed exit tickets about their experience.

To understand the educators and institutional settings in our partnership schools, we analyzed the interviews, LL videos, and exit tickets using codes built around the categories that allowed us to attend to both educators' institutional setting and everyday actions: (1) the broader contexts, (2) existing supports and structures, (3) teachers and school leaders' current expectations, and (4) the everyday practices of educators as they carried out their daily work. In our coding, we were open to other emergent themes (Saldaña, 2016). Coding was conducted by teams of two; subsequently, we met to engage in consensus conversations.

Findings

We examined the two schools constituting this comparative case study to explain how the institutional settings were more or less conducive to supporting teachers' development in order to inform our work as partners when designing and researching teachers' professional learning. In this presentation, we highlight the findings most salient to uncovering aspects of the institutional setting that supported or hindered teacher professional learning.

Partnerships with both schools happened amidst the Covid-19 pandemic, a situational factor that had many implications, including curricula, availability of substitutes to free teachers for collaboration, and teachers and school leaders' wellbeing and health. Differences existed between the schools with regards to the alignment between the instructional program and leader expectations. In School A teachers were expected to continue to use an online mathematics curriculum that was carried over from when learning was offered online in the 2020-21 school year, which was tied to their evaluation. Additionally, how much time teachers were to spend on which instructional activities was prescribed by the district. The online curriculum and instructional block did not supply opportunities for teachers to engage in classroom discussions with students. In contrast, in School B, the mathematics curriculum had embedded opportunities for classroom discussions, as well as a district expectation that teachers would use a "ten minute" instructional routine that included discussion everyday. For both schools, embedded in each curriculum was an assumption about what the work of teaching is and the extent to which teachers are to be responsive to students' current understandings. These assumptions had implications for how we considered beginning our work to support classroom discussions.

Histories of professional learning, as well as orientations toward the improvement of instructional practice differed between the two schools. Teachers at School A had been offered little professional learning opportunities that focused on classroom discussion or that positioned students as sensemakers. Previously School A had been involved in a university-based research experience that emphasized fidelity to the curriculum in teaching. There was variation among teachers' perceptions of autonomy in their classrooms: Some felt they had more freedom to make instructional changes than others who felt like they had to adhere to the district's specified instructional block and curriculum. Thus, in establishing our relationship with them, we had to support some School A teachers in understanding that our partnership with them involved experimenting and exploring new instructional practices to see how students responded, as well as innovating past instructional practices. In School B, there was a richer history of engaging in collective inquiry and experimentation with practice as a means to improve instruction. This history served as a strong foundation for the professional learning collaboration.

Conclusions

We found that attending to aspects of the institutional setting (such as curriculum materials, histories with professional learning, teacher evaluation systems) as well as the degree to which teachers feel a sense of autonomy to make decisions about their teaching had implications for the extent to which they were willing to learn about and experiment with new instructional practices related to facilitating classroom discussions. Future analyses will examine how what we found in each school context informed decisions we made as researchers and professional learning designers to be responsive to their needs.

Challenges and opportunities within RPPs: A tale of two departments in one district

Mee Na Feng, Susan R. Goldman, Mon-Lin Monica Ko, & Allison H. Hall

This paper presents a case study involving two departments embedded in one high school district in the midwestern United States. The research team and the district collaborated to establish a research practice partnership (RPP; Coburn & Penuel, 2016) focused on enhancing classroom discussion to further disciplinary learning in (1) science, and (2) literary reasoning. The interests of the research team were on teacher learning processes as these were manifest through collaborative efforts of the partnership to deepen students' disciplinary practices and reasoning. Especially with inquiry-oriented instruction, teachers need to flexibly apply their knowledge in the dynamic context of the classroom while not compromising on underlying principles and practices central to the discipline in which inquiry occurs (Bereiter, 2014; Brown & Campione, 1994; Darling-Hammond & Bransford, 2005; Zech et al., 2000). At the same time, teachers operate within complex ecosystems: classrooms are embedded in departments, departments in schools within districts located in communities within larger geographical regions, states, and countries (e.g., Bronfenbrenner, 1994; Cohen et al, 1993). All levels of the system impact and are impacted by other levels in the system. Thus, teacher learning is contextualized and situated within particular local and national contexts that impact opportunities for their learning as well as whether their learning is realized in practice in their classrooms.

In the case of high schools, department organization and culture play a significant role in shaping teacher practices, learning, and collaboration (Fullan, 1994; McLaughlin & Talbert, 1993/2006; Siskin, 1991). This suggests that department-level support is important for enacting RPP work. This paper explores how a partnership with a high school played out in the Science and English departments, each with its own values and culture manifest in curriculum decisions and degree of teacher autonomy with respect to instructional choices. The research study investigates (1) the processes by which the partnership evolved – how they were similar and different between the two departments, and (2) what the implications were for teacher learning processes and trajectories with respect to deepening students' disciplinary practice and engagement.

Methods

The district partner for this work was identified via initial contact with the Curriculum Director of this small suburban high school district near a large midwestern city. The Curriculum Director was familiar with the prior work of the research team wherein inquiry-oriented instruction in literary reading, science, and history and teacher professional learning opportunities had been successfully developed and implemented (Goldman, et al., 2019; Goldman, 2018). The Curriculum Director indicated that an RPP focused on promoting classroom discussion was a good fit with the district's direction.

Data sources include transcripts of meetings among the research team and the district partners (curriculum director, department chairs, instructional coaches), field notes and transcripts of researcher-teacher design collaboration meetings, as well as analytic memos written over the 3 - year period from July 2019 – July 2022. Independently, the researchers engaged in repeated readings of these data sources to develop descriptive accounts of (1) the district-level partnership work around shared goals and (2) research-teacher design collaboration trajectories within each discipline. Researchers met to develop consensus accounts, reviewing relevant data sources in the case of disparities in the accounts (Saldaña, 2016).

Findings

Shared goals were established at an early face-to-face meeting in which each department chair agreed that the research focus on teachers' learning to engage students in disciplinary practices through discussion and other means was consistent with the culture and values of their respective departments. At this meeting, the curriculum director endorsed these goals as consistent with the four conditions of learning that had been adopted by the district: (1) independent reading of complex disciplinary resources; (2) composition of original thought; (3) construction of evidence-based arguments and explanations; and (4) discussion used to problem pose, process, reflect, and solve disciplinary problems. These conditions of learning were intended to achieve three broad district aims: (1) create confident problem solvers through relevant and authentic texts, (2) provide post-secondary pathways for students, and (3) work toward equity and justice.

The working plan coming out of that meeting was researcher-teacher collaborations with two science and two English teacher volunteers, for purposes of exploring the supports teachers in each discipline/department needed to foster deepening disciplinary thinking and reasoning practices. The dyads started from their current practices (materials, tasks, and instructional strategies) and worked collaboratively to enhance these to support students in the disciplinary work. Subsequently and based on those small-scale partnerships, the RPP intended to to expand in each department, with the assistance of the district instructional coaches.

The work in science was focused on instruction aligned with Next Generation Science Standards (NGSS) as a vehicle for remodeling the science curriculum per the district remodeling initiative. A member of the research team proceeded to collaboratively work with two biological sciences teachers on an NGSS-aligned unit that they would implement. As that work proceeded, the department head raised questions with the teachers and then with the research team and curriculum director regarding how the unit that was being designed would fit into the course and content sequence within the department (e.g., Honors Biology -> AP Biology). This revealed an inherent tension between the agreed upon partnership goals and the culture, values, and curriculum in place in the science department. The value placed on content and content sequencing relative to that placed on the three-dimensional

NGSS approach was particularly evident in the science department's response to the pandemic: The teachers collaborated to produce one online set of materials (lectures, texts, activities) for each course in the department and abandoned any effort to encourage student interaction and talk. Ultimately the lack of alignment with the RPP goals led to abandoning the NGSS design work and further science department participation in the RPP.

Unlike the science department, the English department provided more latitude for individual teachers with respect to unit design. Rather than specific books or content that had to be covered so that students were "ready" for the next course, the emphasis was on deepening the use and recognition of literary practices (rhetorical devices, figurative language, themes) with increasingly complex texts. The choice of specific texts and practices was left to individual or grade level groups of teachers to decide. Thus, in the design work, the researcher and two teachers in literature focused on choosing texts and designing tasks that opened up opportunities for interpretive discussions that followed conventions of literary reasoning practices. The value placed on student interaction that fostered literary thinking was evident in how the English department responded to the pandemic. Teachers continued to attempt to foster student discussion and engagement with each other through online collaborative tools, experimenting with a variety of different applications purchased by the district and available to all departments. For example, students interacted through text chats and posts to flipgrid, jamboards, and other communication software. Post-pandemic enthusiasm in the English department and among the district instructional coaches was high for expanding the partnership through researcher-coach collaborative work on professional learning opportunities for additional English teachers and to additional disciplines.

Discussion

The analyses of the RPP meetings elucidate the opportunities and challenges that arose in the work within the two departments and the resultant disparate outcomes. That the partnership work was abandoned in the Science department whereas a productive and ongoing relationship evolved with the English department illustrates that all levels of the multiple contexts in which teachers are embedded play critical roles in determining the trajectory of partnership work. Although both departments were operating within the same district mandates regarding objectives and conditions of learning, the course sequence and content structure of the science department was in tension with the process the partnership attempted to enact to achieve the shared goal around disciplinary discussion as a vehicle for deepening disciplinary learning. In contrast, the affordances within the English department provided space for the researcher-teacher collaborative work to develop in ways that led to a commitment of the district to expand the partnership to include the instructional coaches and additional English teachers. This RPP work highlights the criticality of context at multiple levels (research team, district, department) in working to develop shared goals. Consistent with prior work examining instructional improvement in high schools (e.g., McLaughlin & Talbert, 1993; Siskin, 1991), RPP infrastructuring work at the department level surfaced as critical to the success of partnerships as a context for teacher learning.

Measuring the impact of research-practice partnerships: Lessons from the CASPIR math project

Alison Castro Superfine & Benjamin Superfine

Research-practice partnerships (RPPs) are an efficacious and increasingly common approach for educational improvement (Coburn et al., 2021). While there are various forms of RPP approaches, they generally engage researchers and practitioners in long-term, joint work that involves a diversity of expertise around local problems of practice and promote evidence-based inquiry into how such problems might be addressed through the identification and application of relevant evidence (Penuel et al., 2011). As such, RPPs can also be a productive approach for developing the capacities of RPP participants and the organizations in which they are situated if they are strategically and deliberately designed with this goal in mind (Fishman et al., 2013; Kali et al., 2018). However, RPPs do not simply work as intended "out of the box," as sometimes envisioned by researchers. They develop over time and across various stages and require different types of individual and organizational learning as they progress through such stages. Preliminary or initial developmental stages, in particular, have a significant impact on the life of partnerships (e.g., Law & Liang, 2019). Moreover, RPPs generally addressing the same challenge (e.g., mathematics teaching and learning in an elementary school district) may focus on different local problems of practice, given their unique contexts. As such, the focus of improvement work in even similarly oriented and designed RPPs can differ across time and place, creating challenges for both the improvement work of RPPs and research on RPPs. Indeed, despite their growth and visibility in education, there remains a significant gap in our understanding of how to measure the impact of RPPs over time. Current research on RPP effectiveness focuses primarily on the presence or absence of certain principles and features (e.g., Henrick et al., 2017), and not on tracing developmental changes across time and setting.

In this paper, drawing on data from several, multi-year RPPs with elementary school districts, we discuss two challenges associated with studying the impact of RPPs: (1) measuring qualitative changes in RPP participants' understandings of the joint work over time, and (2) measuring and comparing "progress" on different problems of practice across different settings. As part of the Collaborating Around Structures, Processes and Instructional Routines in Math (CASPIR Math) Project, university researchers and professional developers formed RPPs with four school districts. The goals of CASPIR are to co-develop and co-implement a multi-component professional development intervention designed to improve teachers', teacher leaders', and administrators' understanding of effective math teaching and learning, and to enhance the organizational capacities of schools and districts to support such instructional improvements in math. CASPIR employs a design-based implementation research (DBIR) process involving collaboration between researchers, professional developers, and district and school personnel. As such, improvement in math teaching and learning is to be directly responsive to local problems of practice specific to the school districts and identified by RPP participants in each district. In the cases of both districts, district math leadership teams (DMLTs), in collaboration with the university team, constitute the organizational unit responsible for identifying the problems of practice and where the project's efforts at developing structures and processes for ongoing RPP work were focused.

Theoretical background

CASPIR is grounded in a DBIR approach to improving math teaching and learning. DBIR is an expansion of design research to develop and test innovations and supports for improving teaching and learning. There are four key features of a DBIR approach: (1) focusing on user-centric problems of practice, (2) iterative, collaborative design, (3) developing a theory of improvement through systematic inquiry, and (4) developing capacity for sustaining change in systems (Penuel et al., 2011). Such an approach recognizes that "achieving successful change in complex work systems means recognizing that one cannot predict ahead of time all of the details that need to be worked through nor the negative consequences that might ensue" (Bryk et al., 2015, p. 7). Moreover, RPPs, such as the partnership between districts and the university team in the Project, are directly aimed at learning to do such work not simply from an individual perspective but also an organizational one. Indeed, the development of organizational capacities, such as routines and processes, shared insights and understandings, and information processing abilities, are foundational elements for building organizations that can effectively engage in DBIR (Basten & Haamann, 2018). Accordingly, a DBIR approach to RPPs requires that participants adapt their work to the specific problems at hand and the ways in which they change over time, simultaneously attending to organizational processes, structures, and routines that are aimed at promoting improvement.

Challenges of measuring RPP impact

Although the Project focuses on math instructional improvement in elementary school districts, the problems of practice identified by each of the four RPPs were different. For example, given its local challenges, one RPP broadly identified the selection and implementation of cognitively demanding math tasks as an area of improvement, while another RPP focused more narrowly on the teaching and learning of number sense. Particularly in the early stages of RPP development, it is highly unlikely that any improvement work would impact a range of student and teacher outcomes. The initial RPP work focused on instituting the processes, structures, and routines for the DMLTs so that the participants could identify problems and develop strategies to address them. Once the RPPs began to develop and implement strategies (e.g., professional development for teachers around cognitively demanding math tasks), improvement would likely be measurable only in the areas in which the strategies were implemented. Because improvement strategies and focal areas were not the same across RPPs, comparing the progress of RPPs became a significant challenge. To unpack this challenge, we drew on a range of data sources, including teacher knowledge assessments, classroom observations, and student achievement data. Nevertheless, we encountered difficulties comparing the impact of the RPPS across the different settings.

The Project also highlighted a challenge in measuring RPP impact on participants' understanding of the joint work over time. For example, in each RPP, members of the DMLTs met monthly across two years and engaged in inquiry cycles centered on a unique problem of practice. The DMLTs are comprised of teachers, school and district administrators, working alongside each other in ways that disrupted the usual power dynamics between teachers and administrators (DeVoto et al., forthcoming). For the teacher participants, in particular, engaging in continuous improvement work at the district level is work for which they are not professionally prepared. Consequently, the nature of the joint work and participants' understandings emerged and changed over time in ways the research team found challenging to anticipate. As the beginning phases of the joint work focused on building routines and processes within the DMLTs, the qualitative analyses focused on the establishment of such routines and processes, and participants' initial understandings of the joint work. Over time, it became challenging to re-conceptualize the initial qualitative codes in ways that were both grounded in the data and sensitive to future development. This was particularly challenging because the research team could not perfectly anticipate future development of the RPPs, nor did the extant research on RPP effectiveness offer applicable guidance. To unpack this challenge, this paper draws on a range of data sources, including individual interviews, surveys, DMLT meeting transcripts, field notes and DMLT meeting artifacts. We show the challenge of using such data sources to measure the impact of the RPPs on participants' understanding of the joint work over time.

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Out-of-School Time: Divergent Learning, Divergent Opportunities

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Abstract: This symposium presents an exploration of how three different out-of-school-time (OST) or informal learning contexts shape both the nature of learning opportunities and also potential future learning trajectories for the youth engaged in these OST activities. A goal of the symposium is to highlight both divergence and congruence across OST settings, highlighting the spectrum of learning opportunities and perspectives on learning across different contexts. Discussants will critique the work against the larger universe of OST/informal learning study in the Learning Sciences and invite the community to engage with this work towards developing common ways to describe learning in OST contexts.

Symposium overview

Learning happens everywhere. Though much scholarship on learning focuses on formal or school-based settings, the Learning Sciences has long championed work on learning in out-of-school time or informal settings as well (e.g., Crowley et al., 2014; Halverson & Peppler, 2018; Lyons, 2018). This symposium explores learning in three different and divergent out-of-school time (OST) providers in order to highlight how purpose and context lead to different types of learning, and in turn how those differences can shape future learning opportunities. Such an exploration is important for several reasons. First, though there has been much excellent work focused on the design of OST activities, there has been less attention paid to documenting OST learning (Tai et al., 2021). Such documentation can be useful not only for learner use in future aspirations, but also for OST providers in making a case for their impact and for securing ongoing funding. Second, a better understanding of the learning within OST contexts and how that learning is valued by youth and families allows providers to tune their offerings to better serve their intended audiences. And finally, understanding and documenting learning in OST settings can help elevate its role in accessing future learning opportunities.

In this symposium, we aim to both clarify and problematize different aspects of OST learning. The symposium presentations strive to highlight tensions inherent in this work, including how to include a focus on assessment in informal learning without inadvertently “formalizing” it, how to create systems that sustain learning and development, and how to balance sometimes conflicting stakeholder values. Another way to consider this is to ask who “owns” learning, school or individuals/communities (Fishman & Herrenkohl, 2022)? Attempts to formalize learning tend to cast it in a school-based frame, whereas valuable learning often does not fit into formal frameworks or structures.

The three OST contexts represented in this symposium are all partners in the Mastery in Out-of-School-Time Learning, or MOST project, a study exploring the potential for documenting OST learning for future use in college admissions, job seeking, or simply further OST learning. The OST providers were purposefully selected for their differences. One is a university-sponsored college preparatory program designed to enrich learning for high school students in a particular region and prepare them for success in higher education. Another is a middle-grades coding program designed to enhance learner self-concept around computing. The third is a community-based program for mixed income, refugee and immigrant youth. To study learning opportunities in each of these OST contexts, researchers conducted interviews and focus groups with youth and families engaged in the activities, and with the providers of the OST activities. The interviews and focus groups were transcribed and coded qualitatively to identify learning opportunities and other themes related to values, engagement, and similar topics. As part of this same project, researchers are also conducting qualitative interviews with college admissions personnel, with the ultimate aim of developing a transcript-like representation of learning that could play a role in the college admissions process. This symposium will not present findings from the college admissions perspective, though individual presentations will reference this work.

The symposium will open with presentations about the types of learning opportunities observed in each OST context, with cross-cutting discussion highlighting differences and how these differences are related to how we might report on learning in ways that are both valued by learners and which might be recognized by others seeking to evaluate readiness for future learning or work. After the three presentations, featured discussants representing a range of expertise in the study of OST learning will present commentary and critique, and then the conversation will be opened to all. This symposium is a space for interrogating a spectrum of informal learning contexts to consider how activities that differ along that spectrum are framed and understood by different groups, including potential consumers of information about youth OST learning. Our hope is that this symposium advances the field’s thinking about how to frame and study learning in OST settings.

Wolverine pathways: OST learning as preparation for college success

Lo Lee, Denise Jones, CaVar Reid, Steve Cederquist, Xingjian Gu, Barry Fishman, & Leslie Rupert Herrenkohl

Wolverine Pathways (WP) is a supplementary pre-collegiate program that provides free college preparatory enrichment and advanced academic programming for 7th through 12th grade students in Detroit, Ypsilanti, Southfield, and Grand Rapids, Michigan. WP works to confront the barriers that limit the college and career aspirations of highly motivated students from under-resourced communities in Michigan, believing that every student deserves the opportunity to pursue a wide range of professional and academic pathways. Since its inception in 2016, Wolverine Pathways has served over 1,100 students in southeastern Michigan, has awarded over 200 full-tuition scholarships for the University of Michigan, and boasts an overall 90% matriculation rate to competitive four-year institutions for its scholars. The student body of WP is racially, ethnically, and socio-economically diverse, with over 80% being Black/African American and Latinx/Hispanic, and nearly 50% requiring free or reduced lunch. Additionally, over 30% of WP alumni are first-generation college students.

Youth involved in WP experience rigorous advanced coursework, success coaching, and individualized tutoring that sets them up for early college success. They explore career opportunities through internships, career days, and informational interviews with WP corporate partners, such as an automotive company and an IT organization. Participants have opportunities to explore the UM campus and take a summer course from UM faculty. They also gain a network of mentors, professionals, and peers who offer support and guidance on their academic journey.

Through the first round of conversations, we interviewed 24 youths and 10 WP alumni (current undergraduates). All interviews were audio recorded upon agreement and transcribed for later analysis. Following the qualitative content analysis technique (Hsieh & Shannon, 2005) and social moderation process (Frederiksen et al., 1998; Herrenkohl & Cornelius, 2013), we open-coded each document and created codes inductively. Each data source, including verbatim transcripts and interpretable content logs, was coded at least twice using qualitative data analysis software, Dedoose. When one document was finished with coding by two coders, the first and second coders would meet to discuss discrepancies in code applications and excerpts, reach a consensus, or agree to disagree. We also created memos throughout data analysis to record thoughts that may serve to inspire insight in later analysis.

Based on our data, we report four preliminary themes that illustrate how youth engaged in OST STEM learning. First, overall, youth found their participation in WP helpful in seeking college admission, exploring career interests, and gaining real-world experiences. One interesting point shown in the interviews is that although youth may not be willing to join the program at the very beginning when their parents asked them, they still regularly returned to WP because they would like to see and hang out with their friends there. Some youth were also aware of the benefits brought by WP regarding college preparation. For example, Melanie, a senior in high school who has participated in WP since the sixth grade, explained why she chose to stay in WP for years:

> Many of my friends dropped out of Wolverine Pathways around seventh or eighth grade, in one or two years. But I stuck around because I genuinely saw the potential in it. [...] I was fortunate enough not to have sports or anything to do. Plus, even people who didn't have sports just really weren’t committed. I was committed because I honestly valued it enough to keep sticking to

> going because I liked it too. I got to be around my friends, and it was college readiness and all of the opportunities and benefits that come along with it. That's why I stuck around. (Melanie)

Second, other than being aware of the future, youth in WP also displayed a keen awareness of the world around them. This is especially true when youth expressed how they were able to connect OST learning to their everyday life and attach meaning to the learning experience. Relatedly, they touched on the value of sharing when they stated how they got chances to showcase their learning outcomes in a wide variety of settings and with different people. For instance, Tanya, a high school student, elaborated on how she seized opportunities to share what she learned both in formal schooling and outside of classes:

> I'm a big supporter of connecting different assets in my life together. In school, if I learned something from Wolverine Pathways, and it applies to what I'm learning in class, I'll definitely raise my hand and talk about it, like the math stuff we learned. I'll even spout out random facts to my friends sometimes. [...] In Wolverine Pathways, we used to have an academic showcase at the end of every session where all of the scholars would come together and do a little group-project, final-project-type thing and present what they learned in the course for the entire session. I remember when I did in the pharmacology lab [...] at the end of the session, we came back with this giant poster board with all the stuff we learned and all the processes we did [...] The final presentation was a really great way for us to look back and see how much we actually learned. (Tanya)

The third theme we identified revolves around transferable skills that youth developed after joining WP courses. In particular, many youth brought up information and financial literacy and interpreted them as essential skills when asked about what they learned and found helpful in WP. By attending relevant classes in WP, youth developed practical knowledge on how to evaluate the credibility of information sources and realized they could begin managing their finances before college. This point and the mentioned two skills reflect the role of transferability in OST learning by which youth could apply what they acquired to various contexts beyond schooling. Tiffany and Lydia, both high school students who took part in WP for years, highlighted the breadth of WP programming and how it helped them grow:

> I feel the things I get in Wolverine Pathways I wasn't getting in my regular academic regime - like the classes they were offering. I got financial literacy when I was in 6th grade. You don't even get econ until you are a freshman in high school. (Tiffany)

> Wolverine Pathways really holds you accountable for your whole journey, like a big picture of where you want to be and what your values are. Like, they want you to go to them and get into U of M, but they're also like, "what do you want to do in life?" And like, "how do you get there?" And other soft skills like networking, researching topics online or fact-checking the news. So it really is a well-rounded resource base for you to discover ways to be a good person and be a competent student going into college. (Lydia)

The last theme we recognized, which can be considered an extension of our first theme on the significance of peers for youth, is the value youth placed on in-person learning in an OST setting. To youth participating in WP, their continual physical interaction with peers is a crucial factor leading to their profound engagement in OST learning. Accordingly, the lack of bodily interaction resulting from COVID, mainly causing the change from physical to remote learning, was regarded as unfavorable to a lot of youth. Melanie gave a great illustration of how she treated WP as a big family:

> Before the pandemic, it was a very family-oriented vibe because we saw each other in person every day. It was very much giving family in Wolverine Pathways because we had songs; we sang, like we had the good morning song, we had different songs. So I feel relationships, friends, and new friends I made were very valuable at Wolverine Pathways. (Melanie)

Furthermore, the disadvantage of remote learning is also mentioned by some parents who highly suggested WP add more physical events to increase face-to-face interaction between students. For instance, Wayne, a father whose two daughters are both parts of WP, noted that it would be "neat" if WP could "somehow facilitate a monthly potluck dinner in one of the dorms or something for the WP kids" that attended U of M.

Wayne explained that this was especially true for those who went through WP virtually due to COVID because in-person gatherings would benefit youth to have some camaraderie and support during their first year of college.

Based on the preliminary themes above, we identified an emerging tension in documenting OST STEM learning. As shown by youth, what they learned through participating in WP is often unquantifiable. For instance, Melanie illustrated why she decided to be part of WP for many years, whereas she saw some of her friends dropping out. Here, we are able to recognize her perseverance and awareness of the benefit of OST learning as a way to prepare her for the future. In the case of Tanya, she expressed how she was capable of building connections between what she learned and, if applicable, knowing when to demonstrate her learning to people. We find this showcasing skill crucial in youth’s learning experiences in WP, though it may be difficult to appropriately capture in the current documentation system for college admission. Apart from Melanie and Tanya, the information and financial literacy skills described by Tiffany, which are also commonly shared by other youth, are critical abilities to be applied in everyday life. Nonetheless, since such non-academic skills are usually hard to assess using numerical data or a quantitative approach (Stasz, 2001), it can be a potential challenge to overcome in the documentation. In other words, how may we foreground the processual aspect of OST learning by treating it as multidimensional rather than one-dimensional to demonstrate its qualitative and interpretable value?

“The spaces and places she’s in”: Digital divas and the work of families forging a youth STEM identity

Nichole Pinkard, Yolanda Majors, & Alex Samuelson

Evanston, Illinois, a community with about 35% of its public-school students qualifying for free or reduced-price lunch and almost 60% of its public school students identified as students of color (Illinois State Board of Education, 2020a, 2020b), has long been perceived as one of the wealthiest school districts in the nation. However, over the last several years, Evanston has garnered national attention for its large racial and socioeconomic achievement gaps (Rich et al., 2016) and its attempts to alleviate the systemic inequities that generate them (Belkin & Hawkins, 2020). While often discussed concerning the past, the impact of historical fiscal and policy decisions continues to mediate the daily lives of Black Evanston families, particularly those living in the historically Black 5th Ward, who have borne the brunt of the infrastructural changes used to integrate Evanston's schools without integrating its neighborhoods. Consequently, 5th Ward families have had to exert more effort than other Evanstonians to access everyday learning activities from their home addresses, such as walking to school, going to the library, getting to and from sports or music practice after school, and talking about school with neighbors.

5th Ward families, in particular youth, have persistently been underrepresented in STEM programs and STEM-related careers partly because of educational and cultural norms and lenses that have led to *de facto* exclusion based on race, ethnicity, and class. For 5th Ward youth, such exclusion has led to limited access to Evanston’s “participatory culture” (Jenkins, et.al., 2009), where membership cultivates one’s willingness to engage in collaborative, STEM-related work, knowledge of how to manage information, self-direction of one’s learning, meaningful interaction with valuable tools, and the building of collective intelligence (ref. DYN). Long-term STEM-culture participation requires parents to discover their community’s STEM opportunity landscape and motivate their youth to participate in programming where they are most likely the minority (especially as kids get older). Often this results in ‘joining’ a program and entrusting their children’s STEM learning journey to that organization.

This presentation considers *how and why 5th Ward families (decision makers) understand and choose to participate in one Evanston STEM OST space, Digital Divas, as a learning opportunity for their children, specifically their middle-school-aged daughters*. Digital Divas is an OST program located in Evanston that engages middle school girls, especially those from non-dominant communities, in design-based engineering and computer science activities driven by a narrative story. The program supports girls to develop STEM identities by participating in face-to-face and online spaces to design, create, and re-imagine everyday artifacts (jewelry, hair accessories, music) and activities (dancing and talking to friends) using collaboration techniques critique, circuitry, coding, and fabrication. Since 2013, over 300 girls have participated in core Digital Youth Divas in Chicago. Middle school girls involved in Digital Divas have demonstrated increased domain-specific content knowledge and development of initial interest in STEM.

We draw on data from three focus group interviews: one group of 6 Digital Divas, one group of 6 Parents, and one group of 3 program facilitators. In addition to insights into the STEM-based problem-solving capacities of Divas’, our analysis spotlights several themes corresponding to the role of families in developing STEM-related identities, values, understandings, and engagement. One of these is “youth exposure vs. “youth opportunity.” We characterize OST “exposure” to STEM as having fixed boundaries of time and space, where youth can experience a baseline introduction to general STEM skill sets, such as coding and 3D building and printing. Findings from family interviews indicate that while much of Evanston's OST STEM programming does a "phenomenal job" of exposing their child to activities grounded in STEM, such exposure is insufficient:

> "There's a big component of the whole child. It's like, how can we include some other skills… You know? How do we bring in the leadership? How do we include life skills? And then how do we also get out of the exposure and go more into the opportunity"

Across each focus group, a tension emerged: "how do we turn exposure" of STEM skill development "into real opportunity" pathways that further specific development of skills.

Drawing on Jenkins and colleagues' (2009) idea of participatory culture, we characterize OST "opportunities" as participatory engagement across time, place and space where youth expand their knowledge as they move across spatial borders and boundaries, engage and expand upon pre-existing knowledge around something shared and valued, decode it in some way and make new meanings around it. Opportunity spaces, therefore, are youth-serving OSTs that provide practitioners, youth, and families with STEAM (science, technology, engineering, arts, and math) related engagement opportunities that are geographically available, socially equitable, youth access, and at the right learning level (Pinkard et al. 2020).

A second theme to have emerged was parents' emphasis on Divas' gendered identity development as a critical determinant of their child's involvement in programming opportunities throughout Evanston:

> It's not easy to be a Black girl… It's the idea of identity and figuring out who she is in the space that she's in and being comfortable in all the different spaces that she's in.

For parents of Divas, positive identity, interests, and social skill development were greatly desired core outcomes of their child's engagement in STEM inquiry, engineering processes and other associative learning opportunities presented through their involvement:

> What's most important is developing their love for science and different STEM identities in spaces where they can be who they are.
>
> They are learning the scientific method, definitely learning this engineering design process, but they also learn how to create, how to bring their identity into the things that they do.

Fundamental to all points along a STEM opportunity pathway is the human capacity for curiosity –the desire to engage, to develop and extend knowledge and do what is meaningful beyond life's challenges, what is immediately accessible, evident, or within current practice. We argue that this desire for learning through participation in identity-affirming activities motivates Divas' families to prioritize programming that reaffirms black girl identity even over STEM programming, especially if the programming is in non-familiar spaces. resources in exploring what one can learn by seeing, thinking, and doing. Due to the historical disinvestment in the 5th Ward as described in the opening, Divas families, whose aspirations of a more equitable future for their daughters are predicated on reimagining the locations, allocation, and use of the resources they steward to create a more equitable learning ecosystem. We imagine that this more equitable learning ecosystem would be unapologetically tuned to facilitate the ability of Black families to seamlessly navigate and engage in Evanston's full spectrum of learning resources to support the intellectual, physical, social, and emotional growth and development of Black youth, toward their fullest potential.

STUDIO: Designing OST STEM opportunities across stakeholder desires

Jiyoung Lee, Katie Headrick Taylor, & Leslie Herrenkohl

"Culturally relevant learning" often describes the design ethic of OST STEM contexts (Moore et al., 2022). However, without essentializing participants' cultures, ignoring intersectionality as an individual reality (e.g., Cabado et al., 2013; Gutiérrez & Rogoff, 2003), and considering the cultural heterogeneity of urban neighborhoods (and the young people that live there, Iloh, 2018), designing for cultural relevance can generate tensions between co-designers, stakeholders, and participants of different ages and perceived roles (e.g., Worker & Ching, 2016). In an OST neighborhood-based STEM program called STUDIO, young participants from Immigrant and/or refugee families (from across the globe), and their caregivers, described different, sometimes contradictory values and purposes for OST STEM programming. Young people valued joyful modes of STEM engagement too often obsolete in schools; several caregivers viewed *joyful STEM* as ancillary to programming that supports in-school achievement. These differing priorities from young people and their caregivers, as well as from funders and evaluators, create a tenuous design space for OST STEM educators.

STUDIO program context

STUDIO is a research-practice partnership between the University of Washington (UW) and a family-serving organization situated within a HOPE VI housing development in a Pacific Northwest city. Youth in STUDIO are all youth of color from diverse cultural and ethnic backgrounds. Most youth are from South East Asian (13%), and East African (42%) countries of origin and identify as belonging to immigrant and/or refugee families. African American youth living in the area also participate in STUDIO. Our partnership includes organization staff, and university faculty, graduate, and undergraduate students working together to design, research, and facilitate project-based STEM curricula. Youth attend STUDIO sessions twice a week at organization facilities but also use the facility with families for other purposes (e.g. game night, community events) (Please see Herrenkohl et al., 2019 for more program details). Findings for this session come from a total of 15 interviews (4 undergraduate mentors, 5 facilitators, 4 youth, 2 parents), transcripts of which we open-coded. Coders at UW and UM met regularly to discuss common and site-distinctive codes across WP and STUDIO.

The purpose of STUDIO

Interviews revealed that adult caregivers and youth have differing desires and purposes for OST STEM programming; organization staff who especially bear the largest burden of recruiting youth participants (with adult caregiver consent), do their work within and across these differences. Adult caregivers often viewed STUDIO as a supplemental program to school, and valued it as a place where their children can get STEM homework help, or experiences that would position them to succeed in schools and future jobs. Youth valued STUDIO because it provided different social and STEM learning opportunities from school. Hiroshi, one of the longest serving staff members in STUDIO with deep ties with residents in the community, clearly identified tension:

> Parents want youth to participate in opportunities in whatever way that the parents believe will provide them an advantage in applications or scholarships, careers or for schools of secondary education for their youth. For youth, it is often around more soft skills, social navigation or life skills. And, it is often around exploring new opportunities that they normally would not be able to explore in school… Being able to provide those opportunities is definitely a balance, because we want to honor the parents' goals and values as well, but also really want to see the youth for what they are and their own goals for success as well.

A parent of a STUDIO participant expressed this priority (identified by Hiroshi above) in her own words, saying, "STEM is the future; children are going to use STEM [knowledge] in the future, and it will help them to have better education, and a better future." Hiroshi also shared that parents often approached him with requests to provide more homework help, and tutoring sessions within STUDIO time so that the youth can get support in subjects like math and science in school.

On the other hand, when youth were asked to share what they got out of STUDIO, most youth talked about learning within a community where they felt safe to develop their social skills, and "do cool things" with great company. Hiroshi extrapolated that youth want to learn about "life skills and soft skills" because they are anxious about going to college as first generation prospective students. As children of new immigrants in the United States, youth often wondered whether college was the right fit for them, and craved opportunities to explore other interests related to STEM but often separated or obsolete in schools (e.g., computer science, arts-based engineering). STUDIO was one of the places youth experienced as providing opportunities to express their creativity. Youth reported that they "got to go outside the boundaries, and [do] fun things that they wouldn't typically do in school," and were also able to "grow as a community with friends and mentors who encouraged " their ideas and, "always welcomed them." Hiroshi described an example of how an activity in STUDIO might differ from school:

> While there may be opportunities in schools to do cooking as an elective class or as a club, sometimes there's not enough capacity for those classes or clubs or it's around recipes that the youth are not interested in. Youth have more voice, and choice in what they can or want to explore in our program than they may be able to at school.

An example of culturally intersectional STEM programming in STUDIO

In this exchange, Hiroshi is referring to STUDIO's online cooking program called World through Food (designed primarily by Jiyoung Lee). This program models for young people that STEM learning (and teaching) can foster and center aspects of care for one's self and the community. Centering care in STEM programming was especially important during the early and highly uncertain months of the COVID-19 pandemic (Taylor, Lee, Riesland & Ikeru, in preparation). In World through Food, youth cooked food from world cultures and trends that they were interested in (like Dalgona coffee, a trendy drink in Instagram in 2020), and also learned how to make ethnic dishes that represented the participants' diverse cultures (e.g. red beans and rice, Somali style pasta). Making and experimenting with Dalgona coffee on Zoom not only allowed youth to explore the chemistry behind sugar crystals supporting the structure of coffee foam, but also opened-up opportunities for interpersonal encouragement and support as they marveled at each other's creations. Teaching each other about dishes from their families' respective countries of origin provided young people an opportunity to express themselves and appreciate the stories of others. STUDIO activities intentionally highlight the layered and powered dimensions of STEM learning that include affect, aesthetics, and uncertainty. Students recognize these aspects as being absent in their in-school STEM learning.

Conclusions

Co-designers of STUDIO cannot ignore the importance of adult caregivers' desires for OST STEM programming for their children. Additionally, connecting to in-school STEM achievement (including how content is taught and tested) also drives funders' concerns and assessments of the "efficacy" of the organization. However, we see that young people bring a different orientation to OST STEM programming. This orientation values learning in a community that is culturally intersectional and pursuant of current topics, questions, and trends with friends and adult facilitators; these STEM inquiries center cultural knowledge and heterogeneity. We see a failure to acknowledge youth desires in OST STEM programming as detrimental to participation (as in, young people will stop showing-up), but also as a missed opportunity to model STEM practices as un-settled (Vakil & Ayers, 2019), uncertain (Anthony-Stevens & Matsaw, 2020), and joyful. We hope the next step is to see evaluations for OST STEM programs (Stephenson Reaves et al., 2022) that "perpetuate and foster–to sustain–linguistic, literate, and cultural pluralism" (Paris & Alim, 2014, p. 88) and intersectionality.

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Theorizing and Designing Relational Possibilities in Teaching and Learning

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Abstract: Challenging assimilationist science requires examining relationalities—the ways we are bound to each other, our personal histories and interactions, and the broader sociopolitical histories of learning contexts. We take up the need for understanding powered relations in this innovative extended-time and hybrid engagement symposium with opportunities for engagement before, during, and after ISLS23. We recognize all learning as political and examine powered relations and relational possibilities across four settings: drawing on Black methodology to disrupt how researchers and educators come to understand Black girls' learning in a summer camp, two pre-service teacher programs to explore "becoming" and challenging dominant logics, and how an in-service teachers' shifts towards humanizing and empowering kindergarten learners. Together we explore how participants' and researchers' understandings of relations in how we "see" science teaching and learning and ways to theorize and design for spaces that open multiple relational possibilities in science learning and teaching.

Session overview

In the past few decades, the Learning Sciences community has increasingly considered power, purpose, and positionality in teaching, learning, and research (e.g., Esmonde & Booker 2017). In particular, a growing body of work points to how normative K-12 science learning experiences require assimilation into unevenly powered relations between students, teachers, more-than-humans, and science disciplinary knowledge and practice, foreclosing opportunities to consider more just and heterogenous relations between learners and science (Barrett et al., 2017; Rosebery et al., 2010; Warren et al., 2001; Warren et al., 2020). In these assimilationist approaches, science learning has been designed to apprentice children into one way of doing science, established by the standards and not always reflective of professional scientific practice, learners' competence, nor their cultural repertoires (e.g., Hudicourt-Barnes, 2003; Keifert & Stevens, 2019; Levine et al., 2020). Rather than intercultural processes (Warren & Rosebery, 2011), assimilationist science learning imposes forms of alienation; "untenable epistemological positions that work against engagement in meaningful learning of scientific ideas, practices, and phenomena," actively harming learners from nondominant communities (Bang et al., 2012, p. 304).

Challenging this assimilationist approach requires us to reflect on our relationalities—the ways we are bound to each other, our personal histories and interactions, and to the broader sociopolitical histories of learning contexts. Developing alternatives to assimilationist approaches to science motivates us to re-think the relationships between teachers and students, between researcher and researched, between scientists and laypeople, between dominant communities and marginalized ones, and between humans and more-than-humans. Yet, this re-thinking must also involve recognizing the powered histories of these relationships. Recognizing, for instance, that historically, young White women were recruited as teachers to enculturate Native and immigrant populations (d'Amico Pawlewicz, 2020p; we capitalize White per APA 7). Western Modern Science constructed scientific knowledge as property of colonial (White male) scientists that led to the exclusion of the plurality of Black Diasporic and Indigenous peoples' humanity and knowledge systems (Palmié, 2002). That dominant portrayals of science maintain their dominance by continuing to narrate scientists as separate from nature, as omniscient observers and manipulators of the natural world (Castro-Gómez, 2021). Working towards more just and caring relations in science teaching and learning involves reflecting on our conceptual, epistemological, and ontological goals. It also involves interrogating our values, reflecting on our axiological goals to consider "the moral and ethical underpinnings that guide learning and participation in scientific and engineering practices" (Krist & Suárez, 2018, p. 424; see also Philip et al., 2017).

We take up the need for understanding powered relations in this innovative extended-time, hybrid engagement symposium. We explore the design and interactional space held by foregrounding axiological goals as we conceptualize relational possibilities between learners, teachers, more-than-humans, and cultural repertoires of knowledge and practice, including Western and other scientific practices. Considering caring relations (Krist & Suárez, 2018) in this work, we hope to engage members of the Learning Sciences and Science Education community in theorizing & designing for relational possibilities in science teaching and learning. We first draw on prior work to conceptualize the idea of power relations and relational possibilities. We then present questions we will examine together, followed by an overview of the extended temporal wings of this session, starting before the ISLS annual meeting, including a synchronous recorded session during the meeting, and concluding the week after the meeting.

Conceptualizing powered relations and relational possibilities

We are particularly interested in understanding how learners, educators, and science knowledge and practice are positioned in relation to one another. Specifically, our efforts are towards theorizing and designing in ways that explicitly acknowledge the power dynamics in these multiple relationships. Rather than develop new theory in this symposium, we draw on existing conceptualizations of power, relationships, roles, responsibilities, privileges, and relationalities in STEM teaching and learning to examine possibilities that emerge(d) in particular STEM designs. Forwarding a power explicit lens to understand relationships, we enter a speculative space to examine and imagine relational arrangements and possibilities that do not yet exist within dominant power structures.

Collectively we recognize all learning as political (e.g., Freire, 1970). We assert educators and teachers can both be learners, all relationships are powered, power must be interrogated, and the authority and agency for learning must be (re)distributed across participants. We recognize that science learning is fundamentally a relational activity (Calabrese Barton & Tan, 2018), contextualized and embedded in histories of the discipline, particularly science as White property—science as objective, neutral, separate from, based in Eurocentric thought and practice, and owned by White men (e.g., Bang et al., 2012; Mensah & Jackson, 2018).

To understand the particulars of each study and the multiple dimensions of relationality, we draw on multiple perspectives to understand powered relations and relational possibilities. Specifically, while all teacher-student (or adult-child, adult-youth) relations are inherently powered, these relations are multiply impacted by individuals' identities and relations with oppressive systems. Identities may include members in Black, Indigenous, Asian, LatinX, disabled, LGBTQIA+, multilingual, immigrant, and other communities that experience historical and continuing oppression in the U.S. Thus, powered relations between standards-teachers-students, old-timers-newcomers, researcher-researched, scientists-laypeople, dominant communities and marginalized ones, and humans and more-than-humans must be understood within the histories of oppression relevant in their context (i.e., in our case, U.S. informal and formal learning). Thus, to explore ways of disrupting oppressive relationalities in science education, we draw on interdisciplinary Black methodologies (McKittrick, 2020), becoming and diffraction (Barad, 2007, 2014), redressing multiple harms (race- class- gender-based) experienced by pre-service teachers of color (Mensah & Jackson, 2018), and humanizing approaches to teacher education (Kang, 2022; Louie et al., 2021).

Our work in the theorization and design of each learning context requires a powered analysis of "both interconnectedness and difference through how we subjectively construct ourselves and the other" (Calabrese Barton & Tan, 2018, p. 766). As we do this work, we hold space for participants to draw upon existing relations often excluded from traditional STEM learning environments (e.g., teacher as learner, imaginative embodiment) and for potential new emergent relations. This work is critical as it centers meaningful and humanizing STEM learning in ways that acknowledge that "my humanity, my integrity, and my dignity are rooted in my willingness to safeguard your humanity, secure your integrity, and protect your dignity" (Olivares & Tucker-Raymond, 2020).

Session summary and shared questions

Across multiple contexts, our presentations explore powered relations between teachers, learners, science, and culture, as well as how hegemonic relations can be disrupted. The first paper deploys Black methodology to disrupt how we, as researchers and science educators, come to understand Black girls' learning in the context of a summer camp exploration of light through photography and in the context of connections to Beyoncé's music and visuals. This paper questions how normative understandings of "seeing" background political labors and powered relationship dynamics that honor Black girls' brilliance. The second and third papers explore powered relations in the context of pre-service teacher learning, exploring pre-service teachers' relations to science and their own teaching. One paper considers pre-service teachers' "becoming" through noticing focused on videos of their own teaching, and the other explores how pre-service teachers challenge dominant logics to acknowledge relationality in their own scientific journeys. The last paper explores how in-service teachers' relationships to students and science shift in the context of a multi-year professional development to contribute to more inclusive kindergarten science teaching.

In the four presentations and the two discussants' comments, we examine the following questions about powered relationships and their role in science teaching and learning across contexts.

1. How do participants' and researchers' understanding of relations shape how we "see" science teaching and learning?
2. What are the different ways in which we theorize and design for spaces that open multiple relational possibilities in science learning and teaching, particularly in light of dominant relations that often repeat?

Innovative hybrid symposium design

We are excited to submit this symposium in the innovative hybrid category. Our goals are to extend engagement beyond the immediate synchronous session to include broader temporal wings (before/after the annual meeting) and multiple modalities of engagement.

Table 1
Temporal wings and multiple modalities of engagement for the hybrid symposium

	Pre-Conference	During Conference Session	Post-Conference
Discussion Forum	Proceedings include focal studies + discussants Prompts prepared + posted	Discussion forum topics/questions summarized and shared by chair	New prompts based on synchronous session
Video	Short clips visible to ISLS members to intro the four focal studies	Live Zoom Session In-Room chat monitoring + mic use Full hybrid format engagement across in-person and virtual attendees supported	Link to recorded Zoom session available for 1-week post-conference

The primary hybrid recorded session will include a 5-minute introduction by co-chairs, 10 minutes for each focal study, 5 minutes for each discussant, and 25 minutes for collective discussion. Please note, the pre-conference is one week before the opening session and post-conference is one week after the closing session. We have done this to attend to concerns about the safety of making recordings of scholars and their data of learners in action, particularly scholars and learners from nondominant communities, visible over long periods of time and to unknown audiences. We feel that the one-week extended temporal arms give opportunity for the more intentional engagement of the conference with the possibilities of hybrid and asynchronous engagement.

We also wish to point out that the proceedings submission will include brief discussant remarks including recognition of themes and articulation of preliminary questions that push forward our conversation (see next). As a result, the pre-conference proceedings and initial discussion forum prompts will include input from the four focal papers as well as discussants to invite the broader ISLS community into conversation.

Weaving together intersectional identities and positionalities to center justice, equity, diversity, and inclusion

Déana Scipio (discussant)

As I enter into conversation with these scholars and practitioners I am struck by the foundational commitments to relationality across contexts. I am eager to enter into conversations about how relationality foregrounds intersectional identities and creates opportunities for teachers, students, and researchers to explore the relations between their intersectional identities and positionalities within science teaching and learning contexts in order to center justice, equity, diversity, and inclusion. Thinking about intersectionality (Crenshaw, 1991) and positionality can allow us to hold multiple relations while honoring the complexity that students, teachers, and researchers are bringing to science teaching and learning contexts. Humans are negotiating their position with respect to joy, community, relationships, power, privilege, and oppression. I look forward to continued discussions with the scholars in this session that will draw out these commitments and connections across this innovative hybrid session.

How centering relationality in learning leads to just and humanizing education

Phil Bell (discussant)

The images of science learning and science teacher learning lifted up in this session sequence significantly advance our understanding of how ***centering relationality in learning environments*** promotes more just and humanizing education. The approaches explore how to center multiple ways of knowing from across academic and community life (Warren et al., 2020), how to support learning and becoming around the diversities of learners' subjectivities and multiplicities in a relational universe, and how to instructionally attend to the significant relations held by learners in humanizing ways. I look forward to learning more about: (a) specific learning and interactional processes from these situations, (b) the life-wide interactions experienced by learners (e.g., how preservice teachers made sense of the supported relational worldview in relation to others in their program), (c) how the centering of multiple, coordinated epistemologies becomes a desired platform for the learners amidst a powered landscape that is frequently hostile and resistant to such efforts (e.g., how learners learn how to fight the epistemic and ontological harms and insecurities that may resurface in other contexts), and (d) how might we as a field learn to support these vital, insurgent campaigns for a 'science otherwise' (Stengers) centered on multiple ways of knowing in active resistance to the hegemonic, multi-scalar structures of science education?

Slaying and seeing: Light and optics with black girls

Natalie De Lucca & Vanderbilt University

Viewing Blackness, whether within a K-12 physical science classroom or a learning sciences research space, is a deeply political process.

This study emerges from my experiences as a Black woman co-designing and instructing a four-week science course in a summer camp (n=35) predominantly attended by Black girls (n=33). Throughout the class, I prompted students to explore phenomena of light and color towards developing an aesthetic sense of "meaningful" digital photos. Notions of "meaningful" were student-developed: inflected with their lived experiences and evolved as a collaborative photographic practice where students learned to adjust the manual settings of digital single-lens reflex (DSLR) cameras. From a collection of field notes, class session video and audio recordings, and course products, I weave together a narrative case that stitches Beyoncé's (2016) music video and song, Formation, together with a trajectory of a single group of girls' photographic experimentation for two weeks. I present this case to raise questions about how we—as learning scientists, science educators, and researchers—approach "seeing" as an empirical practice.

Here, I deploy an interdisciplinary Black methodology: bringing together multifarious texts "not to capture something or someone, but to question the analytical work of capturing" (McKittrick, 2020, p. 4). Bringing different texts together — relationally — engenders a wonder and curiosity which treats Blackness as a living and active knowledge-making endeavor. The wonder that arises from convening interdisciplinary Black texts is responsive to (yet outside of) violent logics whose claim to absolute knowledge apprehends and delegitimizes Black intellectual labors (McKittrick, 2022). This attunement rejects the extraction of meaning from Black girls as objects of study. Instead, wondering involves posing questions as rigorous scholarly activities that build more livable and intellectually affirming learning spaces for Black girls. For AbdouMaliq Simone (2019), this is a strongly ethical stance toward Blackness: a "care that comes from having endured nearly everything" (p. 58).

Reading across two texts (a single group of Black girls' experimental trajectories and Beyoncé's music video and song Formation), I produce a narrative case which wonders about how we come to "see" Black girls within science educational literature and how we come to "see" Black girls' knowledge production. The narrative case stems from a pivotal moment where members of this group seemed to cohere around the production of a meaningful genre of photos. I reproduce part of this episode below:

Cycling through the photos taken as the girls adjust their ISO settings and positions relative to the ring light, we see an ecology of meanings developing as they experiment with their visual expression. Jaelyn photographs Janine and suddenly shrieks: "Oh my god, that's BOOTIFUL ... SLAY!" Jaelyn shrieks "YASSSS" as she looks at the five-second previews of an image just taken on the camera screen. In the tens of pictures just taken, as both Janine and Jaelyn shift their choreography in response to their shared endeavor, it becomes clear that this is not just a win for Jaelyn or just Jaelyn and Janine. The entire group shifts their orientations and settings in light of this discovery, their experimentation - purposive changes in camera settings, spatial organization, light, and intimacy - to give texture to a shared affective terrain of visuality. In this terrain, sociohistorical grammars of object/capture are not legible; instead, the ways the girls hype each other up, negotiate what settings to change, and share intermediate results signals sensibilities towards forms of self-making and world-making (Monday, June 27th)

Jaelyn's proud cry of "SLAY!" is etched in my memory; it signals a creative genealogy of Blackness outside of the audio-visual record. The term "slay" as an affirmation of stunning self-presentation in attitudes, posture, clothing, and accessories dates back to Black queer Ballroom communities in the 1970s-80s (Livingston, 1990), with particular genres shaped by hyper-local Black queer music cultures and histories (Tan & Smith, 2014). So, while Beyoncé is often credited with popularizing the term with the lyrics in Formation, foregrounding this genealogy centers on the creative, political labor of Black queer and gender-expansive communities for self-definition within intimate spaces of creativity. In Formation, Beyoncé's use of slay is not only to characterize herself, "Sometimes I go off (I go off), I go hard (I go hard)/ Get what's mine (take what's mine), I'm a star (I'm a star)/ Cause I slay (slay)..." her chorus calls in Black femmes to also use this term in a call and response fashion: "We gon' slay (slay), gon' slay (okay), we slay (okay), I slay (okay)." Jaelyn, Janine, and their peers' verbal and visual arrangements call and respond to each other, signaling shared ways of Black living and being beyond the audio-visual record.

A Black interdisciplinary methodology allows us to complicate the underlying assumptions behind empirical questions of "seeing," drawing into relief non-linear ecologies of Black cultural and political practice that actively produce racial and gender formations of Black girlhood. When assumptions of "seeing" — within K-12 physical settings and common video-analysis methods used to understand the process of learning — often depend on describing what is in linear observable time-space, we miss ways of understanding our relationship to the "viewed." Here, we see empirical questions of "seeing" involve withdrawing one's active engagement and solidarity when "viewer" of Black life and precarity (Campt, 2021). When translated into other spheres, bringing these texts into analytic proximity prompts questions about how we come to know Black girls (as subjects of learning research) and Black girls' knowledge (as social-cultural-political activities).

Diffracting noticing to become differently: Re-imagining relationalities

Sophia Jeong

Drawing on posthuman theories, in particular, Barad's (2007, 2014) work on becoming and diffraction, this conceptual paper investigates the productive interplay of diffracting noticing as a novel concept for elementary preservice teachers of science to become differently and re-imagine relationalities in their science teaching and learning. As accounts of wicked problems cause sufferings and loss caused by discrimination, oppression, marginalization, and violence across geo-political contexts (Crowley & Head, 2017), science educators are urged to consider concepts that assume the subject as irreducible, multiple, and continually re-assembled through social, discursive, material relational entanglements with other entities (both human and more-than-humans).

The purpose of this conceptual paper is to provide empirical illustrations and groundings of the concept, diffracting noticing that can be used to nurture elementary preservice teachers' diverse array of becomings in the context of a science methods course. Diffracting noticing theorized in this paper is a relational-ontology-oriented experimentation: it is a concept that can be used to rupture ontological concerns about stable entities that often take a stronghold in our worlds. This paper uses posthuman theories to re-conceptualize our stable "beings" as effects of work produced from the entanglements of the actors of an assemblage - thus, as vibrant becomings.

First, the author re-conceptualizes the notion of preservice teachers' learning as becomings (Barad, 2007, 2014). As opposed to static beings, becoming is based on the notion of dynamicity, multiplicities and differences. Second, Barad's radical concept of diffraction entails "re-turning" as in turning" it on its head over and over again, "iteratively intra-acting, re-diffracting, diffracting anew" (Barad, 2014, p. 168) as a way to re-turn what we would do with the different way of becoming. In addition, the author also applies Haraway's (2016)'s concept of response-ability that invokes ethical sensitivity and the ability to respond accordingly and that offers insights into fostering collective knowing and doing, and considering one's becoming with others and rendering them capable. In the context of this study, diffracting noticing demands one's attention to relational encounters: 1) articulation of the differences that were produced when preservice teachers juxtapose and "see" themselves in relation to others, and 2) the effects or a discursive-material mark on entities that were left by these differences. Diffracting noticing engages preservice teachers to reflect on their experiences in relation to others by re-turning and re-diffracting on what they "see," thereby iteratively shedding new insights about their experiences as well as producing new temporalities, patterns, understandings etc. (Barad, 2014). Diffracting noticing is both a process and an effect of the work produced from the actors who are entangled in that process.

The author's position as the science methods instructor of the course was to provide conditions for fostering preservice science teachers' becomings, or people-yet-to-come (Tillmanns & Salomão Filho, 2020, p. 1), and providing opportunities to enact their conceptualization of equity and inclusion in the way that mattered to them. This science methods course used Science & Engineering Practices (NGSS Lead States, 2013) as entry points to anchor and frame science teaching practices through an equity lens. Alongside the practices, the author shared her own tenets of Duty of Care that articulated ways to foster respect for the preservice teachers, their peers, and their future K-12 students. This paper used and analyzed artifacts of preservice teachers' learning that included videotapes of themselves teaching a science lesson incorporating Science & Engineering Practices. Preservice teachers engaged in course activities to view, discuss and provide feedback. Using feedback, preservice teachers planned or modified their lesson planning.

Preservice teachers' discussion of what they noticed provided an opportunity for them to juxtapose, challenge, and contest their teaching practices as a collective relational experience. They were entangled with one another along with the artifacts of their teaching in these modes of encounters: 1) Articulating, 2) Reflecting+Diffracting, 3) Analyzing, and 4) Re-articulating. During these encounters, preservice teachers reflected on where they were in the "middle" (Deleuze & Guatarri, 1987) of their becomings in relation to others' becoming as they began to see and make sense of equitable and inclusive teaching. In so doing, they were able to "see" differences that were produced in terms of their teaching practices and ideas, and the differences became an artifact that could be used to re-turn to, turn it over to diffract and look at them through a new lens (Articulating and Reflecting+Diffracting). Once these differences were produced, the juxtapositions created productive tensions (Analyzing). The productive tensions with which preservice teachers tried to wrestle seemed to leave a mark on the preservice teachers in the form of re-articulating what they could or would do differently in their future teaching (Re-articulating) and what began to show up as effects.

Differences and juxtapositions about how they made sense of and chose to enact equitable science teaching left a mark by way of preservice teachers becoming accountable or response-able for the knowledge that was collectively co-constructed about equity and equitable science teaching and learning. Briefly, the author argued that preservice teachers were part of an assemblage that is organized and re-organized, and is composed of and entangled with heterogeneous actors or entities (Deleuze & Guattari, 1987). Assemblages produce effects of work that actors do as they organize, re-organize their relations. In this vein, preservice teachers who could "see" themselves and their teaching practices in relation to others were becoming differently. In becoming differently as they were sense-making equitable and inclusive teaching practices in the manner that mattered to them, what began to vibrantly matter (Bennett, 2010) in their becomings was ethics and duty of care showing up in their teaching practices. Preservice teachers were also becoming more response-able and rendering themselves and others capable to become more equitable science teachers.

In summary, diffracting noticing as a concept is not just an experimentation: it is meant to be used, distilled, and applied in order to offer re-imaginings and find infinite possibilities for a different way of becoming. In so doing, science educators can work alongside preservice teachers and other entities to provide a different way of becoming (i.e., knowing and learning) for our preservice teachers and their future K-12 students, thereby creating conditions for more equitable and inclusive learning environments. This notion of becoming differently through diffracting noticing contributes to a re-imagination of the traditional notion of teacher change and agency. Allowing teachers' diverse array of subjectivities and multiplicities of enactment of teaching practices (Kayumova & Buxton, 2021) is a first step in rupturing the notion of power as we know it, and fostering similar opportunities and possibilities for K-12 students' multiple ways of knowing and learning.

Redressing harm: Relationalities in preservice secondary teachers' science prep

Jessica Watkins & Natalie De Lucca

Preservice science teachers (PSTs)—particularly PSTs of color—often endure racialized, classed, and gendered harm in their scientific preparation (Mensah & Jackson, 2018). In this paper we are interested in how PSTs grapple with *relationalities* in science to navigate and redress this harm and to imagine more equitable futures for their students. We foreground relationality to acknowledge that the ways we make sense of ourselves, the broader cultural narratives about our communities, and our social structures are not formed in isolation, but rather through our engagement with others' identities, with other cultural narratives and structures (Hoagland, 2007; Shah, 2017). For instance, historically, Anglo-European scientists did not emerge as a community independently or autonomously, but by demonizing and exterminating of pagan and Jewish women healers during the Roman Catholic Inquisition (Hoagland, 2007, p. 98). Critical race scholars have emphasized relationality in the construction of whiteness: White people obtain privileges through the objectification and exclusion of Black people (Harris, 1995). Leonardo and Broderick (2011) extend this perspective on relationality to smartness, arguing that the ways schooling constructs some students as "smart" (thereby deserving of resources and opportunities) simultaneously constructs other students as "not smart" (thereby less deserving of these resources).

While these relationalities are fundamental to the construction of our world, dominant logics of oppression center on denying relational perspectives (Hoagland, 2007). For instance, Western Modernity is narrated as the culmination of a natural progression of thought, rejecting the ways it developed through colonial and imperial interactions (Castro-Gómez, 2021). These logics therefore position dominant cultures as autonomous, independent and ignore the agency and voice of the oppressed. While these logics pervade dominant discourses, we argue that a relational perspective is imperative for PSTs to make sense of themselves, their students, and the disciplines they plan to teach. Here we analyze how two PSTs grapple with relationalities coming from different worlds, yet both troubled by how to make sense of their family histories, academic presents, and futures as science educators.

This study is conducted within a larger project to redesign a content-focused science teacher education course to create opportunities for PSTs to engage in expansive scientific sensemaking themselves, in which multiple ways of knowing and engaging are valued and integrated. In the course, students engage in two extended units in which they pursue coherent and causal understandings of phenomena. The first unit focuses on light and color, framed by the question "Are all the colors in the rainbow?". The second unit pairs formal experiments with Wisconsin FastPlants with field work in their local neighborhoods to explore the expression of purple/red color in plant leaves and stems. In each unit, students kept an online science journal with their wonderings, observations, reflections, procedures, photographs, and personal notes. Inspired by Kimmerer's (2013) reflection: "Isn't this the purpose of education, to learn the nature of your own gifts and how to use them for good in the world?" (p. 239), students are asked to create a final project that reflected their "gifts" in science, how these could be disruptive and do good in the world. We present case studies of two PSTs to explore how they challenge dominant logics that deny the relationalities that shaped their experiences.

Case 1. Carla grew up in rural Georgia, as a White woman with Cherokee ancestry and the first person in her family to attend college. She pursued a PhD in chemistry before switching to teaching as her intended career. Carla spoke about a rupture in who she is across contexts: At home with her family, her ways of knowing, communicating, and relating to the natural world stood in conflict with how she experienced academic science. In the university, she changed her Southern accent to not be perceived as ignorant or dumb, and separated from her family's knowledge about the natural world in her chemistry pursuits.

While Carla experienced a chasm between her home and academic science, we consider how these parts of herself are relational, constructed as counterpoints to each other. Carla's status as a scientist—the recognition of her and other scientists' intellectual abilities to understand the natural world—comes about due to the subjugation of the ways of knowing and communicating in her family and rural community. Dominant logics of oppression deny this relationality (Hoagland, 2007), positioning scientists as separate, independent entities, while laypeople are recipients of their knowledge, dependent on their discoveries. These logics limited who she could be in science, keeping her from bringing these parts of herself together. For Carla, the field work conducted in the class became a site for the seemingly disparate parts of herself to meet, a place to marry her understandings developed as a PhD student in chemistry with her family stories and farming practices. "I was able to make connections [between]… my field work in class and then my knowledge from my family… Trying to make sure I honor both parts of knowledge."

Case 2. Ally was a sophomore Japanese American student majoring in chemistry and secondary education. Her case highlights the ways Japanese Americans have had to navigate the dominant relationality of serving as "model minorities." Within dominant logics of oppression, Japanese Americans had to transform from "problem minority" to "model minority" to be rendered worthy to be citizens. To realize this transformation, Japanese American internees were forced to pledge loyalty to the country that imprisoned them, suppress their cultural identities, and maintain silence about their oppression; these practices contributed to intergenerational, cultural trauma (Nagata, Kim, Nguyen, 2015). In STEM fields, this trauma re-emerges in the model minority myth that "Asians are good at math," which serves to deny Asian Americans full personhood and again positions them against other minority groups (Shah, 2017). Indeed, Ally grappled with the ways that she is minoritized, but as an Asian American not under-represented in science, leading her to question how she belongs.

In her final presentation, Ally positioned crafting as a practice that pierced these dominant logics. Throughout the course, Ally's journals were populated with images showing her joy and facility with materials: she used her feet to project filtered flashlights on the wall, developed new color filters with nail polish and eyeshadow, used string to develop a grid system to keep track of her plants. For her final project, Ally drew on these material experiences to narrate herself in new ways in science, connecting to her family's history with crafting. She linked her cultural practices to her family's experiences in Japanese internment camps. Ally described that "Crafts were used as a form of expression for internees," elaborating that these practices helped Japanese Americans cope with the emotions of enacting as "model" citizens while being incarcerated and tap into their cultural histories. By incorporating and celebrating these cultural practices as part of her scientific work, Ally re-negotiated the relationalities of the model minority myth, positioning science as entangled with culture, politics, art, and emotion.

Both Ally and Carla experienced harm in their scientific preparation as teachers, in which they had to forgo parts of themselves in science to feel as though they belonged. Our analysis highlights the relational dimensions of this harm, unpacking the relationalities not just between broader narratives or structures, but within their personal stories. Importantly, their stories do not end with harm, but with the reparative work they did to resist dominant logics and acknowledge the social, historical, and political relationalities of their experiences. As teacher educators conceptualize expansive and humanizing teacher education (Carter Andrews, et al., 2019), these cases shed light on the need to create opportunities for PSTs to grapple with relationalities as part of their becoming in science and as future educators.

Teacher-student relationships and inclusive kindergarten science teaching

Ashlyn Pierson, Adam Bell, Bethany Daniel, D. Teo Keifert, Sarah Lee, Andrea Henrie, & Heather Johnson

Teacher education has historically focused on the role of teachers and teaching practices (e.g., core practices; Philip et al., 2019). This focus backgrounds students, their knowledge, practices, and interactions, which is particularly harmful for learners from non-dominant communities (Bang et al., 2012; Warren et al., 2020). Additionally, those in power can interpret national to state standards in harmful ways, positioning young learners (e.g., Kindergartners) as not capable of the practices and interactions central to science inquiry (e.g., Keifert & Stevens, 2019). Along with normative expectations about children, families, and cultural repertoires, these powered dimensions shape how teachers design for learning.

Recently, researchers have called for humanizing approaches to teacher education to attend to students as full human beings with many resources (e.g., Kang, 2022; Keifert & Stevens, 2019). This focus can help teachers see *relations* (between teachers, students, standards, and practices) in ways that challenge previous assumptions about students and about science (e.g., ideologies rooted in whiteness; Mensah & Jackson, 2018). We ask: How do teachers' shifting relations–with young students and science–influence learning designs? We analyze data from 2 years of professional development (PD). In the 1st year (2019-20), PD focused on phenomenon-first science instruction and representations, foregrounding the teacher's role in the elementary classroom. In the 2nd year (2021-22), PD focused on multiple ways of knowing in science and on the many resources that students bring to classroom learning (Warren et al., 2020). We analyze data (video, artifacts) from a kindergarten teaching team's planning and implementation of the same two units after the 1st and 2nd PD years, demonstrating how this shift in teachers' perspectives resulted in more inclusive learning designs.

We draw on the FAIR noticing framework (Louie et al., 2021) and Olivares and Tucker-Raymond's framework for *critical relationality* (2020) to understand how ideological framing influences teachers' relationships with their students and the disciplines they teach. These frameworks are premised on humanizing pedagogies that require teachers to welcome relationships that students have in their lives. We consider how PD helped teachers shift the focus of their teaching to center on relationships students have out-of-school and with classroom peers, in addition to student-teacher and phenomena relationships, all of which are foundational for student-driven learning.

We analyze episodes that make visible shifts in teachers' perceptions of students' *relationships* with others and the relevance of relationships to science learning. We focused on the kindergarten team because we could follow the same unit over multiple years. We created content logs and rough transcripts (Erickson & Schultz, 1997) as a basis for turn-by-turn analyses. We analyzed transcripts of classroom observations and triangulated them with video of PD sessions and interviews with participating teachers. We used Discourse Analysis (Gee, 2014) to closely analyze the ways teachers attended to students, science, and relationships (Louie et al., 2021).

Our findings consider two units the kindergarten teaching team designed which responded to shifts in our PD wherein students' inquiry (e.g., feeling, exploring, questioning) and life experiences (e.g., family structures) were central to the science lessons. First, we present data from a unit called "What animal am I?" designed to address the state standard "make observations to show that young plants and animals resemble their parents." Building on the initial PD of phenomena-based instruction, the teachers focused on selecting a phenomenon familiar to students: baby and parent squirrels in a park near the school because "squirrels abound and kiddos see them every day." This foregrounded an in-school shared experience between students and the nearby park. To describe the phenomenon, students were asked to "compare and contrast a *mother* and her baby, then write about ways the baby is similar to its mother." During the second summer PD, teachers were asked to consider how they could make space (Haverly et al., 2020). One way this was demonstrated was through our use of a Summary Chart. In addition to a space for noting claims and evidence, we added a column for students to make connections to their family, friends, language, experiences as home, culture, etc. One teacher explained a shift to the language of *parent* and baby: "in my classroom, I have students who are adopted [and] students who don't have a mom…Even though they're adopted by someone who has a different skin, they have features that are the same as humans, and that helps us understand that this is still a parent and a baby." This inclusive framing came as teachers attended to students' out-of-school relationships as relevant to science.

Second, we present data from a unit about materials. The unit shifted from teaching students a classification system (e.g., "draw the stick part, that's the wood part") to allowing students to develop their own personally meaningful categories (e.g., sound alike; has a hole in it) and engage with one another as sensemakers. Positioning students as sensemakers led teachers to shift from a traditional Initiate-Respond-Evaluate pattern (Cazden, 1988) in the initial implementation (e.g., "Oh, I'm asking [student]...hold onto that connection, we'll talk about it") towards cultivating Kindergartners' capacity to share their thinking with their peers (e.g., "Orange Tiger, do you agree with that?" and "Blue Cheetah, I like your thinking but you need to share it with your group."). With students positioned as sensemakers, teachers centered students' considerable repertoires of practice in classroom conversation. Ultimately, attention to relationships created a more inclusive classroom environment that honored students' interactions in the shared development of knowledge, recognized young learners' competence as inquirers and sensemakers, and honored multiple ways of understanding the standard.

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Teachers as Transformative Actors to Create Meaningful Learning: Agency in Practice

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Abstract: This international collection of papers examines the many ways teachers exercise agency in light of the challenging realities they and their students face to create caring, engaging and transformative learning environments. The teachers in these studies exercise agency in various ways — as individuals, collectives, and fluid inter-professional and personal collaborations — to construct their professional identities and contribute to social change in their schools and society. Across these papers, we also find empirical evidence about the reflexive relationship between individual agency and social structures in shaping each other.

Symposium summary

Currently, students' lives are touched by economic inequality, racism, environmental crisis, and the ongoing global pandemic. Thoughtful teachers seek ways to reshape their practice in ways that respond to these realities. To support teachers' meaningful learning, professional education needs to account for teachers' agency, particularly as they confront the heightened ambiguity of the present moment. Instead of the commonplace approach of "delivering" professional learning for teachers to apply in their classrooms (Zeichner, 2010), recent scholarship recognizes teachers as sensemakers who are active agents in interpreting what they learn and in shaping learning environments considering their students' needs and public good. Nonetheless, the nature of teacher agency and, relatedly, how teachers' agency can be supported in professional learning and work environments is not well understood. In this symposium, we bring together studies that highlight many ways that teachers exercise agency in their practice, which has implications for professional learning.

This collection of papers takes a sociocultural view on learning and agency. In particular, we are interested in how teachers consciously make decisions and act to deal with problems of practice; to transform and expand their practice; to influence policies and procedures within their departments or schools; and to support their own learning by employing the social, material, and conceptual resources (Edwards, 2010; Engeström et al., 2020; Eteläpelto et al., 2013; Vygotsky, 1997). Importantly, in this sociocultural conceptualization, agency is not understood as a fixed quality, disposition or capability which resides in the individual mind (Biesta & Tedder, 2007; Haapassaari et al., 2016). It is socially constructed, achieved according to the constraints and resources of the social environment, and manifests in social practice (Lipponen & Kumpulainen, 2011).

In Papers 1 and 2, we see teachers improvise during and after the transition to remote learning during the COVID-19 pandemic. Paper 1 describes teachers' strategic maneuvering to prioritize their students' wellbeing during remote learning. In Paper 2, we witness how a teacher and her students collectively exercise transformative agency to overcome the stressful conditions of transition after remote pandemic learning by reconfiguring the demands of the learning environment. Papers 3, 4, and 5 document teachers' agentic responses to longstanding issues in and beyond schooling: lack of administrator support (Paper 3); structural racism in curricular pathways (Paper 4); and environmental crisis (Paper 5). These papers press our imaginations about what it might mean to support teachers' agency in their professional learning and work environments. To conclude, we offer Paper 6, a conceptual paper that highlights the complementary role of different levels—individual, collective, and relational— at which agency is exercised and resources are created.

The studies in this symposium attend to teachers' active role in solving problems, improving their practices and supporting their students' learning and well-being, in the heightened uncertainties they contend with in the broader school and world contexts. These studies show how teachers' environments constrain and enable teachers' agency, with implications for the design of professional learning and the organization of teachers' work. From the conceptual lens provided by Paper 6, we conclude that while most of these studies focus on teachers as individuals, we see evidence of the potential for teachers' collective agency and relational agency as they work with others to solve the complex problems they face. The 90-minute symposium will be organized as a structured poster session. Each author will give a 5-minute overview of their papers (30 minutes), followed by 40 minutes for participants to visit the different posters. For the last 20 minutes, we will facilitate a group discussion.

Paper 1: Achieving agency within the authoring spaces of pandemic teaching

Katherine Schneeberger McGugan

Objectives

The COVID-19 pandemic drastically altered the contexts of U.S. schooling and students' needs, thereby changing what teachers had to respond to. This study examines how teachers made sense of and navigated these complex contexts. I take a socially constructed view of teacher agency as a function of their participation in figured worlds to explore the ways in which teachers' institutional commitments may have shifted.

Theoretical framework

I turn to Calabrese Barton and Tan (2010), who theorize agency through the lens of Holland and colleagues' (2001) conception of figured worlds: the particular set of meanings, practices, and actors that are recognized and assigned significance. The presumed stability of the figured worlds of school practices (Edwards, 2017) was ruptured by the COVID-19 pandemic, making room for teachers to reorganize themselves into a new figured world of online teaching. In this sense, all teachers were novices to the figured world of teaching during a pandemic, drawing an analytic lens toward their authoring space, the boundaries of which are determined by how teachers "choose to accept, engage, resist, or ignore appropriate dispositions tagged to their identities" (Calabrese Barton & Tan, 2010, p. 193). The ways in which teachers take up or reconstruct the identities ascribed to them by the moment and the context is both driven by and drives the possibilities for asserting agency within the new figured world of pandemic teaching.

Data sources and methods

To capture both the moment and participants' experiences as they changed over time in unanticipated ways, I designed an interview method I refer to as Reflexive Longitudinal Lifeworld Interviewing (RLLI). My sensemaking as a researcher evolved alongside my participants, as different phases as the pandemic unfolded, resulting in a need for the researchers to engage in in-process data analysis (Emerson et al., 2011). The findings of these ongoing analyses were then used in the development of subsequent interview protocols.

This study extends a four-year ethnographic study of experienced secondary mathematics teachers' learning. Data for this study includes five interview transcripts from eight participating teachers and content analysis of relevant district announcements and national media coverage of education (Altheide & Schneider, 2012). Analysis revealed that teachers continually prioritized students' wellbeing across three main authoring spaces — *structuring time, content*, and *grading* — as they reorganized their identities in their figured worlds.

Results

Teachers in this study achieved agency by *structuring their class time* in ways that attended to students' wellbeing as a result of negotiating their pedagogical responsibilities (Horn & Garner, 2022) to prioritize their ethical commitment to care. For example, Amber spoke of her responsibility to prioritizing students' social and emotional health during the pandemic, describing the variety of ways she uses this time to create a supportive space for her students' personal needs. Jason described having informal, non-mathematical conversations at the beginning of his classes, explaining that "It's more important that we're making that connection than that we get through the content" (*Interview 3*). Amber and Jason both achieved agency in the way they structured their time with students, prioritizing support and personal connections over mathematical instructional time.

Many teachers described loosening their stronghold on the teaching of mathematical *content* in ways that they hadn't before. Linda prioritized personal connections over her pre-pandemic commitment to mathematics. Kasey expressed a similar sentiment: "Students are not going to look back and be like, 'Whoa, I wish I had learned this.' I think what's important is that students feel like we care about them and that we're there for them" (*Interview 3*). Teachers ultimately achieved agency by valuing supporting students' wellbeing over teaching mathematical content.

Teachers also achieved agency in the *grading* space by attending to their ethical commitments over the institutional demands of assigning grades. As Brad described in Interview 2, "It's just going to be grading obviously at your discretion, being mindful about kids' situations.” Jasmine also explained her commitment to kindness, saying “I decided to give credit in terms of extra credit, so that it doesn't harm their grade at all, and anything that they do, I will take it because I want to be kind right now” (*Interview 1*). When teachers thought about grades in their figured worlds of pandemic teaching, they negotiated the balance between institutional traditions of grades and their ethical commitments to care to better serve their students’ personal needs.

Significance

Situated in a time where norms and institutional structures were temporarily suspended, this study explores the ways teachers negotiated and acted on their commitments to serve a community of students that was particularly vulnerable during COVID-19. Its findings speak directly to established policies by furthering our understanding of how institutional conditions shape instructional practice.

Paper 2: Teacher “response-ability” as sociopolitical allyship: Seeding rightful presence in middle school STEM

Angela Calabrese Barton & Edna Tan

Objectives

This study focuses on three teachers’ “response-ability” in one middle school during the return to in-person schooling after remote learning during the COVID-19 pandemic. We investigate how teachers witnessed the oppressions minoritized youth experience through the political and structural continuities that shape science classrooms during a multi-pandemic, and the practices they enacted to transform these conditions.

Theoretical frameworks

In our study, we use the Rightful Presence framework to investigate teachers’ transformative agency. The Rightful Presence framework attends to historical and contemporary inequities in teaching and learning, calling attention to the necessity of allied political struggles educators and youth collectively engage in to re-author rights. Transformative agency is both collective and relational and involves intentional analyses of power and action in relation to systems of privilege/oppression (Bajaj, 2018). Transformative agency sheds light on teachers’ practices for fostering rightful presence. Learning to notice/disrupt/transform systemic oppressions through critique, action, and reflection involves “response-ability” — “to witness beyond recognition” and “to enable response-ability from others” (Villenas et al., 2019, p. 156).

Data sources and methods

Teachers taught a STEM unit — “how can I make my classroom more sustainable?” — in a school serving predominantly Black and Latinx youth. Students used engineering design practices, disciplinary core ideas and a sustainable communities framework to build authentic projects to support their classroom communities.

Using critical participatory ethnography, the following data were generated: Class video recordings, student/teacher interviews, fieldnotes, and artifact collection. Data were analyzed in the grounded theory tradition (Strauss, & Corbin, 1998).

Findings

We present an illustrative vignette followed by our main claims. Ms B’s students returned to “in-person” after 15 months of remote school. Due to “learning loss” and safety concerns, the school day was restructured: Students stayed in the same classrooms and small groups. Specials were eliminated, and science instructional time was reduced. Students described school as stressful and boring:

> There is a lot of pressure on kids. Me personally, it’s like, *you need to do this! You need to do your work!* They [teachers] don't give us much freedom from that. . . Before [COVID] it was like, we have more fun, getting more breaks. But then when it [in-person school] started, it's like, we couldn't, because COVID. (Ana, 6th grade student)

Ms. B launched the return to in-person with the engineering unit to support students in building a caring classroom community. One morning, when she announced STEM class was over and it was lunchtime, students ignored her and kept working. Instead of reprimanding them, Ms. B. paused, asking how they could keep working and still eat. Students developed plans to take turns gathering lunches, allowing them to eat and work. Contrary to the prevailing somber mood, the 6th-grade hallway filled with the sounds of students’ excitement.

Ms. B then pushed afternoon math to another day, creating more time. She asked students what they needed and how she might support them. The ensuing conversation centered students' desires to be in school differently, while elevating their insights and imagination. Consider the Zen group's project, a "light-up Zen poster" (rainforest mural with lit-up animals) meant to transport the viewer to "not school" with the animals bringing "joy and relief". The group needed help to identify a place where kids could "take a break without a mask." Another group worked on the LEH game, consisting of light-up sliders and a timer to be built on the gym wall, supporting students' "movements breaks." This group needed help getting their light-up sliders to work, and in, seeking support from other teachers for activities that took place outside the required day-long pods.

Ms. B engaged in pedagogical "response-ability" — or to witness beyond recognition — as acts of transformative agency. For Ms B, this response-ability took two forms. First, she *engaged in-the-moment strategic pausing, halting forward trajectories of certain assumptions,* such as when Ms. B paused clean-up to support students in planning their work/lunch sessions, or when she paused the mathematics curriculum. This pausing pushed back against normative stances on what it meant to support student learning and what kind of learning mattered. Second, *Ms. B engaged her students in the material and discursive reclaiming of space and time*. The engineering artifacts themselves paused student stress induced by stringent COVID school protocols, the desired effects of the projects — the laughter, movement, and de-stressing — filled the space created by such pauses, re-creating what schooling and STEM could be and feel like.

Significance

Ms. B and her students collaboratively engaged with existing school structures to transform them by leveraging the youths' wisdom. Strategic pausing created opportunities for transformative agency to emerge through the allied political struggle among teachers and students that transformed the norms of 6th-grade STEM that inserted youth joy into strict COVID protocols. For rightful presence to orient STEM experiences in just ways, it requires educators to be critically aware of how the routine practices of STEM, manifest in the discourses, practices and relationships enacted therein, can (re)produce injustice.

Paper 3: "I'm trying to rebuild a relationship with him": Teachers reconstructing instructional practice amidst conflicting pedagogical responsibilities

Ilana Horn, Yeliz Günal Aggül, Jessica L. Smith, Christine E. Hood, Brette Garner, Katherine Schneeberger McGugan, & Karen Underwood

Objectives

When teachers commit to responsive instruction, they constantly reshape their practice through an interplay between their *agency* and their *pedagogical responsibilities*. But what happens when teachers' commitments are at odds with institutional demands? How do they reconstruct their practice within that complex space? We explore this through a case of a teacher who found herself in such a situation.

Theoretical framework

To investigate teachers' reshaping of instructional practice amidst conflicting demands, we draw on two constructs: teacher agency and pedagogical responsibility. While teacher agency has been conceptualized numerous ways, we focus on *relational agency,* the agency that arises in collaboration with other practitioners and supports expansive interpretations of problems of practice (Edwards, 2017). Additionally, *pedagogical responsibility* describes what teachers view as non-negotiable in their reconstructions of practice—their obligations to ethical principles or situational constraints (Horn, 2019).

Data sources and methods

To understand teachers' reconstructed practice in contradictory situations, we examine the case of Veronica Kennedy, a high school math teacher in a large urban school district in the Western U.S. Through a research-practice partnership, we developed a video-formative feedback (VFF) process to support the teachers' learning about groupwork monitoring practices (Ehrenfeld & Horn, 2020). As part of this process, we filmed one of Veronica's lessons using a five-camera set-up: one whole-class view; one teacher point-of-view camera; and three 360° recordings of student groups. Using the whole-class video and a floor plan of the classroom, we also transcribed Veronica's movement (Shapiro & Garner, 2021). Our team reviewed the videos and movement transcript to understand Veronica's monitoring practices. Then, a debrief session was conducted during which two researchers facilitated a discussion about the lesson with Veronica and her colleague, sharing video clips and discussing her monitoring practices.

To understand Veronica’s reconstruction of her practice in the face of contradictions, we used an ethnomethodological lens, where analysts pursue participants’ meanings (Heritage, 2013). This consisted of two phases: (1) analyzing lesson videos, and (2) analyzing video of the debrief. In Phase 1, we examined Veronica's monitoring practices, looking for patterns and anomalies, such as the notable difference we shared with her. Phase 2 involved analyzing Veronica’s account of her moves/actions in the class.

Results

While preparing the debrief, we noted that Veronica visited one group more often than others. Specifically, she uniquely asked them leading questions, offered step-by-step instructions, and checked to ensure the group was on-task. This unique instance of monitoring was Luca’s group. In contrast, Veronica asked other groups open-ended questions and supported their inquiry. Veronica also checked on other groups half as many times as Luca’s. When we explained that this pattern piqued our curiosity, Veronica leaned back in her chair, saying, “Let’s do it. You want to know the context on Luca?” When we agreed, she spent over seven minutes recounting a critical event (Emerson et al., 2011) involving Luca.

Luca had come to her classroom during a different period, asking to retrieve something he had left behind. When Veronica let him enter, he started a fight with another student. Veronica described this fight as “so freaking traumatic, outrageous, throwing punches, throwing bodies.” When Veronica asked that Luca be assigned to another teacher, administrators insisted that he remain with her, thus excluding her from decision-making and reducing her relational agency. This made Veronica feel powerless in the aftermath of the situation.

Despite compromising her relational agency at the institutional level, Veronica maintained agency within her classroom. Retaining Luca in her class presented her with conflicting pedagogical responsibilities: maintaining her commitment to a welcoming and inclusive classroom and keeping Luca in class. Veronica reconstructed her practice in this narrow space by emphasizing gentleness over challenging Luca’s mathematical thinking. As she explained, “I'm really purposeful, trying to rebuild a relationship with him. Even though…[*trails off*].” An observer without knowledge of this relational context might presume that Veronica simply had low expectations for Luca and his group. However, her interactions resulted from her diminished relational agency, as she did not know how to push Luca mathematically (for fear of him exploding) or request support from her administration (who had shown themselves unsympathetic). These changes to her relational agency and pedagogical responsibilities shaped her practice.

Significance

Teaching is socially embedded, ambiguous, and contested (Horn & Garner, 2022), yet research often treats it as a technical activity. Because of its indeterminacy, teacher agency becomes a critical component of instructional practice, particularly their relational agency within a school. When Veronica’s relational agency was limited, she resorted to forms of practice that were otherwise unusual in her instruction. This study highlights the extent to which teaching practice, and therefore teacher learning, is shaped by sociocultural contexts.

Paper 4: “He should have been giving me a gold f-ing ribbon”: Mathematics teachers’ learning of creative insubordination

Samantha A. Marshall

Objectives

For teachers, creating more equitable learning opportunities for students can be a daunting task. Teachers may feel overwhelmed by the weight of an unjust system (Gutiérrez, 2016), and working against the status quo may come with serious risks to reputation and status. Yet some teachers disregard policies to create more just learning opportunities for their students — what Crowson & Morris (1985) call *creative insubordination.* This study investigates two urban mathematics teachers’ learning of creative insubordination to open liberatory mathematical pathways for their students.

Theoretical framework

To understand teacher learning of creative insubordination, I take a sociocultural perspective, foregrounding context and agency in the learning process (Calabrese Barton & Tan, 2010; Lewis et al., 2007). To conceptualize agency, I draw on Burkitt’s (2016) theory of *relational agency*. In line with sociocultural and ecological views of agency that look beyond the individual (Biesta & Tedder, 2007; Cong-Lem, 2021), this view considers the context as paramount for the achievement of agency. However, rather than viewing agency as simply enabled or constrained by relationships or contexts (Emirbayer & Mische, 1998), this perspective considers relationships as "constituting the very structure and form of agency itself" (Burkitt, 2016, p. 336). Indeed, "one's action is rarely one's own and rarely for one's own sake only … it is always already co-authored" (Phạm, 2013, p. 37). Agency, then, is neither held nor achieved by individuals, but unfolds in and from relations.

Data sources and methods

This investigation draws from a 4-year study of teacher learning (Horn & Garner, 2022), focusing on Lee and Doha, mathematics teachers at Falconer Middle School in a large urban district in the Western United States. Data consist of ethnographic fieldnotes, videos and transcripts from interviews, classroom observations, and PD activities. As primary data, I conducted a series of interviews with the focal teachers, who had restructured their classes to accelerate students who wanted to learn more than grade-level content. Analysis was guided by grounded theory and constant comparative methods (Boeije, 2002; Harry et al., 2005) seeking to understand sources of and sociocultural influences on teachers' learning to open mathematical pathways for students.

Results

Analysis reveals that teachers' learning was spurred by students' self-advocacy, guided by teachers' sense of pedagogical responsibility toward students (Horn & Garner, 2022), and mediated by both oppositional and supportive professional relationships. The teachers described how students' desires catalyzed their learning of creative insubordination; one 7th-grade student asked how he could take algebra as an 8th-grader, which initially seemed impossible to the teachers. However, together they began figuring out how to open this pathway. They helped this student enroll in community college classes, buying his books and successfully advocating for an exception to the 13-year-old minimum age. Through this process, this student (and later, others) achieved readiness for calculus by 9th grade, and gained admission to highly competitive high schools.

Lee and Doha then convinced their principal to allow Lee to teach multiple courses in the same block — with several simultaneous rosters assigned to him — so students could get credit for algebra or geometry in 8th grade. He managed this through strong collaboration with Doha and differentiated curricula, adding this to the community college support as another means of opening mathematical pathways. The teachers' sense of pedagogical responsibility was key — they saw this work as leading to greater equity for their low-income, immigrant students who are typically not afforded such opportunities.

Lee and Doha's creative insubordination also required navigating opposing views, including from respected colleagues. Lee explained that a district employee once told them to "shut it down" because all programs were required to be approved and available district-wide. However, the teachers knew that this would undermine the work; their ability to keep these pathways open at all hinged on their relationships and reputation with the community college. Lee added, "I felt like he should have been coming to me and giving me a gold fucking ribbon but that's not what happened." Lee gambled, "I bet he's never going to check in with me to see if I did all this," but added that they would have found a creative way around it even if the district had followed up. This analysis reveals that in contrast to individual views of agency, teachers' agentic learning to open liberatory mathematical pathways for students was fundamentally co-authored (Phạm, 2013).

Significance

The field knows little about both how teachers learn to subvert oppressive systems (Chen & Marshall, 2018) and the "micro level negotiations" that shape teachers' learning and achievement of agency (Edwards, 2005, p. 180). Theoretically, this case of teachers' learning of creative insubordination highlights the relational constitution of agency and learning (Phạm, 2013). Here, agency unfolded within contradictory social relations (Burkitt, 2016) and was shaped by teachers' relationally-informed sense of pedagogical responsibility (Chen et al., 2021; Horn & Garner, 2022). These findings contribute to our understanding of how teachers learn.

Paper 5: Transformative teacher agency for sustainable futures: Manifestations, conditions and resources

Antti Rajala

Objectives

Schools and teachers can arguably play a role in humanity's learning out of unsustainable, fossil-fuel-dependent human activities, which have already made irreversible changes on the planet's climate and environment (Värri, 2018; Taylor & Pachini, 2015; Rajala et al., in press-a). This paper examines teachers' agency as critical educators committed to supporting their students in taking a critical view of their society and taking environmental action towards more sustainable futures (Freire, 1998; Wals, 2019; Rajala et al., in press-b). Drawing on teacher interviews and observational fieldnotes, this study focuses on teacher's accounts of their environmental action projects in three Finnish Upper Secondary schools. The study asks: How does transformative teacher agency for environmentally sustainable futures manifest in Finnish Upper Secondary School teachers' work, if at all? What conditions and resources support or inhibit transformative teacher agency?

Theoretical framework

Prior research indicates that teacher agency is an important aspect of teacher professionalism, entailing teachers' negotiation of educational visions and meanings that give a long-term purpose to their work (Rajala & Kumpulainen, 2017; Toom et al., 2015). Teacher agency is related to organizational commitment, work satisfaction, and professional learning (Horn & Kane, 2015; Eteläpelto et al., 2015).

To account for teacher agency that addresses the environmental crisis, this study takes a sociocultural and transformative approach (Rajala et al., 2016; Gutiérrez & Calabrese Barton, 2015). Accordingly, human learning and agency are co-constructed by people, understood to be agentive actors of social practices, their own lives, identities, experiences, and common history (Stetsenko, 2017). Thus, agency refers to contributing to collaborative transformative practices, implicating a "sought-after future," and a commitment to realizing it.

Data sources and methods

Data were collected during the 2020-2022 academic years in three upper secondary schools in Southern Finland (two rural, one metropolitan). In the schools, teachers organized environmental education projects to engage students in climate actions. The data were collected for the duration of the school projects, informed by an ethnographic research approach (Hammersley & Atkinson, 2007). The primary data for this study are the interviews of four teachers and fieldnotes. Each teacher was interviewed multiple times throughout the project.

The interview data and observational fieldnotes were analyzed using an inductive qualitative analysis approach (Strauss & Corbin, 1997) based on open coding of excerpts that formed thematically coherent, continuous units of analysis. Guided by the two research questions, coding focused on manifestations of teacher agency as well as the resources and conditions that appeared to support or hamper teacher agency. The two data sets were compared to triangulate the data. Thematic analysis was used to identify patterns and synthesize the insights emerging from the open coding (Saldaña, 2011).

Results

The findings illuminate a rich variety of manifestations of teachers' transformative agency as they facilitated environmental actions of and with their students. The scope of environmental actions varied across school, municipality, and national levels. Examples of environmental actions included: promotion of vegetarian food in the school cafeteria (school level), experimenting with innovative forms of food production (school level), teaching younger students about the environmental crisis (municipal level), and winning an initiative in the city council (municipal level). The degree of radicality of the manifestations of the teachers' agency varied. Dominantly, the environmental actions were about individuals' actions for a sustainable environment. Many of them strived to create infrastructures for such individual actions. However, our analysis also illuminates rare, radical forms of teachers' transformative agency that involved questioning corporate power or fossil capitalism.

These findings also illuminate the conditions and resources that supported and inhibited specific forms of teacher agency. Supportive conditions and resources included teachers' personal networks and lives outside of work (e.g., local political activities, participation in social movements), support of colleagues and school leadership, and cooperation of students. Correspondingly, a lack of these conditions and resources created obstacles for teacher agency and over time made it harder for the teachers to pursue their commitments. Notably, the political climate and dominant values of the local setting appeared to be a central mediator of teacher agency.

Significance

This study highlights the importance of transformative forms of teacher agency as a mediator of educational responses to the environmental crisis. Profound changes are necessary at every level of society, as humanity is crossing planetary boundaries for biodiversity and climate change (Steffen et al., 2015). The findings of this study advance a nuanced understanding of transformative and even radical forms of teacher agency (e.g., Stetsenko, 2019), as well as the conditions and resources that mediate and sustain them in educational settings. These under-researched forms of agency are necessary for teachers whose professional commitments extend beyond the implementation of curriculum to world-building for sustainable futures with their students.

Paper 6: Capturing multiple levels of agency in teachers' workplace learning

Yeliz Günal Aggül & Ilana Horn

Researchers who study teacher agency from a sociocultural perspective largely agree about the reflexive relationship between individual agency and social structures (Biesta & Tedder, 2007; Edwards, 2017; Haapasaari et al., 2016). Yet they differ in conceptualizing it as an individual, collective, or relational phenomenon. We argue that these three levels should be examined separately and seen as complementary so that we can capture different aspects of teacher agency. To frame this conceptual discussion, we organize this paper around these questions: *How is teacher agency conceptualized, and what kinds of resources are at stake at each level? What are the implications for designing teacher learning environments?*

Individual level: Recognizing the influence of identities on teachers' agency

Some empirical studies focus on individuals acting in relation to their environments (Biesta & Tedder, 2007; Eteläpelto et al., 2013, 2015). In this perspective, teacher agency is shaped by teachers' professional identities, i.e., pedagogical ideals, knowledge, and competencies; work-related histories; future goals and motivations; and present engagements, all of which constitute resources for teachers as professionals to exercise agency in making decisions about their practices and improving their work (Biesta & Tedder, 2007; Eteläpelto et al., 2015; Priestley et al., 2012). At the same time, empirical findings reveal the significance of structural factors (e.g., support from school principals, school counselors, or colleagues; or a clear and robust professional discourse of teaching) in influencing individual teachers to continue exercising agency (Biesta et al., 2015; Eteläpelto et al., 2015). We maintain that a collective form of agency that goes beyond the individual level is needed to transform the constraining structures and create the conditions where individual teachers can sustain their agency. As Happasaari et al. (2016) highlight, "although initiated by individuals, agentive actions gain their meaning, their consequences, and their continuity in the interplay between individuals and their collective" (p. 235).

Collective level: Recognizing the community's role in making agency sustainable

The sociocultural teacher learning literature points to the importance of the resources created and owned by teacher communities in influencing teachers' understandings and changes in their classroom practices (Horn, 2005, 2010; Horn & Kane, 2015). Researchers who conceptualize agency as a collective phenomenon do not explicitly reject individuals' agency, but their analytical focus is on how collective agency emerges. They are interested in how communities create shared epistemic artifacts (e.g., Damşa et al., 2010) or transform their collective activity by engaging with the collectively unraveled problems of practice by envisioning new possibilities, employing resources to address them, and taking actions to design new patterns of activity (Haapasaari et al., 2016).

Conceptualizations of collective agency mostly focus on how groups create or transform *established practices and work cultures*. Teachers, on the other hand, need to engage in fluid forms of relations with other professionals to deal with the everchanging situations of their practice (Edwards, 2010). Drawing on Edwards' (2005) notion of *relational agency*, we move our focus from the collective level to the relational level to "understand how people are able to come together, however fleetingly, to interpret a problem and to respond to it" (p. 172).

Relational level: Dealing with the complexities of teaching via fluid forms of relations

Relational agency refers to the individual's capacity to act flexibly to address unpredictable aspects of their practice by engaging with different professionals working on the same problems of practice, taking others' perspectives, and making their own perspective visible to others in approaching it (Edwards, 2005, 2010). Relational agency differs from individual agency since the relational plane is where teachers and other professionals act agentically with resources that emerge only in interaction. Accordingly, Edwards (2010) suggests shifting attention from "discrete activity systems and how they change" to "emerging inter-professional practices and their capacity for knowledge generation" (p. 140-41). However, under "heavily boundaried systems" of schooling, teachers find limited opportunities to interact with others to respond to the challenging problems in their practices in a tailored way (Edwards, 2017). For instance, as Paper 3 in this symposium suggests, the lack of relationality in Veronica's school constrains her development of responsive practice to an unpredictable situation in her classroom.

Conclusion

We provided a conceptual lens to capture teacher agency at the individual, collective, and relational levels. We conclude that teachers' different professional identities are resources that influence their agency, and that teacher collectives and fluid forms of inter-professional engagement are key to achieving sustainable forms of agency and finding solutions to education's complex problems.

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Reimagining Learning Research in “canada” as “road Making”: Opportunities to Move Toward Equity Through Walking Methodologies

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Abstract: This symposium advances walking methodologies, and the kinds of learning and research relations that emerge through walking, as a significant process for “road making” toward more equitable futures in the Learning Sciences. The papers gathered here highlight diverse forms of walking together: from cultural anthropological research (Lee & Ingold, 2006) to walking with and alongside community activists (Curnow, Davis, & Asher, 2018; Takeuchi & Aquino Ishihara, 2021), to walking as learning and coming to know with and from the land (Marin & Bang, 2018), to reimagining place from transnational perspectives (Adams, 2013), and wayfaring as figuring both science and identities (Rahm, Gonsalves, & Lachaîne, 2022). Through dialogue within and across papers, we emphasize the ways in which walking methodologies make visible materiality and relations with the more-than-human world (Marin, 2020), as well as effects and experiences of inequity, with attention to co-constructing caring and equitable relations through shared walking.

Overall focus of the symposium

Background

The field of the Learning Sciences is in the midst of developing broader understandings of central concepts—including transdisciplinarity, design, cognition, technology (Shanahan, Kim, Takeuchi, Koh, Preciado-Babb, & Sengupta, 2022) (1). Situated on the land that is now called as “Canada,” we have been acknowledging the ongoing figuring and refiguring of the field of the Learning Sciences as a pivotal process enabling the field to learn and grow from historically silenced perspectives while moving toward an equity- and social justice-oriented ethos (Takeuchi, Vadeboncoeur, Krishnamoorthy, Hladik, Rahm, Kim, & Clark, 2022). Given the location where the International Society of the Learning Sciences conference will take place, we cannot ignore the histories of settler colonialism (Bang, 2020) and racial inequity that manifests in and through the phenomenon of learning. Where the conference is to be held, Quebec, is also the place where Joyce Echaquan, an Indigenous woman, was verbally abused and died while awaiting care in a hospital. It is in Quebec that six Muslim men were fatally shot in a mosque due to Islamophobia. Our symposium is grounded in our commitment to reconsider and reimagine our learning research and scholarship in ways that take into account and respond to these events seriously.

As one way to advance our commitment, we attend to the seemingly mundane act of walking. Walking together is “a social practice and method for knowledge building” (Marin, 2020, p. 9), as well as a practice of joint road-making, of making our way as we go (Horton & Freire, 1990, p. 6). Walking methodologies include diverse forms of walking together—from those incorporated into cultural anthropological research (Lee & Ingold, 2006) to walking with and alongside community activists (Curnow, Davis, & Asher, 2018; Takeuchi & Aquino Ishihara, 2021) to walking as learning and coming to know with and from the land (Marin & Bang, 2018), reimagining a place from transnational perspectives (Adams, 2013), and wayfaring as figuring both science and identities (Rahm, Gonsalves, & Lachaîne, 2022). There are likely other ways to walk with and alongside community members, to learn from and with them about racialized, gendered, and cisheteronormative practices through walking, and to begin to re-make the worlds we live in through generative interactions that create new ways of attending and seeing with, of becoming together, and of making change. Our research holds space to move beyond walking as a tool, or a means to an end, to advance possibilities for walking as a way of re-centering "bodies-in-motion as well as lands/waters" (Marin, 2020, p. 4) in learning theory, practice, and research. We also see a possibility of learning as being "embodied" and "emplaced" (Takeuchi & Aquino Ishihara, 2021), as a practice of walking toward justice in a material world that is "always already" a living ecosystem. As Lee and Ingold (2006) described, "walking itself can consequently become a practice of understanding, so that the record of the walk, and of the experience it affords, is just as important—and just as valid a source of field material—as the record of the 'discourse' that might have accompanied it" (p. 83). Our purpose in this symposium is to describe and inquire into our own research into learning, which incorporates different forms of walking methodologies located in various places within "Canada," in order to highlight both lessons learned and next steps as we continue to work toward advancing racial equity.

This kind of research requires attending and seeing with each other, in significant ways. Ingold's (2014) notion of attending is based upon the idea of entering into the unknown in our encounters with others. For example, it is worthwhile to attend to what is unfolding, including affects and ordinary encounters (Blaise, Hamm & Iorio, 2017; Taylor, 2020; Taylor, Blaise, & Giugni, 2013), matter and materials (Osgood & Andersen, 2019; Rautio, 2013, 2014), and more-than-human relations (Marin & Bang, 2018; Marin, 2020; Nxumalo & Pacini-Ketchabaw, 2017; Taylor & Pacini-Ketchabaw, 2017). One intention of our work is to decenter the person, or perhaps better said, to attend to what research on persons has previously made invisible, including material worlds and ecosystems and the material effects of racialization, as well as how these components affect or contribute to inequitable conditions for racialized people. Evoking Horton and Kraftl's (2006) invitation to attend to "what else" matters in research, we include bodies, places and spaces, affects, trees, sidewalks, material objects and other "minor actors" (Taylor, 2020) to better understand how what matters makes new horizons visible.

Attending more closely to what matters, and the matter(s) with which we are engaged, enables learning from and with participants and community members, and it also requires becoming affected by our experiences walking together with and alongside. Drawing an analogy to MacLure's (2016) work with children, we note that perhaps participants and researchers "are caught up in events that move at different speeds and are sometimes imperceptible to one another" (p. 180). From the perspective of the researcher, the activity may be ordered and regimented given typical research requirements, while the pace in which the life of the participant unfolds may be interrupted by research. These differences may remain "below the threshold of visibility set by the categorizing gaze that already 'knows' what is and is not significant" (p. 8). Concepts like attunement (Blackman, 2012; Stewart, 2011; Vossoughi, Jackson, Chen, Roldan, & Escudé, 2020), correspondence (Ingold, 2017), and passionate immersion (Tsing, 2010) in the lives of participants, "among other things," may enable researchers and participants to walk together during fieldwork in ways that advance understanding and contribute to social and ecological justice.

Innovative ways of attending, seeing, and becoming—both in research methodologies and when working toward changing larger ecosystems—require changes to research relationships, roles and responsibilities, what counts as learning, and how what is learned is utilized, by whom, and under what conditions. Walking methodologies expose the taken-for-granted in traditional research relationships by changing the balance of power between participants and inquiring into various kinds of power, their limits and limitations. Both highly visible actors in research and "minor actors" contribute in significant ways to the creation of "meaningful places" inside educational institutions (Panina-Beard & Vadeboncoeur, 2022), as well as "place attachment" (Scannell & Gifford, 2010). A logic-of-inquiry that advances research as attending, witnessing, walking, and storying with and alongside participants impacted by inequity offers opportunities to make visible the effects and experiences of racial inequities at a time in Canadian and world history when moving toward reconciliation and racial equity is urgently needed.

Symposium format

As a collective of scholars, and part of the leadership team for the Network of the Learning Sciences in Canada (https://www.canadianlearningsciences.ca), we believe in Open Access and equitable knowledge exchanges that can be achieved through a hybrid format. We are aligned with the vision set out by the International Society of the Learning Sciences, while also amplifying voices and context-specific, place-based scholarship from the geopolitical margins. While we embrace transnational scholarship reflecting the histories of immigration and refuge in Canadian society, and we use "Canada" in our Network to reflect our organizing efforts to foster equity-oriented scholarship of the learning sciences to include non-American contexts, we also acknowledge the colonial histories that the national marker, "Canada," carries. We know that the place we share was first called Turtle Island and as a collective, we commit to reflect on Canada's colonial past, learn from emerging truths, and act toward reconciliation with, and the resurgence of Indigenous communities.

To be aligned with our vision, we aim for this symposium to be a space for inter-university and inter-generational dialogues. We invited faculty members, postdoctoral scholars, and students as well as our community partners (where it is appropriate). In addition to the place-bounded symposium to take place in Montreal, we will create a virtual meeting room where the participants can join our symposium virtually. We will also invite the participants to continue dialogues with an asynchronous, online discussion board. The Network has been experimenting with alternative formats, learning from conferences, and creating our own Invited Learning Symposia throughout the year. During the COVID-19 pandemic, we have learned many things, including the value of holding online conferences. With an online option, we may be able to meet some of our shared goals; for example, we can reduce barriers for participation and our collective environmental "footprint." For this reason, while we honor the participants who wish for in-person interactions achieved through face-to-face conference, we will also mobilize our collective knowledge for virtual conferences to run an effective hybrid session.

The total length of this symposium will be for 75 minutes. Our symposium will start with a five-minute summary from co-chairs to frame the session (Vadeboncoeur, Takeuchi, Rahm). Then, four papers will be presented for 12 minutes each. The Discussant (Marin) will be invited to thread ideas across the papers for ten minutes, highlighting generative differences as well. A virtual discussion board (Padlet) will be used to facilitate online discussion throughout the symposium. During this time, our symposium will be made available virtually for the ISLS participants who decided to participate remotely. We will conclude with a reflection and discussion with the audience, which will happen both in the conference room in Montreal and in the virtual room. Co-chairs will divide the task of moderating discussion both in-person and online.

Paper 1: We make the road by walking: Toward abolitionist research methodologies

Joe Curnow & Abolitionist Futures Collective

Over the last years we have seen a groundswell of abolitionist organizing around the world, calling for anti-racist interventions to defund, disarm, and abolish police and prisons. Abolitionism is a social movement and political ideal that not only calls for the abolition of the carceral state (Gottschalk, 2015), including prisons, police, child welfare, and other racialized and colonial systems of surveillance and punishment, but, more affirmatively, for building a world in which community-led, life sustaining services prevent the harms that these violent systems claim to respond to, but often exacerbate (Davis, 2011; Gilmore, 2007). The abolition of policing and prisons is often critiqued as an unrealistic or utopian dream. To imagine a world without police and prisons requires a radical shift; such imagination is a collaborative learning accomplishment that enables abolitionists to engage in their practice. How then do we shift what is considered possible, and what people imagine justice could look like? This research asks how abolitionist organizers learn to facilitate for expanding abolitionist imaginaries and future-making.

This work takes place in Winnipeg, a city in central Canada, 60 km from the geographic centre of the continent. While much is made about Winnipeg being at the heart of Canada, the fact that Winnipeg is widely referred to as the most racist city in Canada reveals some greater truth about what lays at the heart of Canadian society. Winnipeg's racism, in part, stems from its long history of Indigenous dispossession and settler colonial violence (Toews, 2018). In the last decades, this has manifested through dramatic increases in policing, imprisonment, and child welfare apprehensions (Dobchuk-Land, 2017). More recently, we have seen a proliferation of policing in everything from public libraries to grocery stores, justified through thinly veiled racialized language around the threat that Indigenous people pose. These shifts have not gone uncontested—a coalition of organizers from different communities have come together to fight for a vision of Winnipeg wherein mutual aid and investment in communities might create antiracist and anticolonial paths to community safety that do not rely on the harmful practices of policing, prisons, and family separation. As elsewhere, this coalition has struggled against mainstream attitudes that seemingly cannot imagine a city without police, or where safety means anything other than the securitization, surveillance, and foreclosure of public space.

This presentation builds from work in the learning sciences which attends to the political and ethical dimensions of learning (Politics of Learning Writing Collective, 2017; Vea, 2019), as well as learning in social movements (Takeuchi & Aquino Ishihara, 2021; Tivaringe & Kirshner, 2021; Uttamchandani, 2021). Over the last decade, this work has laid critical foundations within sociocultural studies of learning that emphasize the impossibility of neutrality (McKinney de Royston & Sengupta-Irving, 2019; Philip & Sengupta, 2021), the necessity of political struggle (Curnow & Jurow, 2021), and the importance of using the learning sciences toward more equitable futures (Booker et al., 2014; Politics of Learning Writing Collective, 2017).

This paper considers what an abolitionist methodology would look like, feel like, and prefigure. First, we describe our collective and the principles which underpin our collaboration. Second, we argue that work toward abolition requires a commitment to "slow justice" (Neville & Martin, 2022), which we exemplify through a participatory action research design that has centred relationship building, meal-sharing, skill-building, and mutual aid. We argue that walking is a key piece of our relationship building strategy during COVID-19, in that shared walks have created space for one on ones, strategic planning, and interpersonal check-ins in the face of otherwise isolating conditions. Some of these meetings are in our neighbourhoods, while many are at the rallies, protests, critical masses, and community meetings our comrades have organized. Walking, in this sense, is also a collective action, a solidarity-building exercise, and an intergenerational opportunity to build relationships and power simultaneously.

For the learning sciences, attention to an abolitionist methodology brings a politicized perspective and walking methodology to work on participatory design and reorients us toward world-building as an expression of political and ethical investments in the field. This extends the emerging work on walking methodologies (Marin & Bang, 2018) and learning on the move, and draws out the connections between these methodologies (Taylor, 2020) and the radical world building they can prefigure.

Paper 2: Walking together to heal: Anti-colonial relationality in learning with the land

Miwa A. Takeuchi, Kori Czuy, Anita Chowdhury, Mahati Kopparla, & Sophia Thraya

Walking can simultaneously be methodology, pedagogy, and learning that weave in multiple intergenerational stories and knowings of the land (Hermes, Engman, Meixi, & McKenzie, 2022; Marin & Bang, 2018). This sensitivity to walking is rooted in Indigenous epistemology that centers whole body knowing grounded in "relationality—relationships with humans, more-than-humans, lands/waters, and mobility" (Marin, 2020, p. 281). For communities impacted by forced displacement and detachment from their homelands, resurgence of this relationality is a form of resistance to the destruction of the land and intergenerational knowledge (Betasamosake Simpson, 2014). For us, the act of walking *together* on the land, with people who sought refuge in "Canada" from war is a political collective action (Curnow & Jurow, 2021) that moves us toward healing. We view healing not as an individual act, but rather a political act achieved through "designing resilient ecologies" (Gutiérrez, 2016, p. 187). In this paper, we present the portraits of transdisciplinary learning that emerge through our collective action of walking together, toward healing from intersectional systems of oppression (Combahee River Collective, 1974) that affect both our participants and us as researchers. Our collective action to challenge intersectional systems of oppression is entangled with healing of the land who was damaged by the displacement of Indigenous communities who passed down intergenerational knowledge to live with the land and whose ecology was destroyed due to factory and road building in urban development.

We draw from participatory social design research methodology (Gutiérrez & Jurow, 2016), which centers historicity, diversity, equity, and ecological resilience as design principles, and aims to co-design just practices and futures in partnership with a range of communities. Our collaborative design aimed to re-center embodied and emplaced knowing for refugee children who come from traditional agricultural backgrounds, and whose intergenerational knowledge is often dismissed and disregarded in dominant school settings. By centering this community knowledge of soil, ecosystems, and socio-environmental justice, our design aims to leverage the valuable insights and expertise that refugee and immigrant communities offer. The designed program, called "Soil Camp" (https://www.soilcamp.ca), was held on a 30-acre community urban farm, that served as a space for refugee and immigrant communities to engage in local and sustainable agriculture with visions for decolonization and reconciliation with Indigenous communities (cf. Call 93 of the *Truth and Reconciliation Commissions of Canada: Calls to Action*).

Since the year of 2020, 85 refugee children have joined our program. 18 teachers and teacher candidates, mainly racialized multilinguals, joined us as facilitators. We as a team of researchers collected the following datasets: 1) video data, including Handycam video cameras and Go Pro cameras (worn also by teacher facilitators and children), 2) "life notes" (Dillard, 2000, p. 661) taken voluntarily by us and the facilitators, and 3) art works, makings, and journals made by children.

In our presentation, we draw on both the Go Pro camera video footage of us walking *together*, and our life notes to provide a glimpse into the transdisciplinary learning that occurred as we pursued our collective hopes for healing. Our analysis was conducted collaboratively, guided by our life notes which embody "the meaning and reflections that consciously attend to a whole life as it is embedded in sociocultural contexts and communities of affinity" (Dillard, 2000, p. 664). Through this work, we present instances of our shared learning, such as when we developed shared understanding of number line and scale in the context of colonial histories of the land, which paralleled the refugee children's experiences of colonization and displacement. We also depict our shared learning when the Western notion of pesticide and medicine was questioned during a walk that was shared between a Blackfoot facilitator, refugee children, and ourselves.

These portraits of learning collectively challenge apolitical views of walking, as our collective action of walking is fundamentally aimed at challenging the socio-environmental injustices that have long constrained the emergence and exchange of embodied and emplaced knowings connected to the land. Through our shared experience of walking together, we hope to mobilize land-based transdisciplinary learning toward socio-environmental healing.

Paper 3: Youth co-created photographic journeys that speak to more-than-human relations with nature, mobilities, and future oriented entanglements in the making

Jrène Rahm

In this paper, I explore human-material-nature relations by tuning into two visual co-created data sets that emerged from joint work with youth in science clubs that I ran over time in collaboration with a community organization in the first case (ArtsScience from 2010-2013), and a high school in the second case (ScienceClub from 2015-2017). I assume that more-than-human relations are central to and constitute learning and development (Marin, 2020). By attending to nature-culture relations, I aim to "recover how relations and systems of meaning making between the natural world and cultural worlds" (p. 37) are articulated and lived by groups of urban youth who participated in the club activities. I ask, 1) what relations and storylines do the photographs taken by the youth speak to and center? and 2) how do they shift our gaze and understanding toward heterogeneity, multiplicity, and profusion as radically generative for educational research (Taylor, 2016)? I center entanglements of learning and becoming while also attending to the "multiplicity of identity, the mobility of meaning, and the contestability of knowledge" (p. 7). I am guided by Massey's (2005) definition of space as "stories-so-far" and as essentially unfinished, yet telling of "interconnections between the past, present, and future" (Marin, 2020, p. 38). These ideas position place-based youth-initiated photography projects as stories still in the making, marked by interrelations and coexisting heterogeneity, and continuously reconfigured in light of new imaginaries and possible futures. Stories that speak to mobility, yet also place-making, and embodied perspectives of learning and becoming in and through re-awakened relations with nature and "worlding."

The visual data sets I rely on in this paper were endorsed as an imaginary of being methodologically in the mesh (Ingold, 2011), engaging with the here and then, while also attending to the emergent (Taylor, 2016). The positioning of myself within the complex meshwork of the two data sets made visible the hidden while it permitted me to become attuned to more-than-human-relations and to be affected by the experiences I draw from and that emerged from walking with youth over time. In the first case, we physically walked with youth back and forth from their community to a summer camp in robotics and video game development led by an Engineering School. In the second case, we jointly walked to and within a summer gardening programing organized by the local Botanical Garden where youth were assisting educators of summer camps. Analysis was pursued by attending to the storylines captured by the photos and reflected upon in fieldnotes and journals that centered youth voice. Analysis was possible through reflexivity, remembering, and reawakening our joint walkings.

The first case engages with science and human-nature relations that youth captured on their way to camp and in their maker activities. Photographic journeys seemed to speak to the remaking of relations with more-than-humans, whereas the maker projects seemed to undermine the kinds of material-body entanglements the former supported. This case also offers a glimpse of how affect and sensations drive the taking and sharing of visuals of surroundings. It is a form of multispecies mapping that mediates the rebuilding of relationships with place, space, history and land and questions Eurocentric visions of science and becoming in science. The second case speaks to youths' rebuilding of relations with nature and place, entangled with materials they previously never noticed or engaged with in the manner the camp suggested. Youth became immersed in nature as they walked the botanical garden with the campers and through engagement in creative eco-art projects and working the soil, taking care of youth gardens and crops, and essentially by contributing to the common good —the well-being of self, nature and others within that community—all of which they captured through photography.

I conclude with implications including that visuals and walking methodologies are key tools to center bodies in motion, interrelations between bodies and nature, and socio-material configurations. They also offer rich insights into future oriented entanglements in the making.

Paper 4: Walking alongside/towards desire: Re-thinking and theorizing through a desire-based lens

Sarah El Halwany, Rachael Edino, Sophia Marlow, Nadia Qureshi, Kristen Schaffer, Kristal Turner, & Jennifer D. Adams

Often, there is a tendency in research practices to focus on supposed needs and problems faced by racialized students in postsecondary education in an effort to mitigate experiences of marginalization and discrimination. Tuck (2009) argues that this kind of research unintentionally runs the risk of pathologizing communities, reinforcing a one-dimensional view of people. Tuck distinguishes between damage-centered research and desire-based research and calls for moving research towards crafting theories of change rather than damage (Nxumalo & Tuck, 2022). Inspired by Eve Tuck's proposition, Leitão (2020) draws a parallel between needs-based research used by social designers and damage-centered research to argue how they both reproduce a model of life, whereby "what is 'desirable' is supposedly known from the start and/or externally defined" (Leitão, 2020, p. 2). Moreover, what's desirable continues to be approached through "band-aid solutions." This forecloses the creation of new possibilities and ways of world-making—where multiple centres can flourish, i.e., Pluriverse—while being driven by the desires of the communities with whom we engage.

As researchers in the Creativity, Equity and STEM lab we have been longing to be in different relationships with data. The #BlackLivesMatter movement raised awareness in Canada about racial inequities in society and specifically, education. As such, our team was mobilized to learn about the experiences of racialized students in postsecondary STEM in order to enact change. We became attuned to notions of desire while reading Eve Tuck's work alongside other authors whose scholarship re-center desire as a productive and agentic force (Tuck, 2010) that is often neglected and/or relegated to the erotic/private (i.e., McKittrick, 2020; Zembylas, 2007).

In our presentation, we seek to reclaim desire, as an embodied force that moves us (metaphorically speaking) to craft new desirable worlds with our participants. We attempt to act on those desires by caring with our participants, rather than caring for them (Tronto, 1993). Caring for, in this context, sets the participants in a relation of indebtedness, claiming that they need our empathy and our externally defined solutions. On the other hand, *caring with* our participants compels us to center their own desires, in ways that can transform the world by claiming their dignity and humanness. In this way, we see desire as a *movement* that needs our special attention and care to design for a "pluriverse world" (Leitão, 2020). Often social design (e.g., research and pedagogical design) is limited to problem-solving, similar to a running race, directed by its finish line (Leitão, 2020; Nxumalo & Tuck, 2022). Instead, we view designing with desire as a point of departure for the researcher, where the research path is necessarily open and unpredictable, with the collective yearnings of the different stakeholders and the complex tensions that will necessarily arise along the way (Leitão, 2020).

We discuss how we are re-interpreting some of the data using a desire-based lens, positing creative and aesthetic analyses that attend to desire as an assemblage (Barlott & Turpin, 2022), gathering affirming ways of living and being. Those affirming ways of being entangle the quotidian with the structural. We join others who call for "befriending our desires" as a methodological commitment for "walking the talk" of allowing us to envision, new alternative, oppositional acts (hooks, 2014) of designing for equitable, just, and empowering STEM educational environments.

Endnotes

(1) Author Note: We are intentionally resisting the APA 7th style that requires us to erase co-authors in in-text citations. This practice not only hinders communicating the sense of collaboration and co-authoring, but also makes invisible/erases the presence of co-authors in text, even when they contribute substantively. We are also concerned that the author order could be, in some cases, a manifestation of hierarchies and power negotiations and, instead, would like to recognize the collective contributions of all authors. Therefore, we are citing all the co-authors in in-text citations.

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Centering Critical Youth Research Methodologies of Praxis and Care in Post-Pandemic Times:
From Respectful Relations and Dialogue Towards New Imaginaries

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Abstract: To center critical youth research methodologies of praxis and care in post-pandemic times, we bring together youth and researchers from four different partnership projects. Through dialogue circles with and between youth, we desettle taken-for-granted perspectives on research in the Learning Sciences. We ask: 1) How does engagement in co-creation and partnership projects offer all partners opportunities to reimagine research in education, a re-envisioning of it as humanizing and grounded in respectful relations ? ; 2) What does it look and feel like at the beginning, when relations are established, and later, as they are maintained through joint work and critical reflections about learning, teaching, and becoming? ; and 3) How does such joint-work support new future imaginaries for humanizing learning opportunities and meaningful joint research? A co-creation project will be pursued simultaneously, mediated by a local artist and further enriched by the discussant, leaving traces of the exchanges and shared with the larger community.

Symposium overview

The goal of this innovative symposium is to challenge taken-for-granted perspectives in research by centering youth voices, dreams, and future imaginings in the Learning Sciences. We come to this challenge as educators, learning scientists, anthropologists of education and artists, representing multiple disciplinary and social locations. Together we aim to unpack dominant research methodologies by engaging with youth and young adults from long-term partnerships with community organizations and joint social design studies in unique places across the globe. These partnerships and relationships are deeply grounded in respectful relations with one another, in ways that informed our understanding of learning *together*. As noted by Nasir et al. (2021), not only our understanding of learning calls for an interdisciplinary approach, but the research methods we draw on also need to come from across disciplines. In their words, it is “critical that this future research takes seriously the goal of creating experiences of learning that are liberatory, and which traverse current boundaries and limitations imposed by deficit assumptions and attendant research frames and methods" (Nasir et al., 2021, p.562).

Conceptual framework: Learning and unlearning together

By purposefully changing the presenter format in this symposium, we aim to respond to such calls and desettle taken-for-granted perspectives, and center conversations with and between youth across the globe to highlight imaginaries of just and empowered futurescapes with youth. However, we acknowledge that such work is not easy, and requires a dialogue of care, paying attention to "who we are in conversation with" when imagining and pursuing humanizing, decolonial and transformative joint research projects and community partnerships (Ali & McCarty, 2020). As noted by Takeuchi and colleagues (2023), "refiguring and transforming these histories in the present requires many forms of inquiry, including inquiries into our scholarship as well" (p. 255). It is the latter that is at the center of this session.

We contend that the bringing together of youth organizations and youth for a dialogue across differences and shared strengths is a beginning in the right direction towards "weaving an otherwise." We understand learning and unlearning as "learning together" and imagine creative qualitative methodologies as powerful tools to grapple with and in light of it to then better "align research with our heart, values, visions and hopes" (Tachine & Nicolazzo, 2022, p. 2), which we understand as the crux of joint and ongoing meaning-making in the Learning Sciences. The pandemic made rather clear that times are changing, that none of us can ignore any longer the manner our lives and stories are entangled with the sociopolitical fabric and realities of injustices around us. That reality pushed many of us to more deeply engage with research methodologies, our positionings, and our axiologies, and in doing so reimagine research designs where "human connections are central to, rather than stripped from it" (Tachine & Nicolazzo, 2022, p. 6). As we engage in rethinking and unpacking our dominant methodologies, we will also engage in re-envisioning them from political ontologies of pluriverse whose basis is rooted in care and mutual connection that have been discounted in conventional research (Authors, 2022). Engaging in such methodologies help us envision research as an enactment of knowing-in-being that emerges in the event of doing research itself" (Taylor, 2016, p. 18), as we bring together youth from different community organizations. We aim to re-imagine an otherwise together. Building on the notion of critical response-ability, the idea is that we need spaces where everyone's voices and responses could be heard, validated, and taken as points of action. In doing so, we aim to imagine the "looks" of future partnerships that bring forth values of care, mutual well-being, respect, trust, and relationality. We understand that simply supporting youth is not enough. Instead, we have to put into action re-humanizing policies, practices, and measures that celebrate the full humanity of youth. These practice essentially become about "the cultivation of collective knowing, desiring, being and making-with so that we render each other capable" (Murris & Bozalek, 2019, p. 11).

Format

We propose an innovative symposia format, including a hybrid session during the ISLS annual meeting (in-person dialogue mixed with participants joining in through ZOOM), centering deep engagement with reflexivity, responsibility, and relationships by engaging youth from four community programs and ongoing joint research in a conversation. While interested in a dialogue among youth from across the globe, we begin such a dialogue in this session by bringing youth together from the meeting location with others who will join in from other locations.

To build trusting relations among the participating groups and youth, two dialogue sessions will be organized prior to the meeting during which we will get to know each other and exchange ideas about what themes should drive the session (two one-hour ZOOM sessions in April and May 2023 in anticipation of the meeting). The three dialogue circles we currently imagine for the actual symposia are organized around the following broad questions which will be further refined by the overall team during our online meetings prior to the symposium: 1) How does engagement in co-creation and partnership projects offer all partners opportunities to reimagine research in education, a re-envisioning of it as humanizing and grounded in respectful relations (Argenal, 2022)? ; 2) What does it look and feel like at the beginning, when relations are established, and later, as they are maintained through joint work and critical reflections about learning, teaching, and becoming?; and 3) How does such joint-work support new future imaginaries for humanizing learning opportunities and meaningful joint research? These questions will also be taken up in a co-creation project mediated by a local artist that will happen at the same time as we dialogue together. The artist will summarize ideas the youth raise, while all youth participants physically present will be encouraged to add a personal touch to the mural during or immediately following the actual presentation. The discussant's comments will also be taken up in the mural. Following the session, the art project will be exhibited on the ICLS website and on the meeting grounds.

The conference symposium session will have the following agenda: A brief introduction (3 minutes), followed by three dialogue circles focusing on the questions raised above (15 minutes each/45 minutes). Note that the dialogue circles will be deliberately constructed and facilitated to have participation from in-person *and* remote participants. The first dialogue circle of 15 minutes will imply a brief presentation of the youth program by youth as well. The discussant will then highlight some ideas the mural and youth focused on (12 minutes), followed by an invitation of the larger audience to comment and contribute to the co-creation of the mural and dialogue (last 15 minutes of session).

Description of each project

Each project description below offers a glimpse of the youth voice driven partnership project that the participating teams have been engaged in. Each team also responds to one of the three questions and themes the symposium raises in its description. As suggested by the title, while we aim to center critical youth research methodologies of praxis and care in post-pandemic times, we also have to do so through the creation of communities like the one we aim to create in this session, that are deeply grounded in respectful relations and true dialogue. Only this way are truly empowering and new imaginaries possible. The joint project with an artist and comments by the discussant will ensure that youths' voices are heard, and their brilliance centered. Our invited discussant also brings much experience to such work and will be a further key actor in supporting the creation and maintenance of a safe environment where youth feel free to speak up and where their ideas will be captured in and through artistic expressions. Through engagement with questions intended to decolonise research methods and conference practices, we aim to name together both the transformative potential yet also challenges and limitations of critical youth research methodologies in praxis, as well as arts-based methods (Seppälä, Sarantou, & Miettinen, 2021). And as the descriptions of pertinent themes by each of the participating team and partnership make evident below, pluralism, mulivocality, and dialogue in research unify the different partners, resulting in important critiques yet also new imaginaries of possibilities. Research is about power, yet through deep self-reflection and unlearning, practices can be jointly remade, as this session aims to make evident.

Youth curation in the museum: The Viviendo Aquí Project

Kristina Stamatis, Jose Rogelio Manriquez Hernandez, Tupak Barrios Palacios Luna, & Atzin Rene Luna

Context & setting

The Museum (Muse) is a small local history museum located in the foothills of a small U.S. mountain-west city. The Muse Teen Corps program takes place during the school year. At the start of each season, museum personnel recruit youth from schools around the city and engage them in different aspects of exhibit planning. Youth typically collaborate with museum personnel to learn about the museum and its collection and to participate in different projects based on the Muse's curation efforts. During the 2020 – 2021 school year, in the middle of the COVID-19 pandemic, Muse staff collaborated with two local university researchers to develop and examine programming toward youth curation of museum exhibits. This collaboration grew into the *Viviendo Aquí* project, a museum exhibit designed by Latinx youth in which an undergraduate student and three lead members of the Teen Corps designed and curated an exhibit that drew contributions from 39 Latinx teens across the city. The exhibit was designed around the question: How do Latinx teens represent their lives and their cultures in our city? The teens, all of whom self-identified as Latinx, participated in twelve weeks of programming, designing their exhibit through activities that took place weekly. The exhibit was displayed in the spring of 2021 and drew more than 1,500 visitors.

Methods and analysis

This project was informed by theories of youth participatory action research (Fine, 2008) and community-based design research (Bang & Vossoughi, 2016). In this project, a team of researchers and participants gathered to engage in iterative cycles of design (Condliffe et al., 2020) to create a museum exhibit that would restory the museum toward participants' experiences (Stornaiuolo & Thomas, 2018). Participants include Jose, a Chicano male undergraduate research assistant, Tupak, a Mexican male student who was in tenth grade at the time of the project, and Atzin, a Mexican female student who was in ninth grade at the time of the project. This was Jose's first research project with the Teen Corps, and he acted as both a participant and researcher on the project, leading the design activities and supporting the analysis. He continues to collaborate on the research that resulted from the exhibit. Tupak and Atzin are siblings who immigrated to the United States from Mexico with their brother and mother. They each have been involved with the Muse since 2016 when they immigrated to the city. "Our mom wanted to make sure we were involved with the community," Atzin explained when she reflected on their participation with the Teen Corps. As the participants with the most experience in museum exhibit development, Atzin and Tupak acted as the lead designers, helping to create activities with which their peers would engage. Atzin and Tupak continue to be engaged in the Teen Corps.

Findings & implications

Our preliminary reflections aligned with the questions posed for this session and focused on the notion of projects that reimagine who is centered in research and how that research is interpreted toward more humanizing ends. When asked how our collaboration in the *Viviendo Aquí* project supported them to imagine new possibilities for the museum, Jose reminded us that the exhibit they created was not just about the youth and their stories, but about their families and those who had come before them. For example, when asked about a story that described his life in our city, Tupak spoke about his mom. “We think about social justice because my mom. In Mexico, my mom and I would go to the nearby town and help Indigenous women. They helped us too. Social justice is important to me because of my family.” Atzin agreed, explaining, “Our mom helps us understand that connecting to family means also connecting to our values and to social justice.” When asked to explain what social justice meant to them, Atzin explained, “It’s something that brings us together…fighting for rights, it’s part of our culture and our family ties.” When we consider the ways that joint-work might support new future imaginaries for humanizing learning opportunities, these young people remind us that collaboration and joint-research must not only attend to the needs of partners in the interactions we share, but also to the ways that cultures and traditions have shaped these interactions across generations and political geographies.

Rethinking notions of care and dignity in the context of STEM: Through the voices of junior youth researchers

Shakhnoza Kayumova, Akira Harper, Esmeralda Bereavalez, Feyza Achilova, & Gianna Richards

The context and setting

The youth experiences and voices draw from a longitudinal research program titled, *STEAM Your Way to College*, aimed at understanding the intersection between language-based racialization and science identity development among multilingual youth from nondominant communities. Youth participated in a 2-week all-day summer program engaging in STEM projects tackling sustainability issues in the community. The overall goal of the program was to understand what it means to dismantle deficit-based discourses rooted in raciolinguistic ideologies by positioning multilingual youth in asset-based terms and subsequently equipping youth with research-based tools to re-position themselves as cognitively advantaged. Within the program, we drew on theories of pluriverse and positioning theories to co-design asset-based learning spaces in which the students, teachers, and researchers were positioned as co-authors, co-researchers, and co-creators of knowledge (Kayumova & Dou, 2022; Kayumova & Tippins, 2021).

Methods/analysis

The three girls started in the program 4-5 years ago respectively. They have been positioned as co-researchers, mentors, and junior researchers over the years. In this study, we will provide cases of creatively power research inquiries that youth engaged in around issues of care and humanization in the context of STEM education. Youth researchers took up creative methods of “shared experience” through songwriting, journalistic interviews, sharing favorite music, and drawing to engage in dialogues about their raciolinguistic experiences and meanings of care and humanization as the basis for transforming dominant STEM spaces and expanding what it means to be a STEM person.

Findings & implications

Our results with the youth over time speak to the manner joint-work can support new future imaginaries for humanizing learning opportunities and meaningful joint research. Our research shows that multilingual youth who experienced raciolinguistic ideologies coped with them through the support of their family, friends, and community – a theme this team will speak to. As one of the youth described their dignity-denying experiences in schools and wider society due to their language difference, “[w]e don't have the full rights and [we] don't speak English, as [our] first language and because of that, they find that offensive to them like ‘That's disrespectful, go away.’ For them, to be a true American, we have to know English and if you don't know English, you're not American.” Their social imaginations and hopes for the future were driving forces in their resilience toward racialized experiences. Despite their experiences of marginalization, the youth collectively held on to ideas of care and collective well-being. “I would like to do seminars for kids that are like me now, when I'm in the future… So, I can create a good environment where they can be who they are no matter what and tell them to fight for their dreams, don't give up, and to embrace who they are, no matter if they have accents, no matter if they don't speak English fluently, but they will always be smart and capable of doing great things, no matter what people say." However, the youth were not willing to open up and eagerly share their experiences with adults and teachers. They did not share their perspective as readily as it is suggested in the research. It was when the youth took on the roles and positions of junior researchers and created spaces of inquiry through "shared experiences" the youth and adults began to open up. The youth created songs and videos about what it means to be a caring person in STEM, and they used community wealth posters to illustrate diverse ways of showcasing caring relations. In light of this special session, the work of this team makes evident that not only data and research findings are important but how the research is done. As we will share based on our experiences in this partnership, creative approaches to inquiry and research developed with, and alongside youth, can help develop more response-able relations with youth, accounting for interconnectedness, dignity, and caring relations that stand in contrast to dominant unidirectional, hierarchical, and neutral ones.

Affective solidarity in design-based research

Christian Ehret, Emily Mannard, Karl André St. Victor, & Christian Degenais Rogers

Context

The Côte-des-Neiges (CdN) borough of Montréal is amongst the most culturally diverse in Canada, with over half of its population comprised of immigrants from beyond North America. This paper reports findings from a youth-led project embedded within a multi-year, community-based design research project (cite) at Chalet Kent (CK), a CdN community center. CK serves youth ages 11-17, many of whom are racialized, and who represent the borough's broad diversity of languages and cultures. The larger project has been ongoing for five years, straddling the 2020 global pandemic, and has focused on developing opportunities for CdN youth to learn industry-relevant practices in videogaming, including in esports, game design, and livestreaming. The subproject's goal was to explore how CdN youths' diverse histories of 'low'-tech physical activities, movement cultures (e.g., basketball; freestyle break dance) and related affective practices (e.g., team building; affective intensities produced and shared through dance) were assets for learning 'high'-tech practices, specifically livestreaming and esports. Analysis foregrounds how youth themselves understand their diverse experiences and feelings of learning in 'low'-tech movement cultures as integral to 'high'-tech learning. Through the concept of 'vibes,' they further describe how these experiences and feelings contributed to the research collective's stance toward antiracist, asset-based solidarity-driven codesign.

Feeling the vibes as affective solidarity in design-based research

Through this subproject, the research collective (center youth workers, university researchers, and youth-researchers together) developed concepts of affective dissonance and affective solidarity, established in feminist theory (Hemmings, 2012) and critical educational theory (Zembylas, 2022), as essential tools both for developing concepts crucial to understanding youths' learning, and for putting into action antiracist and re-humanizing practices that honor youths' full humanity. Hemmings (2012) describes affective dissonance as the difference "between an embodied sense of self" and the self that youth "are expected to be in social terms" (p. 149). Through this project, we worked to foster affective solidarity as a means of transforming this dissonance into asset-based modes of learning, knowing, and being together throughout the esports program and across the youth center.

This critical approach emerged from tensions around competitiveness in the esports team that concerned the collective when an affective atmosphere made the esports space feel less welcoming for newcomer participants or onlookers. Rather than discipline the boisterousness, as racialized and youth often experience disproportionately (Diamond & Lewis, 2019), the collective discussed how paying attention to the 'vibe' in esports activity might help players maintain an inclusive atmosphere. Youth participants linked the process of attuning the vibes in esports learning to the vibes produced through the movement culture-oriented hip hop fitness program integrated through the subproject. In the session, two youth will describe the process of transforming affective dissonance into affective solidary through 'feeling the vibes' across movement cultures and esports as part of the collective's research design process. The two youth (15 and 17) from CdN's Filipino community have participated in the program for one and three years respectively. These youths' analysis will develop, and has developed, the concept of 'vibes', which social theorists have defined as the affective register of an experience (e.g., Adjirakor, 2021), as an affective, social design tool for learning scientists.

Implications

A wide body of research has described how youth draw on their everyday social practices for learning and creating with digital media within and beyond schools (Nasir, et al., 2021). However, how youth draw on their specific histories and cultures of moving and feeling for learning is not well understood. Analysis illustrates how youths' histories of feeling the vibes in movement cultures became an asset not only for design but also for collective learning. The design process of moving from affective dissonance to affective solidary in feeling the vibes contributes a uniquely affect-attuned, anti-racist, and asset-based design tool for solidary-driven design work in the learning sciences (e.g., Ishimaru & Bang, 2022). Such affect-attuned tools are necessary for designing more culturally sustaining learning opportunities alongside youth, whose embodied and felt ways of knowing are too often overlooked, especially when those ways of knowing emerge from communities and cultures that themselves are already marginalized. This team will bring such a focus to our joint conversation.

Centering critical youth research methodologies of praxis and care in post-pandemic times: From respectful relations and dialogue towards new imaginaries

Emily Diane Sprowls & Allison Gonsalves

Context & setting

The STEAM Team is a partnership between a public elementary school in Montreal and McGill University designed to facilitate collaborative learning and relationship building among youth, university students, and researchers. Sixteen fifth and sixth graders participate in a weekly after school club to do STEAM (Science, Tech, Engineering, Art, Math) activities with undergraduate student volunteers from the Faculties of Science and Education. The STEAM Team provides a space outside the traditional constraints of a classroom where youth participate as co-learners and co-teachers alongside university students and researchers as they co-investigate and co-create science projects together. The program works to facilitate just relations through knowledge co-creation and shared epistemic authority (Stroupe & Carlone, 2022), while also navigating institutional desires to recruit future science teachers, to enhance teacher education, and to showcase the school's underutilized science facilities. This expansion of science learning beyond traditional teacher-student models has required all actors to renegotiate epistemic positions of learners and "experts," and to refigure their perspectives on science and science learning. This research is motivated by the opportunity and responsibility to disrupt and expand "traditional" science learning and practices, rather than merely expanding access to narrowly defined science knowledge and settings (Ma et al., 2020; Schenkel et al., 2019).

Methods/analysis

The youth are sixth graders that signed up for "Science – Fun – Community" when the club launched in Fall 2022. With a goal of ensuring the activities in the club were "youth-led" (Rahm et al., 2016) we conducted several activities to elicit ideas from the youth about the directions they wished to take for the duration of the term. Youth engaged in discussion circles and sticky note voting to yield several themes around which the facilitators began recruiting university volunteers to facilitate different STEAM challenges. The youth are responsible for bringing to the program their curiosity about science along with their enthusiasm for hands-on creating and their eagerness to connect with university students. To ensure that the goals of the program are met, youth and university students engage in weekly sharing circles and cogenerative dialogues (Tobin, 2006), where they contribute their reflections about their learning and their relationships with other members of the STEAM Team.

Findings & implications

Upon joining the STEAM Team, youth were bursting with ideas for "doing science" activities in collaboration with their peers and vocalized their desires to create and build projects together. Dialogue circles at the beginning of each session prompted youth to verbalize goals of "everybody getting along," even while others shared their struggles with collaboration. In offering multiple opportunities for youth to partner with university volunteers and with each other, their eager engagement in hands-on co-creation opened up spaces for building relationships and acknowledging each other's contributions. Youth from this team, together with the researchers will speak up on some of these issues through their participation in this session.

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International Society of
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Exploring Making as a Pathway to Meaningful Engagement in and With STEM Disciplines

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Abstract: The goals of this symposium are to explore Making as a pathway to meaningful engagement with STEM disciplines and meaningful disciplinary engagement within a STEM discipline, how Making can enrich and transform scientific practices, and the tensions involved. Making experiences will be examined from perspectives such as equity and justice, personal relevance and affect, the role of materiality in scientific practice, disciplinary engagement, educational reform, and the role of teachers. These issues will be explored in different informal and formal US and international settings, and in terms of the diverse identities of the participating adults, teachers, children, youth, high school and undergraduate student Makers. Together, these rich and diverse perspectives and contexts will provide an in-depth and broad discussion of Making and its promise for STEM education.

Symposium overview

Making is an emerging contemporary "do it yourself" trend that capitalizes on the growing accessibility of digital fabrication tools and open-source hardware and software. Makers "play with technology" (Dougherty, 2012); they engage in creating new devices and tinkering. In the last two decades, numerous maker-spaces have opened (e.g. FabLabs) that provide the space and tools for makers to create and share their ideas and designs (Blikstein & Krannich, 2013).

The Making movement holds great promise for STEM education (Bevan, 2017a) through its democratization of knowledge in engineering and science (Blikstein, 2013), its alternative pathways to STEM (Martin & Dixson, 2016), venues for STEM learning that offer equitable opportunities to engage underrepresented youth (Calabrese Barton, Tan, & Greenberg, 2017) and opportunities to experience, express and explore meaningful relations with others and develop a sense of personal value (Vossoughi, Jackson, Chen, Roldan, & Escudé, 2020). Concurrently however, standards, predefined curricula, uneven distribution of resources, and school cultures present many challenges to the incorporation of Making into the classroom (Halverson & Sheridan, 2014). Moreover, meaningful engagement in Making does not necessarily entail profound disciplinary engagement in science or mathematics (Kapon, Schvartzer, & Peer, 2021), and very few studies examined detailed learning processes in which disciplinary practice emerged from Making.

The goals of this symposium are to explore axiological dimensions of Making in the context of deepening meaningful engagement with computing and STEM disciplines (papers 1 & 2) and epistemological dimensions of meaningful disciplinary engagement within a STEM discipline (papers 3, 4, 5). Collectively, the papers illustrate how Making can both enrich and transform scientific practice in educational contexts, while also highlighting the tensions involved, and how these tensions were resolved in each context. The first presentation discusses how moral and affective dimensions of experience can be foregrounded in the context of working with simulations of complex scientific and socio-scientific phenomena in informal spaces. The second presentation is situated in an afterschool STEM Making community and examines how and why a group of Black youth extensively iterated on a "name plate" project, how this expanded iterative process disrupted normative power hierarchies and the emergent tensions. The third presentation discusses a science reform project at district-level in a Brazilian city, and examines the work of a group of collaborating science teachers who employed a Making environment to create and personalize instructional resources (science kits) for their students. The fourth presentation examines how students' disciplinary authentic engagement in physics was facilitated and emerged from Making that was incorporated into the formal instruction of physics in high school. The fifth presentation examines the connections between making, materiality, and disciplinary learning to explore how making deepens and extends students' engagement in a computational physics course at the undergraduate level.

Significance and contribution

Together, the presentations address the goals of the symposium from multiple perspectives: equity and justice, personal relevance and affect, the role of materiality in scientific practice, disciplinary engagement, educational reform, and the role of teachers. They explore these issues in various contexts and settings in terms of informal and formal education, in the US and internationally, and the diverse identities of the participating Makers - adults, teachers, children, youth, high school and undergraduate students. In doing so, the presentations collectively uncover different axiological and epistemological dimensions of the affordances and challenges in transforming Making experiences into meaningful disciplinary learning. The rich and diverse perspectives and contexts reflect different perceptions of 'meaningfulness' that problematize and provide in-depth and broad overview of Making as pathway to both meaningful disciplinary engagement in and/or with STEM disciplines.

Format

The symposium will begin with a brief introduction to the session (2 min), followed by a presentation of five papers (10 min each). The discussant, Flávio Azevedo, will examine themes and juxtapositions across the papers, flash out and raise question about the implications of the collective work (10 minutes), and open the floor for a discussion with the audiences (13 minutes).

Paper 1: Re-making code through moral and historical re-orientations in public spaces

Pratim Sengupta, Marie-Claire Shanahan, Apoorve Chokshi, & Basak Helvaci Ozacar

Introduction & theoretical background

This paper investigates the interplay between moral, affective and epistemological dimensions of making (Vossoughi et al., 2020), in the context of a public computing environment (Authors, A). Our work arises from the concern that technocentric (Papert, 1987), neoliberal (Takeuchi et al., 2020; Irani, 2019) and colonial ideologies (Philip & Sengupta, 2021; Vakil, 2018) that have largely shaped computing and maker education have resulted in an overemphasis on symbolic and technical productions over the heterogeneous and historically embedded human experience of learning (Sengupta et al., 2021; Ames, 2019; Rosebery et al., 2010). Rather than positioning making in terms of technocentric framings of convivial uses of microcontrollers and code (e.g., Halverson & Sheridan, 2014), we foreground the affective, moral and historical dimensions of experience in such spaces (e.g., Vossoughi et al., 2020; Espinoza et al., 2021). Using such an approach, we illustrate how participants re-orient canonical computational simulations of flocking (Reynolds, 1987) and ethnocentrism (Hammond & Axelrod, 2006) toward socially and historically marginalized voices.

Research question

How can moral and affective dimensions of experience be foregrounded in spaces that involve coding and computation?

Study design & method

Observations were conducted in X (name redacted), a public computing environment (Authors, A) located in an indoor public walkway at a large public research university in Canada. X consists of three 80" touchscreens, each powered by a desktop. These screens display open source simulations of complex systems. Visitors can use the screens to interact with these simulations, where the aggregate level patterns (e.g., flocks) emerge from simple, rule based interactions (e.g., alignment, cohesion and separation) between many individual agents (e.g, boids). We present two illustrative cases in which visitors interacted with a simulation of flocking (Case 1) and ethnocentrism (Case 2). Our observations were video recorded and transcribed for analysis. We conducted grounded theoretical analysis using constant comparative method (Charmaz, 2006), identifying how participants re-oriented specific code segments, algorithms and other representational elements of the simulation (e.g., labels of specific variables, parameters of the simulation and visualizations).

Analysis

In Case 1, a female adult with two elementary age children interacted with the Flocking simulation over approximately 30 minutes. The children first modified the flocking algorithm using very high values for the numerical parameters, resulting in the flock taking the form of a pulsating, overcrowded, circular cluster of boids. As the participants interpreted the visualization, they created new linguistic references (e.g., “bonking”; “Boid prison”), and re-contextualized the emergent visual pattern through a discussion on overcrowding in prisons led by the adult with them. In Case 2, a White graduate student interacted with the ethnocentrism simulation over approximately an hour, facilitated by an immigrant graduate student of color. Through discussion they verbalized how the underlying algorithm positioned immigrants (in the simulation) in deficit terms. They worked to alter the parameters of the code to ensure that immigrants were not forced to assimilate in the predominantly White society of the simulation.

Conclusion and discussion

The cases illustrate acts of re-orientation through moral (Case 1 and 2) and historical (Case 2) recontextualizations of disciplined (Mignolo, 2007) formations (algorithms and visualizations). The products of making here are more than computational artifacts. Participants are re-making disciplinary assumptions and models from axiological perspectives.

Paper 2: “This IS me, complex, messy and unfinished”: Community epistemologies and wisdom in iterative black youth STEM-rich making

Angela Calabrese Barton, Day Greenberg, Edna Tan, & Melissa Perez

Purpose

In communities, youth make with a critical awareness of the world as it is and a desire to author a world that could be. Using participatory critical/relational ethnography, we documented how/why a group of 12 Black youth iterated over *four months* on a “name plate” project intended to last *three weeks*, guided by these questions:

- How, when and for whom did youth iterate on the name plate project? How did these iterations support youths’ opportunities to draw upon community epistemologies in conjunction with STEM knowledge?
- How does an expanded iterative process disrupt normative power hierarchies in *community-engaged, STEM-rich* making? What are the emergent tensions in the process?

Perspective

Iteration, defined as successive rounds of design towards optimization within the prototyping process, is an important epistemologically-grounded maker practice (Martin, 2018). However, little attention has been paid to the intentional incorporation of community epistemologies towards new forms of legitimate STEM-rich maker knowledge/practice through iteration.

We use both terms – *community-engaged* and *STEM-rich* – to set up a necessary tension and existing connections historically elided in STEM/making, towards justice-centered efforts in maker education. We foreground how maker knowledge/practice is localized and distributed within community (hooks, 2003), where the necessary know-how to make involve Black youths’ existing knowledge and wisdom (Evans-Winters, 2019). We emphasize the importance of access to STEM knowledge and practices in supporting making, and in the functionality of made artifacts, while noting this is *fraught* given the colonial and racialized history of STEM (McGee, 2021).

Methods

This work takes place in the Green Club program for middle school youth, a community-based makerspace serving a predominantly Black and low-income population. Data generation involved giving critical witness to youths’ making through include maker artifacts, conversation groups, interviews, and video of maker sessions. Analysis involved multiple stages and levels of coding based on procedures for open-coding and method of constant comparison.

Findings

In the first three weeks of the GC program, youth designed and built “name plates” using woodworking tools and materials. Afterward, several expressed interest in expanding the project, indicating they “weren’t done representing me.” Educators and youth spent the next three months co-planning novel ways to iterate on their nameplates, adding new layers (Figure 1):

- Lighting (building electrical circuits).
- Motion (complex circuitry incorporating motors to power youth-designed extensions),
- Sound (programmable speakers/coding)
- Sustainability (replacing batteries with renewable energy, e.g., solar panels).

Figure 1

One youth’s intermedia board: (Top left) woodworking; (Top right) adding lights (soldering circuit); (bottom left) after adding a sound system; and (bottom right) illustrating how the motor powers the moving hearts.

As youth explained, we renamed these “layered named plates” as “intermedia boards” because “this board is to tell about me” … “this IS me. Complex, amazing...really messy, and not finished.” The boards proudly hang in the makerspace.

We illustrate three findings.

1. Youth leveraged a range of experiences, desires, identities and ideas for how they re-presented themselves;
2. Layers of iteration became liminal spaces of expanding STEM-rich maker knowledge while projecting how these ways of knowing are historicized, as youth re-imagined projects in their likeness and desires.
3. Iterations expand how community knowledge/practice becomes more legitimized in STEM-rich making, re-shaping whose knowledge has capital.

Implications for supporting justice-seeking cultures of STEM-rich making are offered.

Paper 3: Reframing the use of makerspaces resources for disciplinary integration in the Global South

Cassia Fernandez, Tatiana Hochgreb, & Paulo Blikstein

Theoretical perspectives

Engagement with science and engineering practices is an essential learning dimension in contemporary science standards (e.g. ACARA, 2016; British Columbia Ministry of Education, 2017; National Research Council, 2012). Makerspaces' tools and resources could enable more meaningful and practice-based ways of learning science and engineering (Quinn & Bell, 2013; Martin, 2014; Bevan, 2017). However, in traditional makerspace implementation models, resources are meant for students to create their own personal projects. While attractive and feasible for after-school programs, or in affluent schools or countries, in more typical school settings worldwide, teachers need to scaffold instruction attainable to a limited lesson time and many students. Moreover, most research in this field has been derived from US-based experiences, and perspectives from the Global South could contribute to a more diverse range of strategies to integrate makerspaces into disciplinary contexts.

Objectives

In our study, we describe how teachers have been transforming models of makerspace use, using its resources for science teaching in public schools in a medium-size Brazilian city, and discuss alternative ways of makerspaces' implementation based on local specificities.

Context & methods

Our data is drawn from an ongoing five-year science reform project at the district level (Anonymous, 2020, 2022) that includes: (1) the redesign of municipal science standards, (2) long-term participatory professional development for teachers, (3) implementation of makerspaces, and (4) hiring a dedicated lab teacher to the makerspace, who co-designs curricular units with other teachers. Since 2017, as part of this project, we have worked with a group of teachers to co-design science curricular units through four cycles of design-enactment-reflection (Anonymous, 2020). Our data includes field notes, documented teacher interactions, interviews, and lesson plans. We analyzed how makerspaces' resources were integrated into the lesson plans using emergent themes to categorize them.

Findings

Our findings indicate that in this educational context, with little time for science classes (around 100 minutes/week) and 30-35 students, teachers soon realized that the US-inspired model of implementation would not work, and instead, after many cycles of redesign with our team, reframed makerspaces resources to produce inquiry-based, constructionist toolkits for students to use as part of their newly designed learning activities. The data revealed three types of goals for these toolkits: (1) create analogies and representations of scientific phenomena; (2) engage with specific scientific ideas; and (3) explore phenomena through testing ideas.

Contribution

Our findings illustrate new ways devised by teachers to integrate makerspaces into instruction for meaningful disciplinary engagement. The toolkits created allowed them to expand their pedagogical possibilities in creating new learning activities, enabling students to engage with more advanced scientific practices (such as using models and carrying out investigations) and with "big ideas." In this context, digital fabrication tools helped produce innovative constructionist materials, which made it possible to implement student- and inquiry-centered, equity-focused activities made available for all students during the regular instructional time--achieving more ambitious learning goals defined by the teachers, as opposed to only resourcing to regular textbook activities or class-wide demonstrations of experiments.

Paper 4: Facilitating the emergence of authentic disciplinary engagement from a meaningful engagement in making

Tal Peer & Shulamit Kapon

Objectives

The integration of Making into the formal instruction of STEM disciplines is not straightforward. Maker projects prioritize creativity and personal relevance, whereas learning mathematics and science is constrained and often driven by predefined curricula and standards (Bevan, 2017b; Sheridan et al., 2014). This paper explores how disciplinary authentic engagement in physics emerges from a personally meaningful engagement in Making, and the role of instructors in fostering and facilitating this emergence.

Analytic lens

We define students' sense of personal relevance (Kapon, Laherto, & Levrini, 2018) during an interaction as high engagement; i.e., when students: (1) actively "choose to engage in the activity, given a choice"; (2) "persist in the activity, given a choice"; (3) "invest personal resources, such as effort, in the absence of coercion or outside incentives"; and (4) demonstrate "affective responses toward the activity" (Azevedo, 2006). We operationalize students' authentic disciplinary engagement in physics as enactments of practices and behaviors that reflect "thinking like a physicist" (Kozminski et al., 2014).

Method

The educational context of the work was a Physics-Maker-Based Challenge (PMBC). The students had to design and construct a launcher to launch a marble that could reproducibly move through a series of increasingly smaller rings placed on a vertical wall (projectile motion), and land in a cup, test its performance, and present and defend their design. The activity took place in a school Maker-space environment during lessons devoted to inquiry in physics (18 academic hours). The participants were 10th grade students (N=18) enrolled in advanced-level physics. Two physics teachers facilitated the activity. Students were encouraged to express their creativity.

We present a case study of a pair of students, drawn from an ethnographic study that documented the intervention. The data include video recordings of group work, follow-up interviews with the students, the artifacts the students generated and used during the inquiry (e.g., spreadsheets), and a research journal. The analysis examines students' discourse to identify instances of students' high engagement and authentic disciplinary practice, as well as their interactions with the facilitating teachers.

Results and conclusion

We present two episodes from the design phase of the launcher. In the first, the students discuss three optional launchers based on different mechanisms which emerged from their independent brainstorming, and try to intuitively figure out how to control the velocity of the launched marble in each. The analysis highlights various aspects of high engagement such as deep affective involvement, and the investment of time and effort without external incentive. In the second episode the students have already worked on the design of one of the launchers, which they imagined as having an explosion mechanism. Because they had trouble translating their idea into a concrete design, they asked for assistance. The analysis illustrates how the teacher's conversational moves navigated and fostered the students' meaningful engagement in disciplinary practice.

Contribution

The findings illustrate how Making can be incorporated into the formal study of physics, its affordances for meaningful disciplinary practice, and the pivotal role of instructors in fostering the emergence of disciplinary engagement.

Paper 5: Expanding meaningful disciplinary learning with computational making

Brian E. Gravel, Ezra Gouvea, & Timothy Atherton

Objectives

We describe a pedagogical approach called computational making. Our paper contributes to research building connections between making, materiality, and disciplinary learning (Bevan, 2017; Blikstein, 2014; Kapon et al., 2020; Manz, 2015). Computation is fundamental to physics disciplinary practice (Humphreys, 2004) and the learning and development of students and professionals (Clark & Sengupta, 2013). We critically re-examine perspectives on doing science—which has been narrowly constructed in physics pedagogy (Weiman & Perkins, 2005). We explore how making deepens and extends students' engagement in a computational physics course (Phillips et al., under review).

Theoretical perspectives

The practice of going back and forth between seeing phenomena in the world to modeling those phenomena computationally (Chandrasekharan & Nersessian, 2017) is challenging for students (Gravel & Wilkerson, 2017), requiring them to select representations (e.g., mathematical expressions) that correspond to the entities of the physical phenomena (Greeno, 1983). We build on computational making (Gravel et al., 2022; Rhode et al., 2015) as a pedagogical approach that foregrounds learner attention to materiality and efforts to describe the "rules" of constructed artifacts. We draw on design as material conversations (Schön, 1992), computing with objects (Knight & Stiny, 2015), and disciplinary engagement (Engle & Conant, 2002), asking students to make objects (Figure 1) they then model computationally. We ask: How does computational making change the accessibility of students' resources to model and make sense of the physical world?

Methods and data

We present data from a design-research project (Brown, 1992) investigating students' changing relationships to tools, materials, and each other. In an undergraduate computational physics course, students were prompted to "make an oscillator" with simple craft materials and to model their creation computationally. We used interaction analysis (Jordan & Henderson, 1995) to identify characteristics of computational making and describe these using three cases.

Findings

We identified three areas where students' relationships with modeling and materials were entwined:

- *Ontological (re)negotiation*. M and C grappled with the bizarre behaviors of their two-magnet oscillator. By trying to represent the poles in these circular magnets, they discovered the magnets did not behave as they expected; they renegotiated their assumptions about the nature of the material, and created a rich computational model.
- *Range of agency in composition*. J and E noticed discrepancies between their empirical results and their computational model—leading them to recompose their model to account for previously unnoticed twisting of the nylon string. Their available agency to iteratively (re)compose both the computational model and their artifact contributed to nuanced understandings of material properties and modeling choices.
- *Iterative accommodation of materials*. The Ramp Group iteratively explored a curved surface anchored at four points. The iterative conversation with their idiosyncratic materials pushed them toward creative ways to process their data in order to build a better computational model.

Figure 2
(Top left) J & E explore the string in their oscillator; (Top Right) C explores the two magnets as M examines magnetic field diagrams; (Bottom) The ramp group explores how objects roll on different configurations of the ramp.

Significance

We illuminate a unique pedagogical pathway. Centering materiality contributes new ways of understanding how students listen and respond to the physical world as they build representations in different ways. The implications open opportunities for future pedagogical innovations and further study of the relationships between computational making and disciplinary practice.

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Making Sense of Machine Learning: Integrating Youth's Conceptual, Creative, and Critical Understandings of AI

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Abstract: Understanding how youth make sense of machine learning and how learning about machine learning can be supported in and out of school is more relevant than ever before as young people interact with machine learning powered applications everyday—while connecting with friends, listening to music, playing games, or attending school. In this symposium, we present different perspectives on understanding how learners make sense of machine learning in their everyday lives, how sensemaking of machine learning can be supported in and out of school through the construction of applications, and how youth critically evaluate machine learning powered systems. We discuss how sensemaking of machine learning applications involves the development and integration of conceptual, creative, and critical understandings that are increasingly important to prepare youth to participate in the world.

Symposium overview

Recent calls to promote artificial intelligence (AI) literacy in K-12 education highlight the importance of engaging young learners with big ideas, preparing them for careers in computing and to be critical consumers and designers of technology (Touretzky et al., 2019; DiPaola et al., 2022; Wang et al., 2021). Within AI literacy, fostering an understanding of machine learning (ML), which involves the use of data rather than code to shape the behavior of computer programs, is crucial (Long & Magerko, 2020; Zimmermann-Niefield et al., 2019). Machine learning is a new paradigm in computing education (Shapiro & Tissenbaum, 2019) that learners must engage with to become computationally literate and be empowered to participate in computing (Kafai & Proctor, 2022).

Despite the fact that machine learning is often black boxed in consumer applications, research shows that children construct naive explanations to make sense of how these work (Druga et al., 2017; Williams et al., 2019). At the same time, designing machine learning applications requires thinking like a scientist and building hypotheses, using data sets to train and test models to make predictions (Shapiro et al., 2018; Langley, 1988). Both using and building ML-powered applications demand making sense of how models work and how data shape their behaviors. Yet little attention has been given to how youth integrate conceptual, critical, and creative understandings in making sense of ML-powered applications. Sensemaking involves explaining observed phenomena using theory and evidence (Newman et al., 1993; Crowder, 1996) to "figure something out" by dynamically building and revising explanations using both formal and everyday knowledge (Odden & Russ, 2018). Whereas sensemaking has traditionally centered on conceptual understanding, learners also engage in explanation building when considering ethics to critically understand how systems work. At the same time, making applications engages learners in creative understanding, by having to make decisions on how to create personally relevant projects they build and revise explanations. In this symposium we bring together research on young people's novice sensemaking of ML, that is how they come up with and revise their explanations of how machine learning works as well as how their sensemaking can be supported through the analysis and construction of ML-powered creative applications in and out of school. Participants discuss the following questions:

(a) How do youth build on their everyday experiences with technology to make sense of ML?
(b) How can youth sensemaking of ML be supported through the design of ML-powered applications?
(c) How do youth critically evaluate and understand ML-powered systems?

The invited works provide examples of how conceptual, creative, and critical understandings of ML and AI can be integrated. Presenters apply Learning Sciences perspectives on embodied cognition, critical literacies, modeling and design-based research to the analysis of ML sensemaking with studies conducted in computing and non-STEM contexts, out of school and in K-12 classrooms: Castro and colleagues investigate youth's understanding and embodied learning of ML and in a computing and dance intervention; DiPaola and colleagues examine how embedding ethics into three project-based curricula supported students to develop understandings of ML applications as sociotechnical systems; Lee and Soep study meaning making processes when youth create projects about and with AI/ML technologies through a critical perspective; Long and Magerko research how embodied interaction through dance can support learning about ML in informal spaces; Morales-Navarro and Kafai investigate how youth make sense of ML when encountering failure cases as users and creators of applications; Solyst and Ogan study girl's funds of knowledge and knowledge gaps around AI/ML and fairness; Tatar and colleagues adopt a situated learning perspective to analyze students' data modeling experiences and their impact on shaping students' understanding of AI/ ML.

The symposium is organized in three sections: (1) the chairs will introduce the topic and then each presenter will give an one-minute teaser about their work (~10 min); (2) the first half of the presenters will have 20 minutes to share their work using posters placed around the room, followed by the second half of presenters (20 minutes)—this arrangement will give the audience and presenters time to see each other's posters; (3) our discussant Sepehr Vakil, an expert in justice-centered computing with experience in community-centered AI education, will synthesize and reflect on findings (10 minutes) followed by a Q&A with audience and presenters (~15 min).

1. Shuttling between contextualized creative computing and learners' understanding of machine learning algorithms in the real-world

Francisco Castro, William Payne, & Kayla DesPortes

Integrating movement practices from dance into computing and machine learning (ML) education can lead to culturally sustaining experiences where learners draw upon cultural ways of knowing as they explore identity across individual, social, and political dimensions (Castro et al., 2022; DesPortes et al., 2022; Payne et al., 2021). Novel dance-computing technologies and curricula, like danceON, must not only leverage cultural assets but set out to sustain communities (Paris & Alim, 2014). In our work, we explore how BIPOC youth shuttle between embodied knowledge and reasoning of ML concepts and how their personal and sociopolitical understanding of ML reaches beyond the learning environment.

Wild and Pfannkuch (1999) articulate the importance of learners shuttling between their disciplinary and real-world knowledge in statistical thinking. Researchers have found this can support purposeful and meaningful exploration of concepts (Ben-Zvi & Aridor-Berger, 2016). We draw on their framing of shuttling as we examine how learners build their mental models of computing systems through creating dance-computing artifacts, then leverage this understanding to explore personal experiences and implications of computing systems in society.

We examined a section of a 15-week internship with 6 high school learners from STEM From Dance (stemfromdance.org), a community organization that engages young women of color in STEM and dance. Within these sessions, learners trained classifiers to identify two poses with Google's Teachable Machine while also working with danceON, a creative coding environment that enables learners to code animations over dance videos (Payne et al., 2021). In tandem, they read articles about misuse and biases within ML systems. We reviewed two sessions that were recorded and transcribed verbatim and identified instances where learners discussed general ML concepts (who uses and develops systems), ML processes (training, testing, etc.), and ML behaviors (pose detection); this enabled us to identify when learners (1) reasoned about ML concepts with their body and (2) shuttled between their embodied experience of ML, their personal experiences of ML, and understanding of ML in society.

Learners regularly encountered limitations of pose detection as they witnessed animations and body points drawn incorrectly. They hypothesized possible causes such as occlusion, movement speed, and clothing, and incorporated strategies for improving accuracy through movement. Through making classifiers with

Teachable Machine, learners identified gaps in the training data and discussed how more iterations of data collection may improve accuracy. Finally, in discussions, learners connected their conceptions and understanding of pose detection with personal experiences with other ML systems, such as limited performance of home assistants within a family of non-native English speakers and reasoned about the impact of biased ML systems for others. Our work highlights the affordances of creative dance computing spaces as avenues toward the embodied learning of ML. By engaging in activities and discussions of ML within the embodied, cultural, and collaborative nature of dance, we found concrete instances of shuttling between their understanding built through dance and their understanding of the real-world context—i.e., the impact of human-driven design decisions on the implementation of ML, and their personal experiences with AI systems. Through continued exploration of co-designed scaffolds, we can further develop the ways in which asset-based experience in cultural practices like dance can facilitate sociopolitical examination of ML, which is a key component of supporting culturally sustaining pedagogy.

2. Use, understand, create: Embedding ethics in machine learning curricula for middle school youth

Daniella DiPaola, Randi Williams, Safinah Ali, & Cynthia Breazeal

Machine Learning (ML) is a powerful computational tool that can greatly benefit, but also potentially harm users, especially those from systematically marginalized communities (Buolamwini & Gebru 2018, Noble 2018, O'Neil 2016). The tension between benefits and harms should be presented in an age-appropriate way to all students learning about ML. However, recent work shows that computer science educators typically withhold or exclude ethical issues in their courses, to the detriment of their students (Fiesler, Garrett, & Beard, 2020).

This work discusses the design principle "embedded ethics" and how educators can incorporate ethical thinking activities into project-based ML curricula. "Embedded ethics" involves teaching ethics alongside technical concepts helps students develop a fuller understanding of the technology, including the long-term implications of systems they create (Saltz et al., 2019, Skirpan et al. 2018, DiPaola, Payne, & Breazeal 2020). This work aligns with the Use-Understand-Create framework for digital literacy and shows how ethical thinking can be a part of every stage of students' learning progression (MediaSmarts, 2021).

This paper presents three project-based curricula on emerging ML topics – generative adversarial networks, affective perception, and supervised machine learning (Williams et al., 2022). Each curriculum includes the use of real-world ML demos, conceptual discussion, and open-ended creation to teach students about ethical thinking. In an introductory activity in Creative AI, students learn to anticipate potential beneficial and harmful uses of various generative AI tools. In Dancing With AI, students employ their technical understanding to predict the impact of ML classifiers trained with flawed datasets. In How to Train Your Robot, students consider different stakeholders' values in their final project designs. In the summer of 2020, we trained 11 middle school teachers, primarily from Title 1 schools, to co-teach one of the three curricula to 78 middle-school students from 8 states across the USA. A mixed methods approach was used to evaluate their mastery of ethical thinking in different activities. This encompassed statistical methods to evaluate AI concept surveys pre-post, thematic coding to evaluate classwork, and rubrics to evaluate final projects. These measures were developed by the authors for the purposes of this project.

Before the workshops, the surveys showed that most students had an agreeable disposition toward AI, associating it with positive words like "exciting" and positive impacts like "making jobs easier." Students' classwork demonstrated an increased ability to imagine potential societal repercussions of AI systems and apply ethical decision making to their final projects. In students' final project creations, students were able to transfer their knowledge of ethical implications of AI systems to areas of personal interest. Overall, the authors observed that embedding ethics into curricula led to students developing a nuanced understanding of ML applications as sociotechnical systems.

This paper describes three approaches taken to teach students about ethical thinking throughout all stages of their learning trajectory. In previous work, researchers found that tools for ethical analysis enabled students to critique and then redesign AI systems that they were familiar with (DiPaola, Payne, & Breazeal 2020). The three empirical studies examined in this work showed students going one step further and implementing reimagined AI systems through their own projects. For example, one student in the Dancing with AI curriculum, inspired by the effects of COVID-19 on their community, created a project to classify different types of masks based on their effectiveness.

3. Learning with and about ethical artificial intelligence through youth-made media

Clifford Lee & Elisabeth Soep

This study seeks to understand how young people underrepresented in STEM make meaning of the role of AI in their lives and society and how their relationship to the technology evolves when they create their own AI-based tools and media. This research analyzes the curriculum and pedagogy behind three ethics-centered AI learning activities housed within an after-school multimedia production organization. Critical Computational Expression (CCE) is a conceptual and pedagogical framework that integrates the three distinct traditions of: critical pedagogy, computational thinking, and creative expression (Lee & Soep, 2022). Interactive youth developers are attuned to the aesthetics, design, and creative representations of their products while being conscious of the sociopolitical messages and computational sophistication of their interactive stories (Lee & Soep, 2016).

Our ethnographic study centered participant observation, through audio recordings of moment-to moment interactions in class, end-of-session focus group interviews, and analyses of youth-generated artifacts within the learning environment over the course of two and a half years. Our research team used a grounded theory approach to code, reduce, and analyze the data to generate themes according to our Critical Computational Expression framework. This paper addresses the following research questions:

1. What can we learn about young people's understanding of AI when they produce media with and about it?
2. What are the design features of an ethics-centered pedagogy that promotes STEM engagement via AI?

In the three activities examined in this study, young people: repurposed their phones' text autocomplete features to produce poetry; countered Spotify's system for rating pop songs' danceability by designing an interactive experience of their own; and developed a drawing tool inviting users to scribble over photographs of faces to determine what degree of disguise was required to dodge facial recognition software. In total, sixteen producers, aged fifteen to twenty-four, who are predominantly youth of color and those contending with economic and other barriers to full participation in STEM fields, engaged in this study.

Our findings suggest that students can feel disempowered by their increasingly intelligent technologies. Through ongoing observation and analysis, we see students deepen curiosity about and understanding of AI that allows them to exercise agency and conceptualize creative projects using their new knowledge to manipulate and hack AI-dependent algorithms. Additionally, our results show that participating in ethics-centered learning activities and developing AI-powered tools do not create a permanent evolution of youth's understanding of their agency as it's related to AI in their lives; instead, these modes of involvement offer meaningful glimpses into how the problematic dimensions of AI systems are pervasive, yet not undefeatable in terms of young people's positioning with respect to technology and their role in the culture it produces.

By drawing on digital tools and practices that youth are familiar with as consumers, young people develop sufficient technical know-how, creative engagement, and critical curiosity about the implications of these systems to demystify how everyday tools work, then start envisioning ways to spark new action and conversation. Understanding the mechanisms that shape human interactions with AI to conform with the patterns embedded in its functioning afforded students the opportunity to discover ways to disrupt these systems with creativity, originality, and new ways of thinking.

4. Using embodied interaction and creative making to foster machine learning sensemaking in informal learning contexts

Duri Long & Brian Magerko

Our research explores how embodied interaction and creative making can engage family groups in discussions surrounding machine learning in informal learning contexts like homes and museums. We design activities to support creative, embodied learning experiences and study participants' learning talk and interest development surrounding these activities.

We conceptualize embodied interaction as physical interaction with and/or control of the activity. Creative making refers to the production of personally relevant artifacts, especially those that persist beyond the activity. We hypothesize that the emphasis of these constructs on the self can help learners reconceptualize AI and ML as relevant areas of interest for people "like me" (Papastergiou et al., 2008; Magerko et al., 2016; Guzdial et al., 2013; Buechley et al., 2008). In addition, we hypothesize based on prior work (e.g., Antle et al., 2013; Horn et al., 2009; Sulmont 2019) that embodied interaction can make abstract concepts–like AI–concrete for learners.

We have engaged in design research to develop two activities that support learning about ML. The first, *Creature Features*, engages learners in building a training dataset for a feature-based ML bird classification algorithm using a tangible interface. Learners can explore issues like dataset bias and representation using cards and tokens and can iteratively revise their datasets after viewing the algorithm's results. The second activity, *LuminAI*, engages learners in improvising dance with an AI partner. After dancing with the AI, learners can explore an interactive, 3D visual representation of the way the dancer uses unsupervised ML to group gestures in memory. We recruited 14 family groups (38 participants; 21 age 6-17 and 17 age 18+) to interact with the prototypes in their homes. Family members were given an age-appropriate survey following their interaction. We asked both Likert-scale and free-response questions to assess interest development, content knowledge gain, and whether the activities elicited creative interactions. We also had family members record audio of their interactions with the activities. We coded the transcribed dialogue to identify instances of *learning talk*—i.e., conversation that was relevant to the learning goals of the activity (Roberts & Lyons, 2017). The quantitative results from the survey data supplemented with the qualitative analysis of the audio transcripts provided insight into which exhibits led to learning talk, interest development in AI, content knowledge gain, and creative engagement.

The tangible interface and iterative cycle of testing and revision in *Creature Features* supported in-depth discussion of features and their impact on the algorithm. The activity was most successful with families with kids aged 10+, and more scaffolding may be needed to help learners connect the activity with "real-world" technologies and issues. Although *LuminAI* focused on teaching AI through a creative activity, the ephemeral nature of dance means learners did not generate a lasting artifact. This may have limited the impact of *LuminAI* on interest development. Although learners scored well on the content knowledge questions related to unsupervised ML in *LuminAI*, learners expressed that they were intimidated by the interface. This suggests that interactive visual interfaces–even when building on embodied metaphors in a creative domain–may necessitate additional scaffolding for novice audiences. Our results indicate that tangible interaction can be an effective design feature for promoting sensemaking about ML. Future research is needed to examine whether creative making can be an effective design feature for promoting learning about ML. Our work contributes to understanding how to design casual AI learning experiences for novices that can integrate into everyday life.

5. Youth's sensemaking through failure cases in machine learning powered applications

Luis Morales-Navarro & Yasmin B. Kafai

Youth encounter machine learning (ML) applications every day and while several studies have investigated their understanding of how machine learning works (Druga et al., 2017; Williams et al., 2019) most of it has centered around success, that is when ML applications work as expected. We present results from an exploratory study in which we investigate how youth make sense of ML when encountering failure cases as users and creators of physical computing applications. By investigating how youth make sense of failure cases we aim to analyze youth's conceptual understanding as well as their consideration of the limitations and implications of ML technologies.

Whereas conversations about ML, society and ethics are often disconnected from technical issues (Fiesler, 2020; Petrozzino, 2021), the consequences and implications of ML applications are closely intertwined with functionality failures (Raji et al., 2022). To investigate youth's sensemaking of ML and its implications, that is how they build and revise explanations using both formal and everyday knowledge (Odden & Russ, 2018), we build on previous work on youth's interaction with failure artifacts. Failure artifacts are applications that have deliberate failures, bugs or mistakes and can elicit learners' understanding of how computing applications work (Fields et al., 2021). At the same time, encountering failure when creating projects can support sensemaking as students resolve failure cases, avoid recurring failure, prepare for novel failures, and calibrate their confidence (DeLiema et al., 2022).

We conducted a ML+eTextiles workshop at a science center in the Northeastern United States with 12 (15-16 years old) youths of Color during the Spring and Summer 2022. In the Spring, youths were presented with consumer applications with failure cases and eTextiles ML-powered failure artifacts. Using stickies and big paper methods (Yip et al., 2013, Woodward, 2018), we asked them to brainstorm how these applications worked and if they encountered any failures how they could fix them. Following, during the summer, youths learned to create ML-powered eTextiles and designed their own personally relevant projects. As they worked on their projects we had several sessions during which they reflected on failure cases they encountered. We analyzed workshop artifacts and recordings using iterative thematic analysis (Braun and Clarke, 2012).

Prior to any instruction on ML, half of the youth voiced ideas of how ML applications used data to generate predictions. They also brought up issues of bias and its ethical implications when discussing failure cases in consumer technologies and reflected on their personal experiences using some of these technologies. As they built models for their eTextile projects, they encountered failure cases particularly with regards to diversity of training data and overfitting. These failure cases generated discussions on the importance of testing and iterative design of data sets, considering who and how the projects would be used, and anticipating how the projects would affect people. This poster provides evidence of youth's understanding of ML as users and producers when encountering failure cases. Using failure cases and failure artifacts in instruction and reflection on failure in their own creations may be particularly helpful to foster youth's understanding of how technical failure and social implications and limitations may be intertwined.

6. Talking about fairness in artificial intelligence and machine learning with girls

Jaemarie Solyst & Amy Ogan

Children are the future users and creators of AI. However, girls and particularly girls of color are often excluded in the design of technology while simultaneously being greatly impacted by issues of fairness in AI. Educational opportunities about AI and ethics designed for girls, their interests, and their funds of knowledge, are essential. Through a series of workshops, we aimed to understand those funds of knowledge as well as their sense making, including knowledge gaps around AI and fairness, focusing on the critical age prior to high school.

In our workshops, we based our learning materials on culturally responsive computing (CRC). Positioning learners as technosocial change agents, poised to advocate for justice in technology, CRC leverages: Asset-building by adding onto what learners know, Reflection by prompting learners to critically analyze and decompose existing power structures, and Connectedness by strengthening and taking into account relationships that the learners have within the learning environment and their broader communities (Scott et al., 2015).

We ran a series of six workshops online and in-person with middle school girls (11-14) and an additional in-person workshop with fifth and sixth graders (ages 9-12). Workshop material was based on CRC with a main focus on AI. We introduced the basics (e.g., what is an algorithm, what is AI, and how training data is involved in machine learning). We then instigated discussions around various AI technologies and how they could be fairer, as well as design activities where learners made sense of and thought of their own AI-powered inventions. We conducted thematic analysis on transcripts, chat logs, and artifacts.

Our findings showed that girls' ideas around fairness followed models of equality/inequality and nice/kind vs. rude/mean, i.e., many learners defined fairness as everyone getting the same resources, as well as having kind interactions (e.g., a nice robot), while unfairness was defined as the opposite. Some learners brought up more complex ideas like equity, or technology accommodating user differences. We saw that in older groups (e.g., seventh and eighth graders), learners had existing understandings of bias and could apply it to technology being unfair. Younger girls and those with lower prior knowledge in computing needed more scaffolding to critically discuss and question technology. Middle school learners were able to see unfairness in existing examples of AI (e.g., bias in Google search image results). Lastly, applying fairness to more technical aspects of AI, such as how training data can impact ethical ML, was a more challenging topic that needed more time and explanation for learners who did not have a lot of prior STEM exposure.

This suggests that fairness should be a main focus of AI and ethics, supporting exposure to more complex ideas about fairness (e.g., equality vs. equity) before considering fairness applied to more technical topics, such as training data. It also indicates that this is a critical set of ages at which conceptions of fairness are beginning to emerge and shift; perhaps necessitating different educational interventions, where for younger children, fairness and ethics may be a specific topic. Older children (e.g., 12-14) were more able and eager to discuss power and privilege, but younger children may need considerably more scaffolding for these topics in a curriculum.

7. The impact of a technology-enhanced unit on high school students' understanding of artificial intelligence & machine learning

Cansu Tatar, Shiyan Jiang, Jie Chao, & Carolyn P. Rosé

Despite the substantial interest in K-12 AI curriculum development, there is a lack of intervention-based research, in particular regarding the effects of AI curriculum on K-12 students' understanding of AI and machine learning (Chiu et al., 2021; Estevez et al., 2019). This study explores high school students' understanding of AI & ML before and after a technology-enhanced curriculum intervention. We adopt a situated learning perspective as our theoretical framework to understand students' data modeling experiences and their impact on shaping students' understanding of AI & ML. Modeling has been an effective learning strategy for knowledge construction that describes a process of developing representations of phenomena being experienced in order to engender conceptual change (Jonassen, 2011).

A Journalism teacher participated in our professional development workshop for four weeks and implemented our technology-enhanced AI curriculum in her Journalism classroom for three weeks. This class included twenty-eight students: three 10th graders, nine 11th graders, and sixteen 12th graders. Students used StoryQ to build machine learning models with text data. Students did not receive any formal training in AI before this curriculum intervention. Before and after the curriculum intervention, students completed a knowledge assessment. This assessment was designed by following the scenario-based representation model (Sun et al., 2003) and validated by machine learning experts and teachers. Students' responses were analyzed by following open-coding strategies (Strauss & Corbin, 1994), focusing on their understanding of AI & ML and reasoning about everyday AI technology.

Our analyses revealed that before the curriculum intervention, students mostly viewed AI as robots that help people perform certain tasks. This could be due to the media portrayal of AI as robots, which is one of the most common themes in movies and popular culture. After the curriculum intervention, students defined AI as a technology that mimics human intelligence. We also asked students to share their understanding of ML. In the pre-assessment, most students indicated that they were not familiar with the term. Their responses included random guesses like learning through machines. After the intervention, their conceptions shifted from random guesses to more detailed explanations including feature selection and recognizing the importance of training data for model development. Additionally, we found that students mostly viewed Siri as a pre-programmed technology before curriculum implementation. In the post-assessment, most students used AI concepts to explain the working mechanism of Siri. During the curriculum intervention, students experienced feature selection when building ML models. This hands-on experience in building ML models might help them reason about how virtual assistants (e.g., Siri or Alexa) work. This study demonstrated that a technology-enhanced AI curriculum offering opportunities for building ML models helped high school students gain a more in-depth understanding of AI & ML and its applications. A fertile area for future studies is exploring patterns of model development in different kinds of ML modeling tasks and investigating how to best support students' diverse ways of building models.

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The Future of Maker Education

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Abstract: The influence and reach of maker education continues to grow, bringing new possibilities for hands-on, student-centered, design-oriented, and/or transformational learning to more people in more spaces. Maker education has also more recently attended to issues of justice, equity, and culture. What does the future of maker education hold? What materials and practices will these spaces offer next? What support do teachers need to enact pedagogically sound and culturally relevant learning? How will developing technologies respond to teachers' and learners' needs for accessibility and sustainability? How will maker-based learning be documented and assessed? To answer these and other questions, we propose convening a panel on the Future of Maker Education to both solicit panelists' ideas on the future of maker education and foster audience discussion around these issues.

Symposium overview

Despite being inspired by several other previous educational ideas and reforms, Maker education as a mainstream movement gained prominence only about ten years ago. However, this rapid rise and expansion into schools has raised crucial questions around its educative purposes (making towards what ends?), cultural processes (the 'how' and 'for whom' of making), and conditions that support expansive making (the design and practice of maker education, and educator learning) (Vossoughi et al., 2016; Barajas-López & Bang, 2018). These questions will continue to drive research on making and learning, and their answers are transforming our understanding of both making, learning, and the relationship between the two. How might educational making transform schooling, and how might research on educational making transform the learning sciences? We propose this panel to convene researchers and thinkers towards answering these questions for future of maker education.

We anticipate that the next decade of work on maker education will pursue multiple paths to disrupt the dominance of traditional STEM schooling goals, outcomes, and identities in order to better serve more learners. One such approach is the study and inclusion of cultural making practices that "powerfully engage youth with the political, human, and social challenges of subverting and transforming one's reality through powerful tools and representations" (Blikstein, 2020, p. 125). In particular, recognition of arts practices as assets that young people bring to learning can offer one way to turn to desire-based scholarship and pedagogy and create equitable education systems. Other researchers advocate for pedagogical designs and practices that nurture justice-oriented forms of worldmaking with students, educators, and communities (Simpson, 2009) and highlight the relationships between making and forms of political education that intentionally weave together critical social analysis, the imagination of possible futures, and the creation of lived-in elsewheres in the here-and-now (Vossoughi, 2014). Yet another approach focuses on recasting the relationships among materials and people to increase inclusion and equity in historically inequitable domains (e.g., Keune et al., 2019). For example, materialized action proposes a new way of integrating (rather than excluding) worldly concreteness into the mathematics classroom, promising a new kind of relatability that may shift participation structures.

In this session, we will discuss how these and other approaches will shape both the research and practice of maker education going forward. We have invited researchers whose work has been foundational in the field to share their thoughts on the future of maker education. We organize the symposium in *four sections*:

1. The chair introduces the topic and gives each presenter 5 minutes to share their thoughts (30 min)

2. Panelists will respond to each others' presentations and to questions from the chair (20 min), including:
   a. How do you see maker education efforts addressing the criticisms of cultural-insensitivity, hegemony, or exclusivity?
   b. From both an environmental and curriculum standpoint, how do you anticipate maker education rising to meet the challenges of sustainability?
   c. As currently new maker technologies become more accessible and novel constructive possibilities arise, which tools or practices most excite you for their potential?
3. Our discussant synthesizes and reflects on the shared ideas (10 min)
4. We will close with a Q&A session for the audience and panelists (15 min).

Innovative features

ISLS introduced for the first time the possibility of "innovative" symposia formats. We intend to take advantage of this possibility by generating more in depth materials that could be accessed before and after the event. Our symposium will have two innovative, "long tail," hybrid features:

(1) Video interviews between the symposium authors: If the proposal is accepted, from March to May we will organize about 6 "interview sessions" in which the authors will interview each other via Zoom for about 10 minutes. Authors will have a chance to articulate their critique and their imagination of possible futures for maker education with more time and in collaboration with a colleague.

(2) Testimonies of teachers and students on their experiences and ideas for maker education: Respecting research ethics and parental consent, we will select participants in each of our research sites and projects, and ask teachers and students volunteers to record about 10 short video/audio testimonies on meaningful, problematic, or promising practices within their classrooms or communities.

All the videos will be posted on the symposium webpage and on YouTube. Around April 2023, we will ask the ISLS organizing committee to include the link to our website in their regular conference communication, so that attendees can watch them before the conference, comment, and ask questions. These will help inform the final presentations and discussion at the conference. After the symposium, ISLS members would continue to have access to the pre-conference materials and the actual video of the symposium.

The following six briefs summarize the participating panelists' work and potential contributions toward the discussion on the future of maker education.

Arts practices as assets as the future of maker education

Erica Halverson

The rise of the STEM movement has provided a fruitful context to re-insert the arts into conversations about what counts as education through the introduction of STEAM, especially if we aim for a "mutually instrumental" relationship between the arts and STEM (Mejias et al., 2021). When we focus on the pedagogical advantages of arts practices, the STEAM framework rejects the concept of "artsy" or "mathsy" people and instead, "places them in a context that is purpose driven, offering an opportunity for creative and flexible thinking that maps onto their key outcomes" (Bevan et al., 2019). Maker education has the potential to build some of the mutuality with the arts that STEAM aims for. However, maker educators face the same challenges that STEAM proponents do – the urge to instrumentalize making in service of accountability measures, such as science content recall or workforce development, without attention to the epistemic practices that STEM and the arts share.

A clear solution is to embrace the asset-based approach of culturally sustaining pedagogies into STEM/Maker education (Ryoo & Calabrese Barton, 2018). *Cultural making* is an approach to asset-based pedagogy that aims for a balance between respecting the local culture and context and the introduction of new elements that teachers or designers bring to the learning setting. Cultural making focuses on, "powerfully engaging youth with the political, human, and social challenges of subverting and transforming one's reality through powerful tools and representations" (Blikstein, 2020, p. 125). Cultural making is visible in art-science projects like the Embodied Physics Learning Lab where choreography is a mechanism to both understand and represent the principles of physics through the medium of modern dance (Solomon et al., 2022). Similarly, the fiber arts can be used to teach math and computing through working with your hands to construct representations of mathematical concepts while valuing the cultural contributions of traditionally feminine art forms (Peppler et al., 2020).

In our work. we use Critical Qualitative Inquiry (CQI) as a methodological approach that seeks to both challenge dominant research approaches, to interrupt discriminatory practices, and to work towards social justice aims (Paris & Winn, 2014; Tunstall et al., 2022). Specifically, we are inspired by Critical Indigenous Research Methodology (CIRM), as scholars who are engaged in CIRM call out the "damage-centered research" that dominates the education space and shift to "desire-based scholarship" in order to avoid pathologizing young people (Tuck, 2009 as cited in Brayboy et al., 2012).

We draw our predictions for the future of maker education from two large studies we recently conducted – one that focused on a maker-mentorship program with rural teens (Nixon, Halverson & Stoiber, 2021) and a second exploring arts practices in community youth arts organizations in historically marginalized communities (Halverson, Martin, et al., forthcoming). In both studies, we gathered longitudinal, qualitative data collaboratively with participants and allowed their interests and expertise to shape the conversations we had and the artifacts they generated. Three key themes are prevalent across these two studies:

1. The arts are not in service of STEM. Leveraging youth assets results in a reframing of what is valuable knowledge and expertise in makerspaces.
2. Drawing on youth's assets highlights how cultural and technical knowing are mutually valuable.
3. Arts-practices-as-assets is broad ranging and includes longstanding, multigenerational practices and rapidly changing youth culture. Valuing this range and living in its complexities is crucial.

The next generation of maker education aims to disrupt the dominance of traditional STEM schooling goals, outcomes, and identities. Cultural making – specifically the use of arts practices as assets that young people bring to learning – can offer us a way to turn to desire-based scholarship and pedagogy and to create equitable systems on our own terms.

The future of making as a return to our roots

Kylie Peppler, Nickolina Yankova, Anna Keune, & Sophia Bender

With close links to mathematics and computing (e.g., Essinger, 2004; Taimina, 2009), historical fiber crafts present an opportune context for maker-centered constructionist learning experiences, focused on challenging domain ideas, such as unitizing within proportional reasoning. Proportional reasoning (PR), or the multiplicative part-to-whole relationship of rational quantities (de la Torre et al., 2013), has persistently challenged learners (Lobato & Thanheiser, 2002). We focus on micro-developmental learning processes within fiber crafts to examine hands-on and transformational learning for youth as they engage in personally meaningful design (Peppler, Keune & Thompson, 2020). We advance the notion of materialized action, the natural inquiry process that results through emergent patterns between learners and the materialized traces of their actions.

We ground our work in constructionism (Harel & Papert, 1991), where learning occurs best when learners design shareable physical (or digital) "objects to think with" that are at once material objects and internalized mental structures. We further draw on relational materialist views (e.g., Hultman & Lenz-Taguchi, 2010) that challenge hierarchies between people and materials, calling for lowering and even flattening such hierarchies.

Situated in an out-of-school workshop developed by crafting professionals and mathematics educators, this study takes a qualitative approach that combines design and intervention. We co-designed workshop activities to support engagement with PR through three fiber crafting traditions (i.e., knitting, crochet, and pleating). Using artifact analysis (Thompson, 2020) and modal analysis (Abrahamson, 2009), we focus on three youth as case studies to capture, analyze, and theorize how the coming-together of materials prompts hands-on and transformational learning. We first engaged with all three crafts to make sample projects toward proof-of-concept. We then drew on video data from the craft workshop and over 200 photographs of learner projects to understand how fiber crafting traditions cultivated mathematical understanding of PR.

We theorize three nested layers of units within fiber crafting. In contrast to preformed units as the basis for ratios and PR, fiber crafts afford tinkerability with units and personalization of produced artifacts. Through choice of materials and individual level of tension, the crafter forms an initial *stitch unit*. Multiplying stitch units produces *pattern units*, larger building blocks, which are reproduced to form the even larger *project units*. Unitizing within fiber crafts reflects materialized actions at play, which we observed in youths' crafting practices. Youth formed relationships with the domain concepts of unitizing and PR through iterative engagement with the materials as they crafted in preferred ways.

Studying relationships among materials and people within maker education can shift not only theoretical understanding of learning in context but can also impact educational practice toward more inclusive and equitable approaches within domains that are still marked by inequitable participation (e.g., Keune & Peppler, 2019). Materialized action proposes a new way of learning about units and PR as well as how to integrate (rather than exclude) worldly concreteness into mathematical practice, promising a new kind of relatability that may shift participation structures in maker settings. We predict that the future of maker education will continue and expand on these practices within and beyond mathematics, opening new possibilities for theory and practice by reconceptualizing traditional dynamics between Maker and material.

The relational, embodied and pedagogical futures of making as transformative educational practice

Shirin Vossoughi

The rise of making has raised important questions around educative purposes (*making towards what ends?*), cultural processes (*the 'how' and 'for whom' of making*), and the conditions that support expansive making (*the design and practice of maker education and educator learning*) (Vossoughi et al., 2016; Barajas-López & Bang, 2018). I will share what my colleagues and I have learned about the relational, embodied, and pedagogical conditions that support making as transformative educational practice, the relationships between *making* and *worldmaking*, and some of the edges of thought that can support the future of making design and research.

I draw on critical (Freire, 1972), socio-cultural (Nasir, et. al., 2021; Vygotsky 1978) and embodied (Goodwin, 2013) theories to elucidate the pedagogical forms, axiological principles (Bang, et. al., 2016), and intentional practices of embodied relationality (Vossoughi et al., 2020) that we have found to be generative within making settings, particularly those nourishing the educational dignity and dreaming of minoritized children and youth (Espinoza, et. al., 2020). I also consider how the empirical study of making settings has contributed to our understandings of human learning and educational justice, and their emergence within moment-to-moment interaction.

Critical, ethnographic, participatory and interactional methodologies (Bang & Vossoughi, 2016; Erickson, 2012; McDermott & Raley, 2011; Paris & Winn, 2013) guide our efforts to carefully attune to the pedagogies and shifts in thinking, making and relationships with learning that emerged within two settings: the Tinkering Afterschool Program (Bay Area) and the STEAM summer experience (Chicago/Evanston). Our inquiries address the specific pedagogical forms that support expansive making and relationality, the relationships between making and opportunities for young people to engage in critical social analysis and dreaming, and the conditions that support robust educator learning.

Data sources include extensive co-authored field notes of teaching and learning interactions in both settings over the span of 3-4 years each; audio-video recordings of making interactions as well as in-depth circle-time dialogues with children and youth; interviews with students, caregivers and educators; images of artifacts in process; audio recordings of routine educator debriefs; and audio recordings of partnership meetings and co-design sessions.

Major themes that have emerged from our long-term research in these settings include:

1. The need to move beyond the binary of adult vs. child-centered education and to consider intergenerational learning, joint-activity and pedagogical artistry as key modes of justice-oriented education (Vossoughi et al., 2021);
2. The significance of moment-to-moment embodied interaction to the experience of educational dignity and expansive relationality (Vossoughi et al., 2020); and
3. The relationships between making and forms of political education that intentionally weave together critical social analysis, the imagination of possible futures and the creation of lived-in elsewheres in the here-and-now (Vossoughi, 2014; 2021).

Brief examples of each will be shared to elucidate these themes.

Looking to the next 10 years of maker education, I consider the conceptions of pedagogical design and practice that are necessary for learning environments organized around making to nurture justice-oriented forms of worldmaking with students, educators and communities (Espinoza, 2009; Kelley, 2003; Simpson, 2009).

A celebration of locally-defined making conceptualizations, technologies, and practices

Marcelo Worsley

For the past ten years, many discussions about making have been dominated by a core set of digital fabrication technologies (e.g., laser cutters, 3-D printers) and a related agenda around advancing STEM education (Blikstein, 2013; Martin, 2015; Vossoughi, Hooper, and Escudé, 2016). Not surprisingly, some of the making opportunities that emerged over the past decade have been among STEM organizations eager to recast their work as new and exciting. At the same time, the field has also seen innovative organizations move outside of the normative frames and technologies of making and embraced local community values (Bodon, Kumar, and Worsley, 2022, Lee and Worsley, 2019; Shaw, Fields, and Kafai, 2019; Worsley and Bar-El, 2020). The next ten years should see more diversified forms of making and a related set of new making technologies.

This work builds on prior work around identity development (Nasir, 2002) and interest-based learning environments (Ito, 2013). Youth identity development interacts with learning and goals in ways that may show up particularly well in making experiences where youth are provided opportunities to bring their identities and interests into the learning space. Moreover, aspects of this work reflect ideas about intentionally centering minoritized identities and interests within the context of making.

Ethnography (Atkinson and Hammersely, 1998) is the primary methodology used to ground this research. The author worked as a researcher, educator, and teacher educator throughout the past 6 years in a variety of in-school and out-of-school making experiences. In aggregate, the author interacted with and observed work with more than twenty making-related organizations. Observations, student work, and field notes from interactions with students and teachers are the primary basis for this presentation.

I identify four trends that I believe will shape the next ten years of maker education. First, teachers and students have gravitated towards making activities that bridge making and student interests related to sports (Worsley, 2022), music (Bar-El and Worsley, 2019; Horn et al., 2022), fashion (Shaw et al., 2019) and games (Kafai & Burke, 2015; Maloney et. al., 2010). In many cases, participants tap into a different set of making tools (Das et al., 2020) or find novel ways to use existing technologies (Bar-El et. al., 2018). Hence, in addition to intersecting making with new disciplines, making will likely see the introduction of new (and old) tools. Second, organizations are developing bridges between making and non-western cultural practices. This observation has particularly been made in organizations in Thailand and Hawaii where students connect a commitment to protect the environment with the practices of making. Third, organizations that work with youth with disabilities are defining making in ways that resonate with their community. This involves re-evaluating the tools that are used in making and questioning normative definitions of concepts like creativity (Worsley and Bar-El, 2020). Fourth, making is becoming embedded into day-to-day learning experiences. As more pre-service teachers engage with making as part of their training, we can anticipate that they will more easily adopt making as part of their practice.

The next ten years will hopefully see making shift and adapt to a broader set of disciplines, concepts, cultures, and communities. In so doing, more of the work currently taking place along the fringes of the community might become more central.

The future of making: A robust focus on maker educator preparation

Lee Martin & Ciara Thomas Murphy

The past ten years have dramatically expanded our understanding of maker education, its potential benefits for learning and identity development, and the ways in which learning environments can be made more equitable for all learners, especially those, like women and people of color, often excluded and marginalized in such spaces. While more research is needed on all these fronts, we already know a tremendous amount about how to create good quality, equitable maker learning environments, and we have several stellar examples of such learning environments documented in the literature.

We believe the next decade of maker education research should robustly study how people learn to become maker educators. Educational reforms too often doom themselves through inattention to teachers and how they learn (Tyack & Cuban, 1995). We must build from the small but significant body of work on maker educator preparation (e.g., Harlow et al., 2018) to develop models and practices that elucidate how people prepare to work as maker educators in ways that support richly meaningful, equity-oriented making.

We discuss insights from our studies of maker educators to outline two possible areas for inquiry. We draw from studies of teacher noticing (e.g., Jacobs et al., 2010) to consider how educators can begin to see students, materials, and learning environments in new ways. We also draw upon the idea of parallel process (Sarnat, 2019) to examine how educators relate their own experiences as makers to their role as facilitators.

Data for this presentation include interviews and written reflections. We conducted interviews with two groups of maker educators: one group reflecting on their efforts to facilitate remote making during COVID (Martin & Thomas Murphy, 2022) and another group learning about and reflecting on making and tinkering by engaging with such activities themselves (Thomas Murphy & Martin, 2022). We also draw on written reflections from undergraduates learning to work as mentors in maker education settings. We engage in thematic analysis of the whole body of interview and written reflection data (Braun & Clarke, 2006).

We identify two interrelated themes that we believe offer a fruitful addition to a research agenda on the future of maker education. First, educators' own experiences with making and tinkering provide important opportunities for them to learn to notice pedagogically relevant and meaningful features of making activities (Mason, 2002). For example, educators learn to see sticking points and avenues for resolution in a new light through their own making. Second, educators must work to transcend their own experiences as makers to see their students' experiences wholly and distinctly (hooks, 1994). Here, we see connections to play (creating non-judgmental space for personal expression) and relationship building (developing empathy and seeing others more fully). Moving beyond one's own experience is a critical move for equity-oriented pedagogies as educators work to recognize and highlight students' assets.

A focus on educator preparation will allow the field to translate findings from the past decade into better maker education experiences for young people in the next decade. This presentation contributes to an agenda for that work.

The future of making: Resolving maker education's category error

Paulo Blikstein, Yipu Zheng, Leah Rosembaum, & Richard Davis

Though certainly not unique to this field, we propose that maker education has reached a crossroads where the multiplicity of meanings ascribed to its name, and the multiple competing historical trajectories that explain its origin, have begun to distract research and development efforts. We suggest reconsidering a taxonomy of making, crafting, and fabrication practices to more clearly delineate the modes of activity, spheres of operation, and possibilities for creativity and learning.

Taking a historical view, and analyzing the literature and non-academic documents, we investigate the history of maker education and its predecessors, to examine some critiques currently leveled against maker education. Before Make Magazine and Maker Faire imparted the Make brand on fabrication activities within educational spaces, kids were doing creative, technology-enabled projects well-aligned with constructionist principles under names like "crafts," "robotics," "tinkering," "engineering," or "digital fabrication" (e.g., Eisenberg (2002); Jeanne Bamberger's (2014) "Laboratory for Making Things" from the 1980s). Research and development on such practices worked to serve diverse and nondominant learners (Milner, 2009; Sipitakiat, 2005).

With the increasing prominence of the MAKE organization in the educational mainstream came MAKE's (now infamous) claim of ubiquity: "every kid is a maker" and, consequently, almost everything is "making." This popularization invited criticism. Buechley (2013) specifically addressed the lack of diversity and representation within MAKE Magazine's publications. Entrepreneurship was part of it, as well as a discourse of national competitiveness, pointed out by Vossoughi et. al (2016). Both researchers emphasized that communities had been "making things" for centuries, and that the "Make" brand was misappropriating the term and recasting it as something invented in Silicon Valley. Many of those critiques were directed at the branded version of the movement; but many of the previous, non-mainstream versions of "making" were doing very different types of work (e.g., Milner, 2009). That nuance was lost in translation, and the critique was generalized, glossing over the very significant differences between mainstream Making and other experiences. "Maker education" needs urgent semantic attention.

We need a new taxonomy of making practices, from industrial production to artisan-scale, that captures its multitude of goals: expression, competition, ritual, learning, subsistence. An adult crafting practical items for their home or community carries vastly different implications for equity, empowerment, and learning than do kids tinkering with robotics or an Indigenous artisan creating a ceremonial item. Referring to all these practices as "making" blurs their distinctions and dulls the generalizability of research claims about them. It also invites critiques that focus on the semantics of the term instead of looking at the empowering and agentic possibilities for learners.

In the last ten years, it has become somewhat passe to extoll the virtues of maker education–and in many cases, for good reason. But project-based, student-centered learning remains leagues better than what traditional classrooms offer. Today we have not one, but many version of "maker education," from the corporate, cookbook-style, and Silicon-Valley-themed workshops, to rich and complex community driven, emancipatory educational projects. In this presentation, we will bring a rich historical and conceptual documentation on the history and theories behind maker education, towards creating a conceptual taxonomy of making practices and pedagogies that can help clarify the research claims and focus of each of its versions, so that their future educational possibilities - and problems - might be better understood.

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Coding as Another Language: An International Comparative Study of Learning Computer Science and Computational Thinking in Kindergarten

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Abstract: This symposium brings together researchers and practitioners from four regions in three countries who localized, adapted, implemented, and evaluated a 24-lesson kindergarten curriculum called Coding as Another Language (CAL). CAL uses ScratchJr and unplugged activities, to promote computer science learning and computational thinking development. Given the growing need for evidence-based curricula that allow the integration of computer science and computational thinking into early childhood, this symposium brings together educational researchers and practitioners who worked with CAL in kindergarten classrooms to share their experiences. This symposium presents comparative experiences, across languages and continents, which involved adaptation of curricular materials and assessment instruments, language localization, training research partners, conducting professional development for teachers, mixed-methods data collection with children and teachers, and analysis of results. Lessons learned about working in cross-cultural settings, integrating computer science in the early childhood classroom, and different conceptions of literacy, across different countries will be shared.

Description

This symposium brings together researchers and practitioners in four locations: two regions of the United States (one on the East Coast and one on the West Coast), Argentina, and Israel. The researchers and practitioners worked to localize, adapt, implement, and evaluate a 24-lesson kindergarten curriculum called Coding as Another Language (CAL). CAL uses the ScratchJr free programming language, along with unplugged activities, to promote the learning of computer science and the development of computational thinking.

The pedagogical foundation of CAL involves the understanding of coding as a literacy, that is, putting powerful ideas of computer science in conversation with those taught in language arts. Since kindergarten is a schooling period in which children are starting to be exposed to symbolic systems of representation, CAL introduces the teaching of an artificial language (i.e., programming blocks of ScratchJr) at the same time as instruction about the children's natural languages (in this case, English, Spanish and Hebrew).

The Coding as Another Language (CAL) approach (Bers, 2019, Bers et al., 2022) views the learning of computer science as a new literacy for the 21st century that supports young learners in developing new ways of thinking and expressing themselves. The CAL approach is not about teaching children how to code so they become software developers. It is about children developing character strengths, problem-solving strategies, and collaborative attitudes, along with technical skills and computational thinking (CT), to become future global citizens who can think and act in new ways. Based on this pedagogical approach, the DevTech team, directed by Marina Bers, has developed the K-2 CAL curriculum units using the free ScratchJr introductory programming language.

CAL was designed using principles of three theoretical frameworks: Curriculum Research Framework (CRF), which proposes different phases of work in the creation of research-based curriculum (Clements, 2007); Constructionism, which presents a computationally-rich project-based methodology based on identifying powerful ideas from a learning domain (Papert, 1980); and Positive Technological Development, which intentionally integrates socio-emotional and ethical dimensions into curricular experiences (Bers et al., 2012). The CAL curriculum introduces powerful ideas from computer science, in conversation with literacy, in playful, structured, and developmentally appropriate ways. The curriculum consists of 24 lessons, designed for a total of 18 hours. Through unplugged games, storytelling, movement, singing, and coding, students learn computer science and develop problem solving and computational thinking in the context of creating their own projects using the ScratchJr coding app. In addition, to strengthen the literacy connection, students explore two books, a non-fiction book exploring a historical figure in STEM and a fiction book with a narrative story and a social-emotional component, to write creative, fun programs on ScratchJr. In the kindergarten curriculum, the two books are *A Computer Called Katherine* and *Knuffle Bunny*, which are both available in Spanish as *Una computadora llamada Katherine* and *El conejito knuffle*. Alternative books were selected for the Hebrew curriculum, as is described in Paper 3.

CAL has been used over the last few years by thousands of children and hundreds of teachers all over the world and has been translated and localized from English into Spanish and Hebrew. Given the growing need for evidence-based curricula that allow the integration of computer science and computational thinking into early childhood, this symposium brings together educational researchers and practitioners from three different countries who worked with CAL in kindergarten classrooms to share their experiences.

This symposium presents comparative experiences, across languages and continents, which involved adaptation of curricular materials and assessment instruments, language localization, training research partners, conducting professional development for teachers, mixed-methods data collection with children and teachers, and analysis of results. Lessons learned about working in cross-cultural settings, integrating computer science in the early childhood classroom, and different conceptions of literacy, across different countries will be shared.

Each of the papers in the symposium addresses four interrelated issues:

1. Researcher-practitioner collaboration to implement CAL and study the impacts of CAL in kindergarten programs.
2. Localization of CAL to achieve feasibility of implementation and evaluation.
3. Learning outcomes in terms of coding, CT, and literacy for students participating in CAL.
4. Teachers' experiences regarding the construct of "coding as a literacy."

As new curricula and experiences are developed, implemented, and evaluated, it is important to understand the factors that make this feasible, sustainable, and scalable internationally. Furthermore, while coding is a universal language, when integrated into classrooms across the world that have different educational practices regarding the teaching of alphabetical and computational literacy, lessons can be learned about culturally responsive instruction.

This symposium will help move the field forward by contributing to the emerging understanding of how to integrate coding and CT in diverse early childhood settings and exploring implications for both research and practice across the world.

The papers in this symposium address each of these issues by presenting the experiences in four different locations: 1) On the East Coast of the United States in a large urban district in Massachusetts and several districts in Rhode Island; 2) On the West Coast of the United States in a large district in California; 3) In Argentina in two large districts in Mendoza and Corrientes; and 4) In Israel in a small school in Haifa.

Symposium structure

The session chair will introduce the symposium theme and goals, as well as the CAL curriculum and ScratchJr programming language and the methodological approach used in the comparative study (15 minutes). Then, four papers, each describing one of the studies: US, East Coast, US: West Coast, Argentina and Israel will be presented in the order listed in the proposal (10 minutes each). After this, the chair will comment on general trends and discuss converging themes and implications (10 minutes). The session will conclude with a moderated discussion between the presenters, coordinated by the chair) and open Q&A with the audience, focusing on implications for research and practice (10 minutes).

Methodology

All papers presented in this symposium involved the following components:

- Conducting professional development(PD) about the ScratchJr coding app, and the CAL curriculum and pedagogy.
- Providing ongoing support to teachers implementing the CAL in kindergarten classrooms
- Examining impact on teacher's attitudes and knowledge and students' computational thinking and coding skills
- Understanding teacher and student experiences regarding coding and literacy

- Trained research assistants administered student computational thinking (Tech Check) and coding (CSA) assessments over Zoom before and after the CAL curriculum was implemented.
- Teacher surveys, lesson logs, focus groups, and end-of-year interviews were used.

Paper 1: Coding as Another Language on the East Coast of the United States

Parastu Dubash, Zhanxia Yang, Tess Levinson, & Marina Bers

On the East Coast of the United States, we conducted a randomized control trial of the Coding as Another Language (CAL) ScratchJr curriculum in kindergarten, first, and second grade classrooms in two New England states. The curriculum was initially designed for this setting, so it was not adapted to be localized for this implementation. This paper will primarily focus on the kindergarten implementation.

Schools were randomly assigned to either the "treatment" condition or a "control" condition. For the treatment condition, the CAL curriculum was introduced in 18 total kindergarten classrooms from three public school districts in one state (Site 1) and five schools from a large urban public school district in a different state (Site 2). These nine schools were randomly assigned to implement the CAL curriculum. Twenty-seven teachers from these nine "treatment" schools received a 4-hour, virtual professional development. The professional development covered ScratchJr, a block-based programming language that enables young children (ages 5 and up) to create their own interactive stories and games, the CAL pedagogy, the CAL curriculum, and the research study protocol. Participating teachers then taught the CAL curriculum, completed surveys and lesson logs, and participated in focus groups.

Nine additional schools participated as "control" schools in this randomized control trial. In these schools, teachers completed "business as usual," meaning they taught their traditional existing curriculum without including the CAL-ScratchJr curriculum or making modification. Therefore, these teachers did not receive ScratchJr and CAL curriculum training and did not implement the curriculum. In these control schools, 10 Kindergarten classrooms with 166 students participated in the same one-on-one virtual coding games assessments with a trained research assistant where student coding skills and computational thinking (CT) were assessed at two points in time, similar to the times the students in the treatment group were assessed.

Two-hundred forty-seven kindergarten students (158 from Site 1 and 116 from Site 2) were assessed on coding knowledge and computational thinking (CT) using the Coding Stages assessment (CSA) and TechCheck assessment before and after completing the curriculum (Ruiter and Bers, 2021, Relkin et al., 2020). Students who received the CAL curriculum had a mean pre-curriculum coding score of 1.87 (SD= 1.23) and a post-curriculum coding score of 7.75 (SD= 3.23). The intervention group showed significantly higher growth of coding performance ($\beta = 4.14$, Hedge's $g = 0.39$) than the control group, who grew from a mean coding score of 2.31 (SD=1.47) to 3.99 (SD= 2.05).

The intervention group also grew on the assessment of computational thinking, with a pre-curriculum TechCheck score of 7.042 (SD= 2.32) and a post-curriculum TechCheck score of 8.53 (SD= 2.43). However, this increase in students' computational thinking scores across time was not significantly different from the control group, who had a pre-curriculum TechCheck score of 7.11 (SD=2.42) and a post-curriculum TechCheck score of 7.96 (SD= 2.36).

Teachers' self-reported efficacy (confidence that they could teach various aspects of the coding curriculum to their students) from both Site 1 and 2 increased significantly after the PD training ($t(42) = 7.48$, $p < 0.001$), $t(31) = 6.97$, $p < 0.001$). Self-efficacy was reported on Likert scale from 1 to 5 and grew from a mean of 2.8 (SD = 1.14) to 3.98 (SD = 0.73). These results include all K-2 teachers who participated in the PD training, not just kindergarten classroom teachers, as the PD and study included both classroom teachers and enrichment and support teachers who taught the curriculum in multiple grades.

Additionally, qualitative data from these teachers who taught and supported kindergarten classrooms provide opportunities to explore many differences in these samples including collaboration, support, and teacher role. While some teachers are the sole participating teacher at their school, others have participating colleagues to collaborate with. Also at Site 1, designated Tech Leaders at each school provide ongoing support to teachers. In addition, classroom teachers may have flexibility regarding when and how often to implement, while enrichment teachers may have limited scheduled times. These conditions along with teacher reports of support and curricular modifications are examined as well as their impact on outcome measures.

Teachers shared that their students, "asked to do it [the CAL curriculum and ScratchJr] every day. If we couldn't do it, they were disappointed." One teacher mentioned, "watching the kids get up to help other kids naturally and organically without being told someone needs help… that's a highlight when you see kids taking over the responsibility in the room themselves."

Yet another teacher emphasized, "Post-Covid, it was just what we needed. It was interaction, it was dynamic, give and take." She also added, "And I had five students where English was not their second language, and loved watching how they all did with this."

In terms of integrating the CAL curriculum into their existing curriculum, one teacher mentioned, "We were learning about different ecosystems... and they [ScratchJr app] happen to have the jungle and the ocean, and so kids were able to explore with those backgrounds and add the animals that belong there."

When asked if they would recommend the CAL curriculum to other teachers, one teacher said, "I've recommended it a million times. We are actually going to be training all of the K-2 teachers in our district; that's going to be my role…They know I've been talking about perseverance, and grit, and applied skills, and those soft skills… cooperative learning, collaboration, and so they know… that this is going to be a really exciting time for them.

Our findings suggest that the CAL curriculum was both a successful program for improving coding knowledge on the East Coast of the United States and was enjoyable to classroom and support teachers. This second feature is promising for future use of the program, as an enjoyable program is more likely to be implemented in the future and remain part of the school's program. As mentioned above, the curriculum was not adapted to be localized for this implementation. However, that does not mean that the curriculum may not have been adapted for local cultural contexts, as individual teachers may have localized the curriculum to meet the cultural contexts of their classroom. In future research, we will examine individual classroom differences in teachers' experiences and implementation practices of the curriculum, as well as student responses to the curriculum.

Paper 2: Coding as Another Language on the West Coast of the United States

Sharin Jacob & Mark Warschauer,

As evidence-based curricula scale, it is crucial to account for local contexts to co-design instructional materials that are appropriate for diverse and often marginalized communities. This paper investigates teacher implementation of the Coding as Another Language (CAL) curriculum for California's culturally and linguistically diverse learners.

Our study draws from the Jacob & Warschauer (2018) model of computational literacy, grounded in sociocultural theory, including the work of Barton and Hamilton (1998); DiSessa (2000); and Gee (2000). The Jacob & Warschauer (2018) model takes an asset-based approach to understanding how teachers can leverage students' literacy skills to develop their computational thinking skills and vice versa. This paper builds on this work to consider the cultural and linguistic factors contributing to the development of computational literacies for diverse learners. As a result, this new culturally responsive model explores how teachers can mobilize the rich traditions and cultural practices present in marginalized communities.

This Design-based Implementation Research (DBIR) pilot study followed three teachers as they implemented the CAL curriculum in their culturally and linguistically diverse classrooms. The participating district in California has among the highest percentages in the US of Latinx students (93%), low-income learners (89.7%), and students designated as English learners (62.7% in the elementary grades). Therefore, we focused on culturally responsive instructional adaptations and strategies teachers used to develop computational literacies for Latinx and multilingual students.

Data sources included field notes on co-design meetings with teachers who engaged in reflection cycles, in which we collected their feedback and reflections to improve the intervention. The field notes focused on instructional strategies and their relationship to student engagement, coding activities, and language use. Co-design teachers were also formally interviewed at the end of the year to better understand their instructional goals and practices and to collect feedback for improving the curriculum and PD.

Teachers suggested several adaptations to the curriculum that would better meet the needs of their Latinx and multilingual students, including 1) integrating culturally responsive materials, such as storybooks depicting Latinx computer scientists, into the curriculum; 2) providing additional language support; 3) balancing guided instruction with exploration; and 4) increasing multimodal and digital resources. We will use these and other findings to revise the curriculum to meet the needs of the district's diverse learners.

Considering that Latinx and multilingual students have unequal access to technology and CS learning (Irwin, 2021), it behooves researchers to focus more attention on culturally responsive CS interventions that promote equitable participation for these students. Implementing culturally responsive instruction that accommodates local contexts of diverse communities leads to increased teacher uptake of evidence-based curricular interventions such as CAL and better supports both scaling efforts and overall sustainability.

Paper 3: Coding as Another Language in Haifa, Israel

Avia Ben-Ari, Rinat Rosenberg-Kima, & Marina Bers

In this case study, we implemented the CAL-ScratchJr-K curriculum in a Hebrew-speaking kindergarten classroom in Northern Israel. The implementation included a professional development (PD) training for teachers and curricular implementation over the course of seven months. We were interested in teachers' self-efficacy and objective ability to implement coding in their classes while using the CAL-ScratchJr-K curriculum. Furthermore, we were interested in accounting for the adaptations needed to implement the CAL-ScratchJr-K curriculum as a program developed in alignment with American pedagogical standards and culture, which are very different from the ones in Israel.

Kindergartens in Israel are part of the preschool education system as opposed to the American elementary school system. As such, kindergarten programs in Israel differ greatly from their American equivalents in terms of literacy instruction, which officially starts in the first grade. Thus, the children we worked with were not yet exposed to formal reading and writing. Nevertheless, informally, students were immersed in a culture in which the Hebrew language is written from right-to-left, as opposed to left-to-right. The ScratchJr coding language is assembled left-to-right, which might create a mismatch in directionality between coding and natural language in Israeli children. We were interested in whether this would interfere with children's development of coding skills.

The CAL-ScratchJr Kindergarten curriculum was implemented in a Hebrew-speaking kindergarten classroom for a period of seven months. Two teachers and 26 children (14 boys, age mean=6, sd=0.33) participated in this project. All student and teacher-facing materials were translated to Hebrew, and necessary cultural adaptations were implemented. For example, instead of using the book *Hidden Figures*, teachers taught the book of *My First Hero: Marie Currie* to better integrate the coding curriculum with their broader science unit.

Teachers' coding stages assessments (CSA) and their self-efficacy surveys were collected before and after PD completion. Teachers also completed a mid-curriculum survey. Furthermore, teachers reported all adjustments made to the curriculum. Students' pre-CSA (coding) and TechCheck (computational thinking) assessments were collected at the beginning of the curriculum and again at the end. In addition, 26 ScratchJr projects created by each child were scored using the ScratchJr project rubric. Teachers' summative in-depth semi-instructed interviews were also conducted at the end of the curriculum.

Children's average CSA stage was *Pre-Coding* at baseline, with an average TechCheck score of 7.56 (SD=1.7). At post, children's average CSA stage was *Emergent*, with an average TechCheck score of 8.23 (SD=1.86). Both teachers scored higher on their CSA stage following the PD training, moving from the *Emergent* stage to the stages of *Fluency* and *New Knowledge*. Likewise, their self-efficacy to teach basic coding principles improved following PD completion. In terms of cultural adaptations to the curriculum, age-related cognitive abilities and cultural considerations urged the omission of all charts and tables as well as of most nursery songs, and required further scaffolding in literacy activities. Interestingly, teachers reported that the platform's inherent English aspects did not hinder learning.

Results suggest that the CAL-ScratchJr-K curriculum may support teachers' perceived self-efficacy and objective ability to implement coding in their classes, contributing not only to the teaching of coding at early ages but also to the empowerment of early childhood teachers and children *within* the educational system. This conclusion is depicted in the following account, given by the primary teacher who taught ScratchJr in her classroom: "I've always thought that computers were a 'boys' thing' [and] I used to have a serious computer phobia (…), and today I do everything on my own! Suddenly, I've come to realize that I am a programmer, a technician, that I *solve* problems! I really went through an empowering process. I felt valuable. My [coding] knowledge gave me strength." Furthermore, despite pedagogical and linguistic differences, the translation of the curriculum and its cultural adjustments do not seem to require the adaptation of the ScratchJr coding platform itself.

Paper 4: Coding as Another Language in Argentina

Tess Levinson, Pamela Gonzalez, Hernan Gonzalez, Carolina Gimenez, & Marina Bers

According to data provided by the World Bank, the rate of learning poverty, an indicator that combines the concepts of schooling and learning at the end of primary education, based on reading literacy and school enrollment indicators generated in the reporting process of Sustainable Development Goal 4- showed in the 2018 Development Report, that in low and middle-income countries more than half of children cannot read and understand simple text at the age of 10 years (World Bank, 2017). On average, learning poverty in Argentina is 53.9%.

This project was designed to address learning poverty in two provinces in Argentina, Mendoza and Corrientes, by focusing on the development of new literacies (coding and computational thinking) in conversation with traditional alphabetical literacy. Additionally, the pilot project was designed to learn lessons that could later be replicated to other provinces in the country and in Latin America. The CAL-Argentina study in kindergarten reached 39 teachers across the provinces of Corrientes and Mendoza. Assessment and data collection was done both virtually and in-person depending on Wi-Fi-dependency and other resources available at each site. All instruments, training, consents, and study materials were translated and localized into Spanish. Spanish versions of the curriculum books were identified at this time. In the classroom while teaching, teachers made further decisions regarding localization, including adapting songs, games, and lesson activities to fit their classroom and curriculum. These decisions were documented in teachers' lesson logs and further recorded during focus groups and will be analyzed in future papers.

Like in the United States, schools were randomly assigned to a treatment condition (receiving the CAL curriculum) or a control curriculum (with instruction as normal). Seventeen schools, with 62 teachers and 529 students participated in the study, with 284 students receiving the CAL intervention and 245 students in the control condition. Both student and teacher data were collected to parallel data collected in the CAL-ScratchJr studies in the United States. Student data included the Coding Stages Assessment of coding knowledge and the TechCheck assessment of computational thinking collected before and after the curriculum and ScratchJr projects collected at three time points during the curriculum. Teacher data included the CSA and TechCheck assessments before and after training, surveys at four timepoints, and focus groups before, during, and after curricular implementation. 223 kindergarten students participated in the study.

In the kindergarten sample, the mean coding stage for a child at baseline was in the Pre-Coding stage with a CSA score of 3.32 (SD = 2.55). There was a significant interaction effect of condition and timepoint on coding knowledge, $F(1, 435) = 100.25, p < 0.0001$. Students who received the curricula scored higher on the post-curriculum coding stages assessment (M = 9.90, SD = 4.07) than students in the control condition (M = 4.70, SD = 1.97).

Overall, kindergarten children had a mean TechCheck score of 7.37 (SD = 2.14) at baseline, with a mean score of 8.40 (SD = 2.66) for children in the control group and a mean score of 7.79 (SD= 2.47) for children in the treatment group. This difference was statistically significant. Unlike in the United States contexts described above, there was a statistically significant interaction of condition and timepoint on computational thinking, with the treatment group (M = 10.42, SD = 2.23) surpassing the control group (M = 9.56, SD = 1.73) on post-curriculum TechCheck scores, $F(1, 435) = 11.69$, $p < 0.001$.

These results, and the differences between the Argentinian and United States findings, suggest that in adapting an early childhood curriculum across international settings, collaborators should consider that expected developmental trajectory across the school curricula differ across different countries. Curricula and resources for kindergarten programs, both generally and specifically for technology, vary across countries. Additionally, when discussing kindergarten programming, we should consider that language and literacy programs for kindergarten students differ across languages and countries. The available resources may also affect the implementation of the CAL curriculum, as different schools may have different environmental features such as movable tables, flexible seating, or available crafting materials. Further research should examine how these factors play a role in the effectiveness of the CAL program implementation across countries. We should also consider variations in the existing computational thinking and computer science curricula experienced by the children in control conditions in various countries, as what is considered developmentally normative for the control group may in fact be a feature of a country's existing curriculum. Moving forward, this variation in development should be accounted for as we continue to develop coding language and computational literacy curricula and programs for children in early childhood in a variety of national, cultural, and linguistic contexts.

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What Schooling is and What it Could Be: Exploring How We Learn the Discourses and Technologies of Public Education in School-Adjacent Spaces

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Abstract: In the US in recent years, public engagement in public schools has become highly politicized, reflecting the polarized discourses circulating in media and inflamed by national figures. “Official” spaces for public input exist alongside multiple less officially policy-relevant spaces where youth and adults learn and negotiate the function/ing of public education. This symposium examines how diverse school-adjacent spheres of public life function as pedagogical spaces - spaces where the discourses and technologies of schooling are learned through the cognizant and non-cognizant design and organization of discourse and activity. The cases considered span from youth-centered spaces such as the school bus and a middle school debate team to a case examining the intersection of how news and social media is negotiated at a public committee meeting and closing with two contrasting examples of school district-sponsored public forums addressing issues such as overcrowding and budget.

Symposium overview

As persistent issues of inequality in educational spaces rise to the forefront of national conversations in the US, we are reminded that education and schooling is everyone’s business. Even those who are not presently children, parents, teachers, or school administrators have at some point experienced school, learning through experience what school is, shaping ideas about what it should or could be, and licensing public commentary on education from people in all walks of life. Notably, the school building is not the only place where we learn what school is, what it can be, or how to participate in public discourse shaping policy in response to these questions. In this symposium we consider how people learn in and through school-adjacent spaces both what school is or can be and how to participate in public discourse about school.

In the US, public engagement in public schools (schools supported by public funds) has become a highly politicized space, reflecting the polarized and often vitriolic discourses circulating in media and inflamed by national figures. “Official” spaces for public input, such as through the election of public school boards, open school board meetings, and district-sponsored public forums exist alongside multiple less officially policy-relevant spaces where youth and adults learn and negotiate the function/ing of public education, drawing on long histories and reflecting possibilities for our children’s futures.

Public school boards, one type of semi-public forum for shaping public education, is one space where an official governing body has substantial power as it “(a) defines reality, (b) orders behavior, and (sometimes) (c) allocates resources accordingly” (Levinson et al., 2009, p. 770). Public participation and commentary on policy making is one place we can look to to see how the status quo is maintained or challenged. On the one hand, public spaces like school boards can be places of possibility where citizens have the opportunity to affect policy making decisions, as described by Collins (2021): “This opportunity for efficacy [in affecting policy decisions] is particularly available at the local level, where schools boards and city councils govern within reach of the citizenry” (p. 790). However, school board meetings in particular are often an authoritative and ritualistic (e.g., Robert’s rules of order) space where local politics and civic life collide in less-than-transformative ways. Learning to engage with the body politic of school boards, and likewise learning to participate in formal debate, requires learning genres of public comments, of argumentation, rebuttal, and the power of non-authorized policy actors (i.e., students, teachers, community members; Collins, 2021; Jenkins, 2022; Levinson et al., 2009; Tracy & Durfy, 2007).

Other types of spaces organize public engagement with education in different ways, opening alternative affordances for learning and numerous ways that actors can be positioned. For instance, public engagement in participatory grassroots organizing efforts—building on affinity spaces as well as affordances of connected social media spaces—shows potential for citizenship that can organize into powerful vehicles for demanding critical and consequential change (Ito et al., 2015). This does not mean that informal or grassroots organizers are inherently equitable, as social power differentials can lead to the privileging of certain narratives and inequitable results—particularly narratives driven by white supremacy (Ewing, 2018; Joffe-Walt et al., 2020).

Youth participation in public narratives on education abound, but are seldom recognized as legitimate civic participation and may even be positioned as disrespectful or insubordinate (Kelly, 2020). Interactions in places such as social media or after-school clubs and activities provide insight into youth perspectives and the ways they both learn and teach the ways of talking, thinking, and participating in shaping the future of education and school. We are interested in how youth spaces such as the debate team or even school buses may be important political spheres for learning about schooling.

Conceptual framework: School-adjacent spaces as pedagogical

We examine how diverse school-adjacent spheres of public life function as *pedagogical* spaces - spaces where the discourses and technologies of schooling and public participation in public schooling are learned through the cognizant and non-cognizant design and organization of discourse and activity in those spaces. In other words, “space is treated as a product of social practice, not simply a frame for it” (Nespor, 2000, p.25). We bring together diverse cases in order to consider how different spaces beyond the school building may shape how the public learns what public school is or can be. We see this work as extending emerging work in the learning sciences that explores learning as political by examining learning in and as a feature of power in the political spheres of public life (Booker et al, 2014; Esmonde & Booker, 2016; The Politics Writing Collective, 2017). Moreover, we suggest that understanding these spaces as pedagogical may provide critical insight into how our imaginations are shaped regarding what is possible in schools and add to work that “elucidate[s] the way that policy typically serves to reproduce existing structures of domination and inequality” (Levinson et al., 2009, p. 769) as well as looking at ways these policies can be disrupted.

Format

The cases considered span from youth-centered spaces such as the school bus and a middle school debate team to a case examining the intersection of how news and social media is negotiated at a public committee meeting and closing with two contrasting examples of school district-sponsored public forums addressing issues such as overcrowding and budget. The symposium format intentionally brings together diverse cases in order to consider official and unofficial policy-relevant spaces, voices from youth and adults, and examples of both the perpetuation, disruption, and re-storying of existing narratives surrounding purposes and possibilities of public schooling. After each case, virtual and in-person participants will have time to discuss and compare the pedagogies of each case.

The symposium itself will be briefly introduced by the Co-chairs, Karis Jones and Emma Gargroetzi. Each of the five cases will be presented. Following these presentations, Discussant Tanner Vea, with expansive expertise studying power, politics, and learning, particularly in social change efforts and design, will provide commentary on the necessity and potential of understanding school-adjacent spaces as pedagogically consequential for education and public school. A significant portion of the time will be held for discussion and conversation with attendees. We invite participants to consider with us: Where and how does learning across these five cases suggest reproduction or transformation in the face of material and discursive systems that shape schooling? How might unveiling these possibilities and constraints support new forms of learning and engagement with public education?

Significance

In a moment where high-stakes decisions about banning books, silencing history, restricting bathrooms access, and arming teachers with automatic weapons threaten the lives and livelihood of both children and adults in schools, the stakes of the political life of schools continue to grow. Yet, these decisions are largely made outside of schools themselves. This symposium contributes needed attention to the question of where and how people learn what can and should be expected from schools, and what it means to participate in conversations about these very topics. In framing and examining the activity of these school-adjacent spaces as pedagogical, we offer a lens that may be productive for uncovering insights about the design and organization of these spaces as products of social practice (Nespor, 2000). In unveiling the socially produced nature of these spaces, we leave them open for disruption, and can perhaps more freely imagine them being produced anew, with more just and joyful possibilities for the future.

Re-storied journeys: The school bus and the narrative of public education

Antero Garcia

This paper explores the role of the school bus as a form of public discourse about education and the ways youth voices are largely silenced in their daily commutes as passengers to and from sites of formal education. Everyday, millions of students across the US rely on public school buses to get to and from school. These gigantic vehicles-brightly painted, hissing with hydraulic brake systems, and puttering away slightly below the speed limit improbably operate out of the vision of school policy and social discussion. These vehicles impact nearly every school in the US and yet seem to be invisible when it comes to discussions of schooling and structure. The fact that the school bus does not come up as a central policy discussion (except for when a global pandemic causes it to stop operation) is a reminder of how central the school bus is to the day-to-day operation of schooling.

Despite not changing in design for nearly a century, the school bus's function as an intervention on the educational outcomes of students in the US makes it the most substantial form of educational technology in this country (Garcia, in press). As a cognitive technology, the school bus disrupts education in two ways. First, its role in shifting school demographics post Brown v. Education is so profound that the verb "busing" is synonymous with addressing desegregation mandates. Second, as a hulking piece of machinery, the bus is a form of (albeit) archaic technology that acts on the lives of young people every day. Both of these disruptions are so persistent and long lasting that it's arguable that they are even disruptions at this point rather than a part of the status quo.

Spending a year of ethnographic participant-observation (Geertz, 1973) alongside young people on a school bus and engaging in historical research on the development of the school bus and the policies that structure it, this paper explores how public engagement with the school bus reinforces an understanding of the bus as implicit and necessary in the operation of public schooling. Every moment of on-bus bullying, of traffic-control through the use of a blinking set of lights, and of picking up and dropping off of kids at local stops is a reminder that these buses act as a part of the seamless infrastructure of American schooling (Edwards, 2021). Further, as a temporary space that reorients and transforms the behaviors and possibilities of its users, the archaic bus is also a reflection of contemporary representation of the role of platforms on education and policy (e.g. Gillespie, 2010; Srnicek, 2017).

Finally, drawing on the work of Thomas and Stornaiuolo (2016), the narrative of the school bus is not fixed; we can "restory" it. While the narrative of the school bus conveys it as a sometimes uncomfortable but necessary component of how students interact with and participate in schooling in the US However, through shifting the gaze of schooling from a structural analysis of school systems to a humanistic perspective of young people's learning opportunities, this paper argues that school buses might be sites for resistance, imagination, and realigning public discourse.

Reconstructing debate as public pedagogy: Advocating for speculative civic futures

Nicole Mirra

Purpose

This paper illuminates the organization of learning within a middle school debate team that sought to transform the activity of debate from an academic exercise to a critical enactment of public pedagogy aimed at envisioning new possibilities for civic life. Specifically, it examines how youth who identified as recently arrived immigrants remixed a policy debate topic asking them to consider "both sides" of immigration restrictions. By rejecting artificial premises of "pro" and "con" argumentation, sharing personal family histories, and inviting judges, opponents, and community members to consider a borderless civic future, the team fostered a transformative public learning environment encouraging heteroglossic dialogue (Bakhtin, 1981; Vossoughi, 2014) to temporarily create a speculative public sphere (Mirra & Garcia, 2022).

Theoretical framework

The paper draws upon frameworks of cultural historical activity theory (Cole & Engeström, 1993), critical pedagogy (Freire, 1970), and borderlands theory (Anzaldúa, 1987/2012) along with critical race approaches to debate (Reid-Brinkley, 2012) and shares interpretive ethnographic analysis of several key interactions among the debate team participants to reveal how the activity system of the afforded opportunities to re-mediate binaries that often stymie efforts at critical civic dreaming and movement building in hybrid formal/informal learning spaces (Zavala, 2016) – binaries including citizen/immigrant, school/community, and objectivity/bias.

Methodology

The Debate Liberation League (DLL) - the name that the debaters chose for their team - included ten middle school students and three adult mentors. Grounded in social design-based methodology (Gutiérrez & Jurow, 2016), data collected over the course of one school year included field notes from 15 debate practices (2 h each), as well as audio recordings of selected discussions and practice rounds (5 h). Interviews were conducted with the three adult mentors (30-60 min each) and two focus groups were conducted with the students (60 min each). Artifacts included student reflections/notes, debate case materials, poetry, and analytic memos co-written by the students and researcher.

Findings and implications

Student debaters altered the structure and function of traditional policy debate structures in order to claim their right to public space and re-define the terms of persuasion from a policy win to an ontological affirmation of their humanity. They utilized performative literacies to re-envision debate not as a battle for a zero-sum win, but as a way to discursively construct a more equitable civic sphere that valued (immigrant) marginalized voices. This paper focuses on moments of public pedagogy that speak to possibilities of dialogue across difference as well as the ways that the grammar of schooling and normative structures of US civic life continuously interrupt and complicate these moments. For instance, during debate rounds, the DLL made translated copies of all of their personal narratives and calls to advocacy around borderless society so that opposing team members and judges would be able to understand everything students were saying and to encourage them to participate in a border crossing linguistic experience. An adult mentor also provided live translation services when the team began qualifying for national tournaments as both a means of ensuring accessibility for all during a round and of stressing the importance of bilingualism as a method of opening debate to a wider range of expressive possibilities.

“We cannot sacrifice one child for another”: Articulations toward public theories of learning

Jasmine Y. Ma, Christopher Ostrowdun, Lauren Volgelstein, & Ali R. Blake

While a substantial goal of the learning sciences is the construction of theories around learning, alternative theories simultaneously develop in other domains. In this paper, we investigate theories of learning constructed in public spheres of discourse around education. We begin to characterize these *public theories of learning* and offer one way they get shaped, through *articulations* (Hall, 1986), or linkages, of news and social media content that mediate the boundary between activity internal to schooling and public spheres. There are multiple interacting lines of communication between school and the public at play simultaneously (e.g., news, social media, parent councils), and these are not neutral, but subject to interpretation as fragments from across lines are articulated by the public. In other words, instead of concerning ourselves with meanings inherent in these communications, we analyze meanings produced through connections between fragments through public discourse. Interrogating these articulations helps us understand “how ideological elements come, under certain conditions, to cohere together within a discourse” (p. 53). In our case, we explore how they serve to make connections between the contentious space of what happens in schools and public discourses about schooling. These articulation practices are one way that news and social media are organized as pedagogical spaces, shaping the public’s perspectives about what *does* happen in schools and what *could* happen in schools (Hall, 1989).

We explore public discourse around a New York City (NYC) public middle school, M.S. 100, where, in the fall of 2021, students were involved in a series of verbal and physical fights (as were students at several schools at the time; Green, 2021). We focus here on incidents that occurred at M.S. 100 and how they were addressed by the parents of the children involved, school staff, members of the local school board, known as the Community Education Council (CEC), and others in the public sphere without direct involvement in the incidents. Disagreements and physical altercations between students are not uncommon, though detailed knowledge of their occurrence rarely leaves the school’s sphere (e.g., the students involved, parents, school administration), in part to protect the privacy of children. The incidents at M.S. 100, however, circulated beyond the school’s sphere and became highly publicized in mainstream news and social media.

While there is no singular “public,” the term is salient to the CEC, which is charged with solicitation of public input and is required to hold regular meetings open to the public, with time allocated for public speaker sessions, where anyone can sign up to speak on a topic for two minutes. The CEC's use of "public" refers to anyone not a member of the Council itself. Additionally, we recognize that public discourses may address what could be named a "common concern," but in fact are not common at all due to systemic societal inequities (Fraser, 1990). For example, "common concerns" of violence reported at a local middle school: a concern for the safety of a primarily white portion of the student body; a concern for effective use of taxpayer money in public schools; or a concern for healing and restorative justice of a community hit hard by the pandemic lockdown and remote schooling. The public sphere is multiple, with its discourses populated by counterpublics "where members of subordinated social groups invent and circulate counterdiscourses, which in turn permit them to formulate oppositional interpretations of their identities, interests, and needs" (p. 67). Using a critical perspective, we take up the multiplicity of common concerns at a public NYC CEC meeting to better understand how news and social media were articulated to construct public theories of learning.

Methods

Data included a publicly-available recording of one 5.5-hour CEC meeting which occured in February 2022, as well as news and media items featuring M.S. 100 between September 2021 and February 2022. We investigated how news and social media were variously deployed and resisted in the service of public understandings of–and arguments around–fights and subsequent events at M.S. 100, a large racially and economically diverse public middle school. Rather than attempting to identify what "really" happened, our analysis focused on how articulations were constructed and used by various people and groups, depending on their position and priorities. Then, we surfaced public theories of learning embedded within these articulations; we treated arguments about how learning happens and what factors influence it as public theories of learning, looking for arguments that were constructed and deployed regularly (in demonstrably relevant ways) within the meeting we analyzed. We used methods of interaction analysis that privilege the meaning-making of participants (Jordan & Henderson, 1995). We examined turns at talk that showed how people contributed to shaping the lines of communication and articulations of information, and how they were linked to spheres of discourse (Hall, 1986). Articulations are "thus the form of the connection that can make a unity of two different elements, under certain conditions." (Hall, 1986, p. 53). For our analysis, we position the CEC as straddling the spheres of the school and the public, and the CEC meeting as a space where members of the spheres engage in shaping and using lines of communication.

Findings

Below, we summarize two articulations of news stories centering interviews of Isabella, the parent of a student involved in incidents at M.S. 100, and zoom in on how one of them gives shape to a public theory of learning commonly deployed by conservative members of the CEC. In news stories published by conservative US news outlets Fox News and the New York Post, and in a speaking turn at the CEC meeting, Isabella provided descriptions of the "verbal and physical abuse" their son had experienced, arguing that the school's approach of "restorative justice is not working [and] kids need to learn accountability for their behavior." She also publicized two Snapchat groups as evidence of the severity of the incidents called "Yo, we on drugs" and "M.S. 100 Fights" where students shared video clips of the incidents.

One articulation from within the sphere of the school by Naomi, a Parent Teacher Association co-president at M.S. 100, critiqued both the information within and the existence of the line of communication itself. Naomi remarked on "concerns around the misrepresentation, misinformation, and misunderstandings" about what information was conveyed. She also critiqued Isabella's and others' publicizing this information as an "organized campaign of negativity" and a "major distraction" that "has traumatized, demoralized, and…confused the children." In Naomi's articulation, the "negative light" in which Isabella and others who publicized M.S. 100 "reeks of fear and racism." She contrasts this with depicting M.S. 100 as "a school that represented every child" in the district, and that believes "children make mistakes. Children are not disposable." These linkages between fear and racism and the negative misrepresentation and misinformation about M.S. 100 are further held together by the counter-representation of every child being cared for and not disposed of at the school.

In contrast, Councilmember Leung, of the CEC, supported the use of news outlets as a mechanism to make the happenings of schooling public and accountable to public spheres. Leung argued, the Department of Education (DoE) had a history "where incidents happened, [and] it's been covered up," and that the "free press…[has a] responsibility…to report on things." Leung urged "all families to report it to the police and make noise." Leung's articulation of school safety, DoE cover-ups, reporting to free press and police to protect children leveraged Isabella's representations of *some* children at M.S. 100 as violent and disruptive, ratifying her public representation of M.S. 100. Additionally, Leung produced a linkage between the free press and the police holding the DoE accountable against a backdrop of debate over whether school safety is the concern of social workers or the police, as well as discourses of carcerality (Wang, 2018) in schools. We argue that these elements articulated together in this way reproduced, as Naomi argued, a racial ideology (Bonilla-Silva, 2018), the articulation and ideology mutually elaborating one another.

Leung continued, pitting "violent children" against "the 29 other students in that classroom," arguing that "we cannot sacrifice one child for another," that "children will not learn" if there is fear in the classroom, and "they will have social emotional problems on top of that." At the same time he acknowledged "this child…need[s] support, but…we cannot wait, put them back in the classroom." Leung's rationale for police intervention brought into relief a theory of learning that centered the fear, social emotional state, and learning of "the other 29" while denying those for the child he characterized as "violent" and "disruptive" (as opposed to, for example, considering the violent incident as situated and a characteristic of the context rather than an individual). This is an example of a public theory of learning–pitting hypothetical, individual, undesirable children against "our" children who for a variety of reasons, deserve safe, rigorous, or otherwise well-resourced learning environments–that emerged repeatedly in speakers' articulations of news and social media that ferried information from within schools into the public sphere.

Significance

Leung's call to report information to the free press is not what it seems. The news and social media do not simply communicate neutral pieces of information, but instead provide a space for articulated interpretations that uphold particular ideologies. These articulated interpretations are not held together as natural fact but made to cohere (Hall, 1986) by people, and give shape to public theories of learning. Our paper provided an example of how fragments from the same event (Isabella's report to the news and the CEC) were made to cohere in two different articulations, with different ramifications for how the public understood what was happening at M.S. 100. As well, the associated public theories of learning are necessarily situated and sociopolitical. The analysis is important for expanding our understandings of how members of the public sphere make sense of what is happening in schools and participate in collective action.

The production of a crisis at Wilhelm Elementary: Collective construction of a discourse through parents' public comments

Carlos Nicolas Gómez Marchant, Alexandra R. Aguilar, & Emma C. Gargroetzi

We demonstrate our modeling of the "webs of mutually constituting statements that represent and position people and social phenomena in particular ways" (Shah & Leonardo, 2016, p. 51) from a community's two opposing sides on the attendance rezoning of Wilhelm Elementary. Our objective is to demonstrate the collisions and coalescences over time of each side's shared discourses. We see the construction of a collective model through civic and political engagement as a form of learning the racialized discourses of a political space to be more influential in determining district policy and regulations. Castro et al. (2022) emphasizes the need to focus on the racialized discourses existing within the constructed models of rezoning schools within these political spaces.

Theoretical framework

A critical race spatial perspective follows the tenets of critical race theory (see Delgado & Stefencic, 2016; Solórzano & Yosso, 2002) and expands them to incorporate a spatial dimension inspired by Soja's (2010) and Du Bois' (1904/1994; see Morrison et al., 2018; Solórzano & Veléz, 2016). These tenets guided our exploration of whiteness in the political discourse revolving around the two opposing sides in the rezoning of Wilhelm. A critical race spatial perspective provided the tools necessary to follow Leonardo's (2004) call to reveal the discourses of whiteness. In this study, we view the parents' continuous interactions with racialized discourses as learning how to participate in differing political spheres of influence.

Method

Creator ISD is a large independent school system located in central Texas. The district administration organized five opportunities for public comments to be made by community members about changing the attendance zone of Wilhelm Elementary. A total of 81 public comments were given by 45 individuals. The five meetings were recorded by Creator ISD and made publicly available online per the Texas Open Meetings Act. Public comments were transcribed by the research group for analysis. We implemented a grounded theory approach for our discourse analysis of the public comments (Malagon et al., 2009; Solórzano & Yosso, 2002). We began by coding for actors (e.g., students, renters, homeowners) and issues (e.g., overcrowding, infrastructure). Through a process of code comparison within and across code groups and the five school board meetings, analytic memoing, and research team conversation we articulated a theory describing how three layers of discourse collided and coalesced to produce an outcome of school rezoning that re-segregated a district along racial and socioeconomic lines. Specifically, we identified these three layers of discourse as: 1) Production of a crisis; 2) The modeling of the crisis; 3) Leveraging the model for political gain.

Preliminary results

Those advocating for the shift of Wilhelm's attendance zone instigated the production of a crisis. Consequently, the first layer of discourse focused on the production of the overcrowding student crisis that necessitated urgent intervention by the school board. The crisis discourse emphasized costs to children's learning and well-being. This forced those opposed to the changes to Wilhelm's attendance zone to respond to the constructed crisis. The second layer of discourse entailed modeling the crisis as a mathematical model of equality (Tate et al., 1993) that included and excluded certain variables as ir/relevant and in/appropriate. Thereby shifting the framing of the crisis from one of overcrowding to one of student population balance across school sites. The final layer of discourse involved parents leveraging the objective and neutral myth of mathematics to gain political influence. These layers of discourse are evidence of the parents' learning of political engagement within the confines of school boards. These findings help in deconstructing political discourses and emphasize the role mathematics plays in civic engagement.

Schools can't do more with less: Reframing budget narratives in the Jersey City public schools

Karis Jones, Jyl Josephson, & Nooreen Fatima

Context

Often cited as the most diverse city in the U.S., Jersey City is a rapidly gentrifying area with a divide between the city residents and the youth enrolled in the public schools, as the Jersey City Public Schools serve a larger percentage of Black and Brown youth (and a lower percentage of White or Asian youth) compared to the city's overall population. In 2008, New Jersey adopted a new funding formula intended to provide guidelines for how much revenue local districts should contribute as well as the level of state funding required to provide for the educational needs of students in each district.. By 2018, the legislature passed S2, a revision of the School Funding Reform Act of 2008 SFRA, with a seven year time frame to reduce state adjustment aid to districts that, according to the formula, were "overaided"--receiving more in state adjustment aid than the state formula indicated they should receive. This was bad news for Jersey City. The state adjustment was scheduled for a seven year process of defunding, with an increasing percentage taken from Jersey City each year. Given how the formula was written, the actual dollar amount of state aid withdrawn would be determined each budget year, adding more uncertainty to the process. The "local fair share" for Jersey City was hundreds of millions of dollars more than the existing school tax levy. This meant that the school tax would need to be increased significantly and quickly. Without significant annual increases in the local levy, it would be impossible to run the school district. This paper will examine how this issue of school budget was framed and contested in the discourse surrounding a Jersey City school board budget vote in March 2021.

Theoretical framework

With respect to school funding, one current ideological battle in the public square is the conceptualization of school as a commodity vs. a public good. Kumashiro (2020) explains that viewing schooling as a commodity leads to problematic consequences with respect to social-economic status, as poorer communities pay greater percentages of their income while still seeing less per-pupil spending. Kumashiro urges that such issues must be seen through an intersectional lens (Crenshaw, 1991), particularly as histories of racism and classism contributed to the structural inequalities built into property tax systems. Thus, we take up a critical framework on equitable public funding in a way that surfaces the intersectionality between race as well as other identities such as SES, disability, and immigrant status.

Data & methods

The researcher team intentionally brings together various positionalities across the Jersey City educational landscape: Dr. Jyl Josephson, resident since 2004 and parent of a child attending the local schools as well as a leader in the Education Team in the grassroots activist group Jersey City Together; Dr. Karis Jones, resident since 2015 and relative newcomer to the JCT Education Team, and Nooreen Fatima, joining as an analyst with experience in local public organizing contexts. See Table 1 for the breakdown of research questions, data sources, and analysis techniques.

The team collaboratively applied critical discourse analysis tools to critically examine these sources for ideological conflicts around the budget crisis. Following Ewing (2018), we take up tools of muted racism--"when people make statements that are subtly racist not because of what is said, but because of what is not said" (p. 178)--to show how stakeholders are constructed in public discourse in racialized ways. This framework from Davis (2007) includes three tools surfacing racism in discourse even when it is not directly mentioned: deflection, indexicality, and omission. Deflection is the technique of minimizing and dismissing racism as the cause of social problems clearly connected with race. Attending to indexicality allows the researcher to examine how people use coded words to make statements about race without explicitly saying it. Finally, omission is the way that data showing racial disparities is discussed without mentioning racism as the cause. We take up all these tools through an intersectional lens, looking for ways that the intersectionality between SES as well as other identities such as race, disability, and immigrant status were defected, indexed, or omitted.

Table 1
Methods Table

Research Question	Data Sources	Analysis Technique
RQ1: How are the stakeholders and competing narratives around the JCBOE school budget constructed and leveraged in public discourse in intersectional racialized ways?	-Jersey City and Jersey City Public School Demographics -Newspaper articles relating to JCBOE Budget from 2020-2021	Critical discourse analysis using tools of muted racism (Davis, 2007) and intersectionality (Crenshaw, 1991; Kumoshiro, 2020)
RQ2: What are some of the discursive moves used by the public to engage/combat discourses of inequity?	-Transcript of March 2021 Special Budget Hearing -Field Notes of JCT Meetings collected from 2020 - 2021	

Findings & significance

Addressing RQ1, we saw several ways that racism and other intersectional identities were deflected, indexed, or omitted with respect to marginalized youth in the district but explained more thoroughly with respect to adult stakeholders. In local reporting about issues of equity in the district, the marginalized status of youth were indexed through categorizations such as English language learners, students with special needs and students who qualify as free and reduced lunch (often used as a proxy for low socio-economic status). However, in the article no work was done to contextualize for the readers how these categories related to educational barriers, even though each of these categories have complex ties to race (Flores & Rosa, 2015; Abrham et al., 2011). On the other hand, in reporting discussions about the tax base, the concerns of taxpayers were described in detail, with journalists reporting on complex sociopolitical forces at play in the city including rising rent costs due to gentrification--a phenomenon explicitly at the intersection of race and SES. Oddly enough, the equity concerns relating to low-SES city residents who had not even called in to the budget meeting were animated in detail while the forces oppressing the 16,000 students qualifying for free and reduced lunch were left for the readers to parse out for themselves.

To answer RQ2, we saw that to respond to narratives of deflection that elevate low-SES taxpayer struggles above the needs of youth, parents explicitly named the structural inequities experienced by children in the city. Instead of othering certain groups of students by merely indexing marginalized categories, parent activists used collective possessive pronouns (e.g. "our kids," "our schools") to emphasize how the collective student population was being harmed by underfunding. Parents responded to issues of omission by calling in with specific examples of ways that the underfunding led to inequities, describing how they had seen their children's schools struggling with overcrowding, overworked teachers and staff, and lack of resources and support services. Though they point to the experiences of particular marginalized groups ("I have been hearing a lot, lately, some of the woes of the parents with children with special needs and how they have to fight to get the services that their kids deserve"), they also pointed to the collective benefits of these services ("All kids could benefit from [smaller class size, one-to-one support, gyms, occupational therapy]").

To combat tools of omission, we saw parents explicitly naming the connection between deprioritization and students' intersectional identities: "Our schools only have 27% of the property tax pie when the state average is 53%. Why do public officials think our children deserve so much less? Is it because a majority of them are English-language learners, come from under-resourced neighborhoods, are Black, Indigenous, and other people of color, and have special needs?" In this comment, the parent activist explicitly named how intersectional forces of marginalization keep resources away from the youth in Jersey City, in explicit contrast to other wealthier and whiter cities across New Jersey. Through the use of such tools which worked to "unmute" racism hidden or omitted in stories about taxpayers, activist parents worked to shift the narrative, leading to the passing of a fully funded local budget in 2021.

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Designing to Disrupt While Encountering Disruption: Engaging With the Unexpected in Educational Research and Practice

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Abstract: This symposium brings together eleven projects across three continents to examine notions of disruption in educational research. Historically, notions of disruption have pointed to the ways research leverages innovation and transformative practice. However, amid global pandemic and intersecting unrest, the authors in this session recognize the need for deeper conversation across contexts to understand the ways that educational research in the learning sciences can leverage disruption toward transformational learning. To respond to this year's call for building and sustaining knowledge in community, we seek to foster conversation about the ways that designed for and encountered disruptions act as opportunities for critical reflection and new kinds of engagement in educational research. Together, we examine various notions of disruption as they exist in our disparate work. We seek to provoke meaningful conversations about the ways educational research can embody the contemporary realities of learning with and toward disruption.

Overview and significance

Notions of disruption have been used in educational research to recognize innovation, shift oppressive systems, and engage in transformation of business-as-usual across organizations. Historically, educators and scholars seeking to design and study expansive and liberatory learning environments have characterized their work as a disruption of entrenched systems (e.g., Kafai et al., 2014; Ma, 2016; Nasir & Vakil, 2017; Stetsenko, 2017). However, the global turmoil of recent years — the COVID-19 pandemic, as well as the continuing escalations of the climate crises, white supremacy, and authoritarianism — have sparked ongoing conversations positioning disruptions as forces external to educational settings that must be overcome lest they lead to "learning loss" (e.g., UNICEF, 2021). Recognizing the dichotomy between what we conceptualize as *designed for* and *encountered disruptions*, the scholars in this symposium consider how we might foster dialogue across projects to see both forms of disruption as opportunities for critical reflection and engagement in educational research. Specifically, we look across 11 projects that took place on three continents and within a variety of educational contexts to examine the ways that notions of disruption in education can be not only theorized but also operationalized to change hegemonic expectations of educational systems toward expansive ways of knowing, doing, and creating.

Responding to the ISLS call for innovative symposia to respond to changing times while building community, we use this hybrid structured poster session to question the ways that both designed and encountered disruptions to educational structures can offer opportunities to co-construct new ways of knowing across intimate networks, learning communities, and institutions. We follow colleagues such as Lopatovska et al., (2022) to consider the ways that young people and their educators are not only resilient but powerful agents of change in the face of challenging circumstances. In this proposed session, scholars draw from sociocultural and constructivist theories of learning, as well as notions of criticality, embodiment, temporality, and design to reconsider the ways that our work can build knowledge and community collectively *because of*, rather than despite, the continuing disruptions in our individual lives and global society. We also examine the ways that different groups of learners, particularly those with historically marginalized identities, have been positioned as disruptive and have experienced disruptions to learning in differing and often violent ways (e.g., Patel, 2015; Tuck, 2009). This session will provide theoretical, methodological, and practical tools that can inform learning sciences research concerned with promoting change in educational opportunities toward more liberatory, participatory, and just futures.

Although the posters feature a variety of methods, all share perspectives that data can and should be representative of the multiple and complex ways that learners and educators navigate the world (Bridges, 2020). This complexity is part of the analysis that examines *designed for* and *encountered disruptions* across projects. While each project investigates notions of disruption, they span different timelines before, during, and after the pandemic. These multiple timeframes also mean that the authors take up a spectrum of perspectives ranging across constructivist, critical, and post-structural epistemologies. Despite these differences, each of the projects suggests new ways of theorizing or operationalizing disruption toward equitable and transformational ends for learners.

Poster abstracts are listed below alphabetically by first author and referred to here by number in this sequence. Some of the posters, including 3, 4, 6, and 11, examine disruption as an outside-of-project force that asked partners to reimagine what it means to collaborate in the face of environmental changes, including COVID-19 and the climate crisis. Others, including 1, 2, 5, 7, 9, and 10 take up socio-cultural/critical perspectives to question what it means to design learning experiences and environments toward the disruption of traditional systems of power. Many of the posters speak to the tensions in between these perspectives, addressing the ways that both kinds of disruption intersect and reshape educational research. While a few of the authors engage more traditional methods and perspectives around technology and design, all question the ways that young people have been positioned to learn (or not) within traditions of education. Finally, poster 8 pushes critically against other perspectives in the session, questioning the ways that notions of disruption are often embedded in theories of whiteness. These authors offer creative counterpoint, enriching the potential for conversation by posing questions of institutional resistance that requires learning to be theorized as a fugitive act (Patel, 2015) if it is to serve those historically marginalized and barred from educational spaces.

To effectively bring these pieces into conversation, we engage in a 75-minute innovative structured poster session that will include hybrid and multimodal components alongside traditional posters to allow for participation from across continents. The session will open with a brief introduction, followed by highlights of each poster. There will be two rounds of free-form time during which the audience can engage with the different posters; in each round, only half of the poster-presenters will be at their posters, to allow presenters to engage with each other. The session will conclude with two discussants, both with extensive research in the learning sciences related to the ideas in the session. Drs. Sherice Clarke and Joseph Polman will offer both provocations and contextualization of the works in the context of the field. There will be ample opportunity for audience active participation during free form segments, and following the commentaries. We see this session as an opportunity to facilitate necessary conversations responding to the conference theme about how to engage in learning research toward community, while attending to technology, relationality, and the ever-present need to disrupt whiteness toward more expansive ways of knowing and being.

Poster 1: Biliteracy practices by indigenous language teachers

Zaynab Gates

In Latin America, home to 42 million Indigenous peoples speaking more than 500 languages (Sichra, 2009), bilingual education is key to protecting Indigenous children's right to learn in their mother tongue. Teaching in Indigenous languages requires, in turn, the preparation of Indigenous teachers who can develop effective oral and written bilingualism in their students. Centering the voice of Indigenous language teachers and drawing from the continua of biliteracy framework (Hornberger, 2004), this study at two teaching institutions in Northern Argentina examined the challenges and strategies Indigenous language (Qom or Wichí) teachers employed to disrupt hegemonic notions of language acquisition that have historically stolen language from Indigenous youth and instead become Indigenous language promoters.

This paper responds to the session call to examine notions of *designed disruption* by theorizing Indigenous methods of storytelling as a means of language preservation that can halt the white supremacy and settler colonialism (Tuck, 2009). The authors will use the poster to explore the ways that Indigenous storytelling can act as a tool to disrupt the loss of culture and transform educational experiences for Indigenous youth. Using Indigenous storytelling interviews (Iseke, 2013) and collaborative analysis of data with Indigenous researchers, this study contributes to understanding motivation, strategies, and concepts used by Indigenous language teachers to persevere in their educational trajectory and to design learning experiences as Qom or Wichi language teachers.

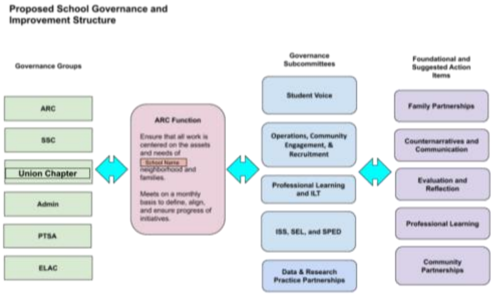
Poster 2: School governance policy for racial justice: Disruption as impetus for policy infrastructuring

Ung-Sang Lee & Marcus Van

This poster presents a case study of efforts to refine the infrastructures (Dantec & Disalvo, 2013; Penuel, 2019) for a research-practice partnership (RPP) between a university and a partnership secondary school serving historically minoritized students to center racial justice. Such infrastructuring led to the formation of new school governance policies that reconfigured the roles of students, teachers, family members, and researchers. This work was situated in a school-university partnership that housed multiple RPPs in their formative stages. The *external disruption* to schooling from the COVID-19 pandemic, as well as broad anti-racist organizing, created opportunities to engage in RPP infrastructuring work framed by three priorities identified by partners: 1) to center anti-racism in the school-university partnership, 2) to align the somewhat disparate RPPs around shared goals and processes, and 3) to deepen the participation of students and their guardians in RPP efforts. In response, over a six-month period, 30 students, guardians, teachers, school administrators, and researchers met weekly in efforts to redesign the school-university partnership infrastructures. The school's Anti-Racist Committee (ARC), successfully reformed governance structures so that ARC members had representation on the School Council. Further, ARC was able to guide all RPPs that took place in the school (Figure 1). ARC members viewed this localized policymaking as a model for broader systemic change and sought to scale the governance policy even beyond the school district.

The case illustrates the ways efforts to disrupt policy contexts in the face of unexpected disturbances, such as the COVID-19 pandemic, can support educational change that privileges minoritized school stakeholders and the assets they bring to bear. Such forms of participation serve as fertile ground to disrupt traditional notions of educational policy making. As such, universities and policy makers are encouraged to consider how policy making intersects with RPPs and how such intersections may advance justice-focused educational change.

Figure 1
ARC School Governance Proposal



Poster 3: Remote classroom research toward equity during the COVID-19 pandemic

Tomohiro Nagashima, Gautam Yadav, & Vincent Aleven

School classrooms are a critical part of learning sciences and technology research that aims to understand and support learning in an *authentic* learning environment. However, during the COVID-19 pandemic, K-12 schools in the U.S. were forced to make a transition to "emergency remote learning" (Khlaif et al., 2021), where students and teachers were required to continue their teaching and learning remotely, at least to some extent (e.g., hybrid teaching). While this drastic change in schools led to issues that made teaching and learning challenging, especially amongst students and families in under-resourced communities, it also offered new opportunities to make sense of the realities that students, their families, and teachers were coping with during their teaching and learning activities. To align with this session's examination of *external disruption* that catalyzed educational change, we ask: What can the the COVID-19 pandemic teach learning scientists as they continue to collaborate with school partners in times of crisis?

We propose that remote classroom studies can help advance the learning while proactively promoting equity in educational technology research during such a crisis. Although remote classroom research on learning technology (i.e., observation through a video conferencing platform while students are using the technology) can be challenging, it has potential to offer new opportunities for learning and participating in research in remote and under-resourced communities that may not have been accessible for partnerships before the COVID-19 pandemic.

During the COVID-19 pandemic, we conducted nine classroom studies remotely in five states in the U.S. These studies created opportunities for partnerships with educators in rural and remote areas that had been unavailable before the pandemic and offered a window into students' learning by allowing for study of unmoderated home learning. Analysis of teacher interviews from these experiences led to the development of a framework for conducting remote classroom research on learning technology (Nagashima et al., 2021), which can be used to help researchers address equity and logistical issues when planning and conducting classroom research on educational technology remotely. In the proposed poster session, we will discuss the possibility for this framework to act as a *designed disruption* of more traditional notions of classroom research and the ways that remote engagement in learning research might offer more equitable perspectives on the learning communities in rural and remote areas.

Poster 4: COVID-19 opportunity for transformation within research-practice partnerships

Robbin Riedy, Kristina Stamatis, Caitlin Farrell, Paula Arce-Trigatti, Alison Fox-Resnick, & William R. Penuel

Research-Practice Partnerships (RPPs) have potential to "support the mutual learning of partners to change practice while continuously adapting to turbulent environments of schools" (Penuel, et al., 2021). However, as the COVID-19 pandemic and its intersections with political unrest and police violence created one of the most turbulent environments schools in the U.S. have ever faced, many RPPs found themselves struggling to continue pursuing collaborative goals (Ishimaru et al., 2022). In this poster, we explore data from 24 RPPs to understand the ways that members characterized their work together amid these global *encountered disruptions*. We ask: What are the characteristics of RPPs that leveraged the COVID-19 pandemic toward transformation?

This work acts as a secondary analysis of interview and survey data from 24 RPPs in which 112 members provided self-evaluations of their partnerships across five dimensions of effectiveness and equity (Farrell et al., 2022). We frame this analysis with theories of active waiting (e.g., Lee et al., 2020), which refer to the planning and action that can take place during periods of turbulence and offer a way to theorize the characteristics that supported some RPPs in leveraging *encountered disruptions* toward more transformative goals (Tanksley & Estrada, 2022). Our data illustrate in RPPs that aimed to improve traditional measures of school success; many partners said their work was delayed during the pandemic. In some cases, the pandemic reinforced a sense of futility. As one partner said, "COVID has shown that a lot of things in our society are broken." However, in RPPs that had focused their work on disrupting traditional power relationships in education, many partners said the urgency of the pandemic energized their work. In these RPPs partners spoke of developing more empathy for their colleagues while revisioning the ways their work could transform education. This kind of active waiting meant partners acted toward change, even as their intended work was disrupted due to COVID-19.

Given initial analysis, we conjecture that RPPs' stances towards how they achieve their objectives — through either working within traditional measures of educational success or attempting to disrupt the system all together to create new models of educational equity–influenced how they approached the period of active waiting during the pandemic. This paper contributes to the objectives of this symposium by exploring the ways that RPPs were able to navigate their work and relationships in the midst of *encountered disturbances* and addresses the conference theme by examining the ways RPPs can leverage disturbance and change toward transformational community learning.

Poster 5: Memes in memory institutions: Youth interests and literacies as encountered disruption in design-based cultural heritage work

Emily Oswald, Line Esborg, Palmyre Pierroux

Cultural heritage institutions face changing expectations about engaging with and representing diverse constituencies, including young people. While many museums and archives have developed projects and programs that involve collaboration with new audiences, these activities can reproduce the very power dynamics they seek to disrupt or introduce disruptions that institutions are poorly equipped to engage with productively. How can museums develop new practices to become more just, democratic and participatory institutions?

Building on a previous study (Oswald, Esborg & Pierroux 2022) of youth, memes and memory institutions, this poster explores an encountered disruption in New Voices in the Archive, a youth engagement program at the Norwegian Folklore Archive. Aiming to expand the representation of young people in the archive's collections and their participation in institutional practices, the program was developed through a university-initiated, design-based collaboration (McKenney & Reeves 2019) involving educational and cultural heritage researchers and young people (ages 16-19) from Oslo, Norway. The study involved three interventions over the course of approximately one year. During the implementation of the second intervention, researchers identified young peoples' knowledge of internet memes (Shifman 2013) as a potential focus area for the third intervention.

To explore how the New Voices program resulted in the emergence of novel and participatory knowledge practices at the Norwegian Folklore Archive, we propose that young peoples' interest in and knowledge of internet memes can be conceptualized as an encountered disruption within a design-based research process. We describe how researchers responded to initial references to memes during in-person meetings and the ways in which the task of selecting and contextualizing memes supported the young people's agency by demonstrating their literacy with memes as a genre of digital media. We argue that New Voices, a program designed to disrupt the archive's established approaches to collecting folklore, was successful in large part because the ways researchers' and young peoples' engaged with this encountered disruption.

Poster 6: Frames of the planet: Climate justice in the science classroom

Sushil S

The latest report by the Intergovernmental Panel on Climate Change (IPCC) projects some damage to human systems and ecosystems in the near future if we fail to limit the global temperature level increase to 1.5 degrees Celsius above pre-industrial levels (Pörtner & Roberts, 2022). At the same time, around 84% percent of the children in the ages of 12-14 years across the world are enrolled in schools, with younger children enrolled at even higher rates (UIS, 2019). However, particularly in early grades, while there is some evidence of strong scientific teaching, the "overall picture of understandings of scientific inquiry is not what is hoped for after completing 6 years of elementary education in any country" (Lederman et al., 2019, p. 486). Worldwide, there is a prevalence of compulsory school attendance laws that suggest that schools must take an active role in attending to and planning for *encountered disruptions* such as climate change. Recognizing the precarious situation of young people in the world due to the impending impacts of climate change, this study examines how teachers draw from their own knowledge and potentially reach beyond pedagogy and content to shape students' frames of the planet.

In this study, I take up Goffman's (1974) notion of frames as the multiple ways that individuals construct, organize, and differentiate meanings of their lived experiences. I examine the ways that teachers drew upon their own knowledge of science and its application in their own lives and cultural backgrounds to understand how they shape student framings of climate change. Data collection took place through qualitative inquiry into a high school earth science teacher's pedagogical practice. The data for this study, collected over two units across 8 weeks, include conceptual interviews, classroom discussion transcripts, and field notes to examine how the science teacher's frames traveled through their planning, teaching, and reflection as they taught two different units. Additionally, the data also include student conceptual interviews at the beginning and end of each unit to examine connections between how the students' frames shifted through each unit with and against the frame deployed by the teacher. This study adds to the literature of how frames are deployed by teachers and learned by the students in the classroom. Findings from this study can inform further research and action on how researchers and teachers might redesign and disrupt unsuccessful or limited processes of constructing scientific knowledge in the classroom to make way for knowledge that engenders actions towards climate justice worldwide. Reframing scientific inquiry toward more action is a necessary step in research and classroom design if we are to use collective action to address and disrupt the disaster that climate change and global warming currently promise.

Poster 7: Re-imagining learner identification with discursive protocols in times of change

Stephen Sommer

This ongoing research project explores notions of *designed disruption* within the process of unlearning, reimagining, and cultivating belonging as high school students (re)discover how they identify as learners through multiple iterations of structured community presentations of learning (POLs). This study took place at an independent, tuition free school for "students who were not otherwise finding success" in traditional learning contexts (school website). As a move to disrupt students' experiences with traditional schools, three times each year across their multi-year tenure, students organize a POL of their own human development. These POLs act as interactive portfolios in which students present examples of both their academic and personal growth. Students then use a discursive protocol based upon exhibitions of learning (Sizer, 1992) to engage in structured discussions with peers, teachers, and community members. These conversations take place in multiple rounds over two or three days. Throughout this discursive process of presentation and then in the subsequent fielding questions from community members, students come to recognize sites and experiences of growth beyond the confines of the classroom (Tracy & Robles, 2009).

In this study, I examine the process through which learners develop identifications (e.g., Polman, 2011) and how that process is supported and enabled through the designed structure of the POLs, the investment and sense of belonging in a committed community of learners, and multiple opportunities to engage in this performative ritual (e.g., Bucholtz & Hall, 2005). This multi-year ethnographic study draws data from video recorded POLs, interviews with students, faculty and school designers, as well as an analysis of student generated artifacts including visual aids, letters to community panelists, personal reflective essays, and guided prompts such as "I used to be…but now I am." My findings indicate that throughout the process of engaging in POLs, students recognize and articulate an expansive view of learning that is attentive to their full self well beyond a narrow assessment of gaining or retaining academic content. Additionally, findings suggest that the POL experience empowers young people to recognize sites of their own learning and increase agency in exploring and articulating their evolving identities. This paper has potential to support understandings of designed disruption by bringing youth voice to bear on the ways traditional learning design requires disruption to support the development of learner identifications.

Poster 8: Plática as circle and crossroad: Fugitive counterstories of chị em author: Fugitive chị em apapachando

Trang Tran, Marlene Palomar, Adria Padilla-Chavez, Ashieda McKoy, Brenda Aguirre Ortega, Fabiola Palomar, Trang B. Tran

Patel (2016) reminds us that learning is, at its core, a fundamentally fugitive act. In this paper, we push back against the notions of disturbance included in this session. Identifying as first-generation femmes of color, our endeavor to seek doctoral degrees in the field of education has faced enduring opposition. These include institutional resistances to change and difference; curricula and pedagogies that reinforce white supremacy, oppression, and trauma; and personal interactions that left us with feelings of tokenism, isolation, invisibility, and invalidation (Harris, 2016; Hubain et al., 2016; Patel, 2015). In addition, systemic pushback has created disruption against heterogenous ways of knowing and has historically forced learners towards a dominant, assimilative culture. In this reality, our group strategically fled from institutional hostility to seek a counter space. Fugitive wellness is an act of self-preservation and political warfare (Lorde, 1988, p.130). Our *fugitive wellness* has been grounded at the crossroads of healing, *hermanidad*, and quenching desires for dignity. In an alternative space we have created, imagined, embodied, and nurtured an environment for safety where we allowed ourselves to be vulnerable; this is where we laid a foundation for critical dialogues and collective sense-making of our own experiences, intellective survival, and our futures in the academy. We seek to develop *fugitive practices* (Patel, 2019) to defy and disrupt individualistic, competitive, and linear trajectories of achievement—ones that are perpetually reproduced in our academic institution. Our practices redefine learning through a lens of solidarity where learners are attentive to each other's emotional and spiritual health. As a group, we become a beacon of hope for one another.

We disrupt this session through collective and creative autoethnographic work. In this symposium, we will use artistic portrayals of selves as data to reflect on our group's engagement with different modalities during meaning-making, storytelling, and writing. As we frequently find each other in counter space to process, affirm, and devise strategies for wellness, we explain how such fugitive practices took place in various mediums of human communication, including poetry, imagery, sound, sensory, emotion, and movement. Such multimodalities have been important for how our group makes available physical, mental, and emotional support for each other as we sustain this sacred fugitive counterspace. Such processes of joy and strength have sustained our collectivity and offered nutrition–like *apapachos (hugs)*--for our souls.

Poster 9: "It was nice to know that they felt the same things we did": Disrupting generational hierarchy and mental health stigma in a youth program through adult facilitator vulnerability

Sari Widman

To address the mental health crisis that has increasingly gained attention following the COVID-19 pandemic, educators must move beyond traditional notions of social-emotional learning (SEL) and invest in collective intergenerational work that is designed to disrupt oppressive systems that contribute to mental-unwellness (Jagers et al., 2021; Rosen et al., 2021). Prefigurative practices of relationship-building, that put into practice caring relations to disrupt hierarchies, are core to justice-oriented learning and collective social movements (Uttamchandani, 2021). Here, I look at the role of "check-ins" as a prefigurative relationship-building practice in a youth leadership program.

The program engaged BIPOC youth who identified as facing a variety of mental health challenges, as being neurodivergent, or as having queer identities. Interviews were conducted with 7 of 11 youth participants in June 2022 following the first months of the 1.5-year program. There were six adult facilitators (including the author), who regularly attended sessions and provided support. The program was designed to create social change by engaging youth in collective art making around issues of mental health to disrupt cycles of intergenerational trauma and strengthen networks of community care. Check-ins were conducted at the beginning of each weekly program session to give youth and adults the opportunity to share about their lives and emotional states. Based on analysis of interviews with youth to understand their perceptions of adult facilitators' participation, I found facilitators' vulnerability during check-ins helped to disrupt generational hierarchy, stigma, and traditional narratives around mental health.

While youth consistently talked about the importance of check-ins for feeling less alone in their experiences and creating a safe environment, the process of opening up was gradual. One youth, who described opening up during check-ins as shifting from their least favorite to favorite part of the program, said that facilitators modeling openness and vulnerability helped her feel comfortable doing the same, "It's okay to you know, not be okay. It's okay to open up." Youth also described adult sharing and "being themselves" as creating a sense of safety in the space that built connections between their experiences as teenagers and those of the adults. This sense of relatability and connection shifted ideas of differences between how adults and teens might experience mental health challenges. As one youth put it, "It was nice to know that they felt the same things we did, even though they were adults, you know, like the generational gaps didn't really change anything." Youth also expressed that adults sharing was "eye opening." One described hearing that teen mental health struggles were "just a phase" and so thought adults "don't have any issues." Disrupting this idea of mental health struggles allowed youth to revision their own experiences. This poster unearths the potential for *designed disruption* of the hierarchical and linear narrative of youth as struggling and adults as authoritative figures.

Poster 10: Disruption of gender representation in computational toys and kits for young children from a design perspective

Junnan Yu

While the importance of introducing computational thinking (CT) to young children has been widely acknowledged, inequities persist as CT is accessible differently along gendered lines. Despite these inequities, early childhood is fertile ground for cultivating young people's interest in computing and has even been found to hold potential in mitigating gendered stereotypes around coding and robots (Bers, 2017; Clements & Gullo, 1984; Papert, 1980). Computational toys and apps, also called coding kits, are the major media for children ages seven and under to engage in coding and CT (Yu & Roque, 2019). Although many coding kits are available, much remains unknown regarding their impacts on young children, especially how they may welcome participation from children of different genders.

In this study, I seek to understand how designers might use *designed disruption* as a means of reimagining expressions of gender equity in computational toys and coding kits. This perspective is critical because children start to conceptualize gender at approximately 18-months (Martin & Ruble, 2004; Rubegni et al., 2019; Weisgram et al., 2014) and may have already formed the stereotype that boys are better at programming than girls as early as six years of age (Martin et al., 2016). Further, children's gender conceptualization can impact their engagement with toys–for example, avoiding toys that do not fit with their formed gender identity (Carter & Levy, 1988; Weisgram et al., 2014)–which can perpetuate inequities in access to CT. Creating gender-inclusive coding kits are especially important to disrupt gender stereotypes about computing and welcome participation from children of different genders, particularly given that computing is already a field heavily dominated by males (Hill et al., 2010). However, no studies have examined gendered design features in coding kits and so few guidelines exist for designing gender-inclusive coding kits and broader learning technologies for young children.

This poster will examine gender representations in coding kits for young children and present a framework for *designed disruption* of traditional computational kits and toys. Specifically, I will (1) present a developing framework to evaluate and disrupt gender-related design features in toys for young children and employ the framework to analyze how existing coding kits represent genders; (2) discuss the ways young children (target users of coding kits) and their parents (gatekeepers of coding kits) assess the gender orientations of some representative coding kits. This poster contributes to the symposium by raising notions of gender in discussions of disruption and presenting a potential framework that can be used as design guidelines when designing for disruption in computational settings.

Poster 11: The effects of educational technology games on students' conceptual understanding of algebra in the context of COVID-19 pandemic

Jenny Yun-Chen Chan, Avery H. Closser, Vy Ngo, Hannah Smith, Allison S. Liu, & Erin R. Ottmar

Prior work has shown that middle schoolers struggle with algebra (Kieran, 2006), but educational technologies, such as DragonBox12+ (Liu et al., 2015) and From Here to There! (Decker-Woodrow, in press) have potential to disrupt this struggle by engaging students in game-based (Connolly et al., 2012) and embodied learning (Abrahamson et al., 2020) to support students' algebraic performance. Uses of technology became even more important during the *encountered disruption* of the COVID-19 pandemic when students were often receiving inconsistent instruction in mathematics. However, it remains unclear *which* aspects of algebraic knowledge are impacted most by these technologies. Leveraging data collected during the 2020-2021 academic year, we aim to advance understandings of whether these technologies improve students' *conceptual knowledge*, *procedural knowledge*, and/or *procedural flexibility* in algebra during these kinds of *designed disruptions* of traditional educational instruction.

Using an experimental design study with pre- and post-tests, we found that seventh graders significantly improved and maintained learning gains on conceptual knowledge throughout the technology-based interventions (Pretest: M=46%; Posttest: M=53%). However, they did not improve on procedural knowledge (Pretest: M=55%; Posttest: M=51%) or procedural flexibility (Pretest: M=52%; Posttest: M=44%). This pattern of results was consistent for students across interventions, suggesting that while these technologies may support conceptual understandings in algebra, further work is needed to explore how technologies might support student learning of algebraic procedures.

These findings have implications for research on the educational impacts of the COVID-19 pandemic and ways to support algebraic learning through technologies beyond educational disruptions. Specifically, DragonBox12+ and From Here to There! can engage students in algebraic learning and improve conceptual understanding. These gains are worth noting given the drops in math performance among U.S. students during the pandemic (NAEP, 2022). Both may help students engage with mathematical content and foster their positive attitudes towards math especially during educational disruptions. Supplementing middle school algebra curricula with game-based technologies may provide additional opportunities for students to deepen their conceptual knowledge. This poster contributes to the symposium by raising issues of impact within designed disruptions of traditional teaching, particularly when intersected with other *encountered disruptions* that may necessitate the use of technologies for learning.

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Computation Within and Beyond Disciplinary Communities: Learnings From K-12 In-School-Time Studies

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Abstract: Computation has become an essential part of today's personal, educational, civic, and career living, which necessitates preparation of a generation of future citizens who are knowledgeable of computational thinking (CT) concepts and are able to apply CT skills in daily life and work. Because of CT's use across fields, it is important that we take an interdisciplinary approach and ground the teaching and learning of CT in authentic and meaningful contexts with learners. This symposium explores different approaches of integrating CT into topics in formal settings. The six empirical studies of this symposium present designs of authentic environments that aim to infuse CT into plant science, literacy, ecosystems, general biology, and chemistry. These studies also report the findings of teacher and student learning from the implementations. Collectively these studies provide unique insights towards design recommendations, challenges, pedagogies, and opportunities in the rapidly developing STEM+C field.

Symposium overview

In today's high-tech and ever-changing world, computation is and will continue to be used in almost all walks of life (Vogel et al., 2017). It is increasingly clear that our students must learn to think computationally and resolve complex and ill-defined problems using computational tools for future thriving (Ventura, Lai, & DiCerbo, 2017). To meet this urgent need, public policy makers and educators have called for the incorporation of computing into K-12 education. For example, broader educational initiatives such as the CSforALL movement have emerged. Code.org has developed a suite of activities to expand access to computing opportunities in school (e.g., the Hour of Code program). The CSTA has created a framework for K-12 CS education and subsequent national standards. Despite these efforts, there remain substantial barriers to implementing computing education during K-12 in-school-time activities, often intersecting with positionalities of race and ethnicity, gender, socioeconomic class, and/or additional markers (Blikstein, 2018; Rodriguez & Lehman, 2017).

One barrier may be related to the fact that the field of computing education remains relatively new and there exist controversies surrounding the definition of computational thinking (CT). For example, Wing (2006) posed a seminal (re-)definition of computational thinking (CT) that "involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (p. 33). Weintrop and colleagues (2016), in collaboration with practitioners, developed a taxonomy that defined CT specifically in math and science classrooms, including details about practices of modeling and simulation. More recently, Kafai and Proctor (2021), drawing upon their experiences in crafting, computer science, and language arts, have positioned computational thinking in three framings under an umbrella of *computational literacies* (*cognitive*, *situated*, and *critical* framings). They urge a reframing of CT from "a general-purpose skill" towards a tool for various individual/cognitive, collective/community/identity, or cultural/societal/liberatory purposes (p. 147). Amidst these various framings, researchers have agreed that CT is a foundational skill for a variety of STEM and non-STEM professionals (Malyn-Smith & Lee, 2012).

To accelerate the take-up of CT in K-12 classrooms, one emerging theme and endeavor is to employ interdisciplinary approaches to integrating computing into other disciplines. The traditional method of teaching computing through computer science coursework, while successful for many students, often is difficult to staff, disengaging to learners who are from groups underrepresented in STEM/computing education, and reinforces the stereotyped views of professionals working in CT related fields (Rodriguez & Lehman, 2017). An interdisciplinary approach can expose students to authentic contexts of using CT to solve real and meaningful problems across content areas. It can help students draw connections between application areas of interest and CS and broaden the participation of students, to whom such integrated learning environments can appeal (National Academies of Sciences, Engineering, and Medicine, 2021). Despite the efforts to promote interdisciplinary learning in CT (e.g., Lee et al., 2020), there remains a knowledge gap of how to develop authentic interdisciplinary learning experiences for students and teachers in K-12 settings.

Our contributors are from different disciplines and backgrounds (e.g., learning sciences, literacy education, science education, and human-computer interaction) and explore interdisciplinary STEM+C education in classrooms from different perspectives. Specifically, this symposium consists of (1) three presentations around promoting CT through computer modeling: Lee and Perret investigate a high school chemistry curriculum featuring computational modeling and decoding practice; Chao et al. present the design of a modeling environment using domain-specific modeling languages to support high school students in assessing the risk of natural hazards; Wagh et al. examine an interdisciplinary curriculum that bridges 6th grade Math and Earth Science through interactions with computer models of scientific phenomena; (2) two presentations around promoting CT through scientific experimentation and problem solving: Zhang et al. illustrate the unique affordances of using physical computing to foster middle school students' interest in CT and plant science; Jackson draws on perspectives of social identities and participant structures to investigate teacher learning in fostering student interest during four iterations of a smart greenhouse project; and (3) a presentation on promoting CT through digital storytelling: Proctor explores assessment of both English/Language Arts and CT through digital storytelling, employing rhetorical analysis to show how sixth-graders used computational affordances to expand notions of character identity and reader agency. Together, these papers exemplify different approaches to overcome the barriers of bringing CT into K-12 classrooms and shed light on strategies for promoting CT's nature of interdisciplinarity from the angles of learning environment design, pedagogy, and assessment. This symposium will contribute significantly to the field's understanding of infusing computational education into existing school coursework, in order to help achieve and sustain the adoption of equitable computing education for all K-12 learners.

We will structure the symposium following these steps: co-chairs introducing the contributors (2 minutes), contributors briefly presenting their research in a sequence (8 minutes per presentation and 1 minute transition, total: 54 minutes), discussant briefly discussing the themes emerged from the presentations and future directions (7 minutes), contributors engaging in a Q&A with attendees facilitated by the co-chairs (10 minutes), and co-chairs summarizing the discussed topics (2 minutes).

Interrogating and assessing computer models to deepen students' understanding of scientific processes

Irene Lee & Beatriz Perret

Numerous attempts have been used to integrate computer science (CS) and computational thinking (CT) into science classrooms through computer modeling and simulation practices (Grover et al., 2020). A common approach involves engaging students in constructing computer models of scientific phenomena via programming in a computer language. While this "programming first" approach has shown promise, its adoption has been hindered by teachers' limited preparation in CS, time constraints, and lack of understanding of how to integrate CS into their classrooms (Israel et al., 2022). Thus, Education Development Center's "Computational Sciences Pathway Option for Massachusetts High School Students" project ("Science+C") was funded by the National Science Foundation's STEM+C program to investigate a different approach. Rather than constructing computer models, the project's Chemistry+C curriculum engages high school students in using, decoding, and modifying *existing* computer models of scientific phenomena as the means to deepen their understanding of scientific processes while exposing them to computer science. This approach is "authentic" in two ways: it provides students with agency to investigate and solve problems, and it mimics the work of modern scientists who need to interrogate models to assess their validity and adapt computer models for their own uses rather than creating them from scratch.

The Chemistry+C curriculum was implemented during the 2021-2022 academic year by four Massachusetts high school chemistry teachers who participated in the year-long Science+C professional development program. In the curriculum and PD, a new practice called “decoding” was operationalized as a thinking process necessary when analyzing a computer model made by someone else. In particular, in a science context, decoding involves comparing a coded mechanism in a model to the scientific process it represents in the real world. When the coded mechanism closely matches what the student knows about the real-world scientific process being modeled, the model is deemed “valid” whereas when a mismatch is identified, the student is encouraged to modify the model to increase its validity. Our research aims to investigate whether and to what extent students who experience the integrated Chemistry+C curriculum featuring decoding show changes in knowledge and skills in both computational thinking and science learning. Summative assessments of student learning (pre-post surveys) were used to measure students’ ability to map between coded mechanisms and the scientific processes they represent, students’ understanding of CS constructs integral to CT for modeling and simulation, and science concepts. This paper describes the design of the Chemistry+C units and findings from our exploratory study of student learning through the intervention. We close with insights on design, challenges, pedagogies, and opportunities for future decoding curricula that may be of interest to designers, researchers, and practitioners who wish to engage students in computational thinking within science contexts.

Designing a domain-specific modeling language for secondary students to explore multivariate probabilistic simulations of scientific phenomena

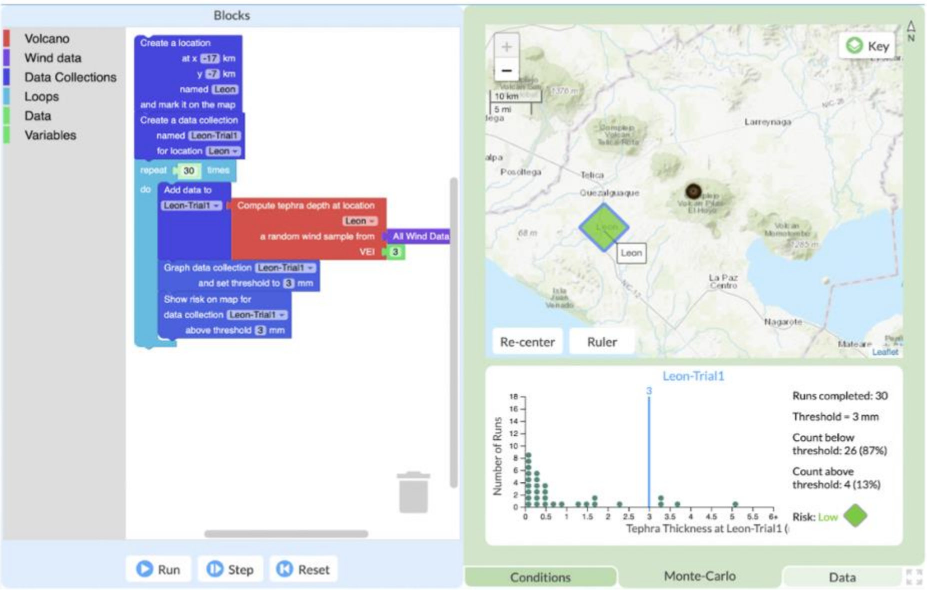
Jie Chao, Amy Pallant, Hee-Sun Lee, Christopher Lore, & Charles Connor

Computational modeling has become an essential practice in various fields of science. Scientists use programming languages to construct computational models of natural phenomena and run simulations to test theories and evaluate solutions (Shiflet & Shiflet, 2014). Recently, this practice has received much attention as an approach to integrating computational thinking (CT) into science classrooms (Wang et al., 2021). Computational modeling has been adapted as a form of learning activity that engages students in using, modifying, constructing, and evaluating computational models in programming environments (e.g., Aksit & Wiebe, 2020). As most students in science classes are not formally trained in programming, teachers are reluctant to devote too much class time to learning programming languages. Often, teachers themselves are not familiar enough with programming to support students in complex programming activities. Due to these constraints, block-based programming languages have become popular for their novice-friendly interface, syntax error prevention, and instant visual feedback (López & Hernández, 2015). However, generic block-based programming languages still require students to learn many lower-level language primitives as well as the syntax for composing with these primitives. To address this issue, researchers have been developing domain-specific modeling languages, which include alternative language primitives, often called custom blocks, for students to grasp more intuitively and interact more directly with the models of the target phenomena (Hasan & Biswas, 2017; Anderson & Wendel, 2020; Hutchins et al., 2020).

How can domain-specific modeling languages be designed to support high school students in learning multivariate probabilistic simulations? This study investigated this question in the context of the Monte Carlo simulation application for assessing the risk of being impacted by volcanic ash fallout. Some volcanic eruptions produce tephra, i.e., rock fragments and particles of various sizes. The tephra can disperse over a large region and affect people’s health, damage crops, block transportation, and even collapse buildings. Its dispersion is mainly influenced by the explosivity of the eruption, wind speed, and wind direction. Geoscientists have developed tephra dispersion differential equations and computer algorithms to predict the tephra fallout at a specific location based on these three parameters as well as others. However, numerous eruption scenarios exist because each parameter has a wide range of possible values. For example, wind speed and wind direction change every day. This makes forecasting a challenge because the weather condition at the time of a volcanic eruption event cannot be known. Yet it is possible to forecast the likelihood that the depth of tephra is beyond a dangerous level at a specific location. To assess this risk, the tephra dispersion computational model needs to be run many times, each time with a set of parameter values (wind speed and wind direction) randomly sampled from the probability distribution of a historical wind data set for that given location (wind measurements taken several times a day for years). When the outcomes of all the runs are aggregated, the risk can be assessed.

We designed a computational modeling environment with domain-specific custom blocks called GeoCoder, shown in Figure 1. It includes a collection of custom blocks to address the critical aspects of investigating tephra dispersion after a volcanic eruption, a set of dynamic visual tephra outputs in real-world geography, and the probabilistic sampling mechanism in a Monte Carlo simulation. For instance, there is a custom block for the tephra dispersion model. It takes three inputs: a location, volcanic explosivity, and a set of wind speed and wind direction randomly sampled from historical data. The block generates a predicted tephra fallout thickness displayed on a graph. The idea of running the model many times and aggregating all the outputs is often difficult for students to grasp. To make the idea concrete, we designed a data-collecting block to collect individual outputs from the tephra dispersion model and dynamic graphing blocks to visualize the individual outputs and the aggregated results. This set of custom blocks can be configured and wrapped in a loop block to implement the Monte Carlo simulation. When students step through the code, the output from each iteration is added to the graph, and as more iterations are completed, the aggregated results emerge.

Figure 1
GeoCoder, a domain-specific modeling language for multivariate probabilistic simulations (i.e., Monte Carlo simulation) in geohazard risk assessment


```
Create a location
    at x -17 km
    y -7 km
    named Leon
and mark it on the map
Create a data collection
    named Leon-Trial1
    for location Leon
repeat 30 times
do  Add data to
    Leon-Trial1   Compute tephra depth at location
                      Leon
                      a random wind sample from  All Wind Data
                      VEI 3
    Graph data collection Leon-Trial1
        and set threshold to 3 mm
    Show risk on map for
    data collection Leon-Trial1
        above threshold 3 mm
```

Runs completed: 30
Threshold = 3 mm
Count below threshold: 26 (87%)
Count above threshold: 4 (13%)
Risk: Low

We developed a two-week curriculum module using GeoCoder to introduce computational approaches for geohazard risk assessment to secondary students. We piloted the module with 84 ninth-grade students taught by four teachers in a suburban public high school in the southwestern US. All four teachers implemented the module remotely due to COVID-19 restrictions. Our findings suggest that students showed varied understandings related to random sampling from multiple parameters and the visual outputs from the Monte Carlo simulation in GeoCoder. At least half of students understood that the variability in model input parameters as well as the random sampling method itself would generate variability in individual outputs, resulting in different distributions of tephra depths among aggregate outputs. Other students' suboptimal understandings might result from the lack of opportunity to see that the same Monte Carlo simulation code could produce different aggregate outputs and think accordingly. These students may benefit from guided interactions with the sample code and close examination of outputs with specific characteristics that promote conceptual learning.

In this presentation, we will describe the design of GeoCoder, discuss student learning patterns from their written and block code artifacts, and propose several principles for designing domain-specific modeling language for secondary students to learn and use multivariate probabilistic simulations.

Physical computing learning experience for middle school science classrooms

Helen Zhang, Mike Barnett, Sheikh Ahmad Shah, & Jaai Phatak

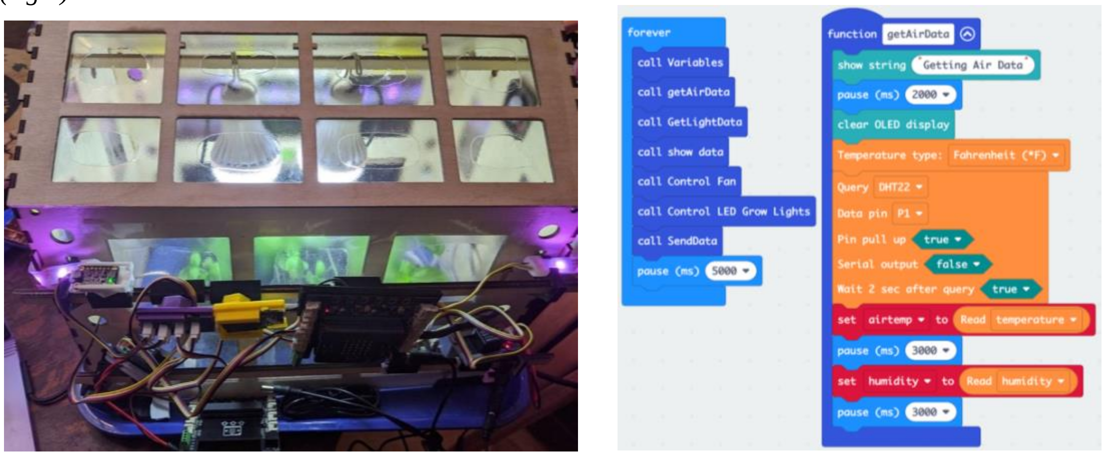
The past two decades have witnessed the rapid growth of computer science (CS) or computational thinking (CT) education at the K-12 level across the United States. Despite its expansion, CS/CT education for students who have been traditionally underrepresented in STEM education remains a challenge. Recent research shows that most current approaches to implementing computational science in educational settings have focused on programming and mathematical computing via decontextualized coding skills training (Fowler & Vegas, 2021; Margolis et al., 2011). Such decontextualized approaches are highly likely to continue to disengage the majority of students from underrepresented populations, who have already felt that computer science is boring and distant from their life (Garcia et al., 2020). Thus, a new report by the National Academies of Sciences, Engineering, and Medicine (2021) called for teaching computational science through authentic experiences to cultivate youth's interest in learning about computation and understanding the role it plays in their future endeavors.

This paper contributes to the call by presenting the design and implementation of a physical computing learning experience among middle school students. Physical computing involves combining software and hardware to build interactive physical systems that sense and respond to the real world (Hodges et al., 2020). A physical computing system includes sensors to sense its environment, a microcontroller to process information, and devices such as actuators or displays to perform actions accordingly (Psycharis, 2020). This "sense–think–act" cycle connects the physical world with the digital/virtual world. When working on physical computing projects, learners engage in building tangible computational artifacts that allow them to explore connections between real world phenomena and computer programs. The interweaving of building and programming makes coding more meaningful and concrete to students, engaging those who might be turned off by decontextualized approaches of teaching CS/CT. A few research studies have found that physical computing can be much more positive than a more traditional screen-based experience because it more readily supports open-ended ideation, rather than causing frustration through syntax restrictions (Przybylla & Romeike, 2015). Students appreciate building real devices and report that physical computing stimulates their creativity (Devine et al., 2018; Sentance et al., 2017) and fosters collaborative learning as it enables students to work together in a visible way (Horn, 2018; Marshall, 2007).

In this paper we report the design of the smart greenhouse project, during which students learn to use and code a tabletop greenhouse (a physical computing system) to control and manipulate the environmental conditions to grow plants. Learners utilize a BBC micro:bit microcontroller to collect data from a variety of sensors including air and water temperature, light, and humidity, then display the data on a small screen and stream the data using a WiFi chip. They use actuators (relays) to control components of the greenhouse such as the lights and air flow (e.g., turning on the grow light when the light level is low and turning on the fan when the temperature is high). To support learners in wiring the sensors to the micro:bit, we use a shield that allows them to simply plug in the sensors rather than using a breadboard or soldering. The sensors are coded through Microsoft's MakeCode block-based interface, and each sensor is enabled through the micro:bit extension library, allowing students to focus on how to code the sensors to collect their data rather than spending time getting the sensors to work. Figure 2 shows an image of the greenhouse and example code. The curriculum includes four modules: Module 1 focuses on assembling the greenhouse, how to code micro:bit using MakeCode, and fundamental concepts of plant science; Module 2 focuses on how to connect the sensors to the micro:bit and how to program to display temperature, humidity, and light levels data from the sensors on the OLED display; Module 3 centers around automation, i.e., students learn how to program so that the greenhouse acts (e.g., turning on and off the fans and the lights) based on the data from the sensors; and Module 4 focuses on using the WiFi chip to stream data to ThingSpeak for students to monitor and visualize the environmental conditions in their greenhouses in real time. In total students spent 12 days on this project (55 minutes per day).

Figure 2

Smart Greenhouse Made by a Student (left) and Excerpt of Block-based Code to Control the Greenhouse (right)



```
forever
  call Variables
  call getAirData
  call GetLightData
  call show data
  call Control Fan
  call Control LED Grow Lights
  call SendData
  pause (ms) 5000
```

```
function getAirData
  show string "Getting Air Data"
  pause (ms) 2000
  clear OLED display
  Temperature type: Fahrenheit (°F)
    Query DHT22
    Data pin P1
    Pin pull up true
    Serial output false
    Wait 2 sec after query true
  set airtemp to Read temperature
  pause (ms) 3000
  set humidity to Read humidity
  pause (ms) 3000
```

We implemented the smart greenhouse project in two middle schools (*N*=175 students and families completed assent and consent forms, respectively) with diverse student populations: 46.9% male, 42.9% female, 9.1% non-binary/blank/prefer not to say; 3% African-American, 23% Latino/x, 45% White, 4% East Asian, and 25% Mixed-race/others. The data collected included a pre/post-survey assessing students' interest in coding (12 items, α=.92), career futures (i.e., views of the value of coding in future jobs; 4 items, α=.80), competency belief (i.e., beliefs about their own competency of coding; 6 items, α=.86), anxiety (4 items, α=.71), and STEM identity (8 items, α=.94) using 5-point Likert-style questions. We also collected classroom observation notes of student reactions when learning with the smart greenhouse curriculum, as well as post-interviews with a group of students (*N*=30) selected for maximum variation (Creswell, 2013) with respect to race and ethnicity, gender, and performance in science class. The interviews addressed students' conceptual understanding of the code and their views of using coding in science. A paired t-test of means for student responses to the pre- and post-survey found statistically significant increases at the α=.05 level for students' competency belief (Pre Mean=3.21, SD=.71, Post Mean=3.43, SD=.84; *t*(141)=3.14, *p*<.01) and STEM identity (Pre Mean=2.79, SD=.88, Post Mean=2.96, SD=.97; *t*(141)=2.14, *p*<.05). The classroom observations showed that almost all students actively participated in the project. They worked in pairs: typically, one student led construction (e.g., assembling the greenhouse frame, connecting wires) and the other focused more on coding. Students tended to work together on troubleshooting. Exit interviews further confirmed these social dynamics. Almost all interviewees commented that they could start from building the greenhouse or from germinating seeds if they were not comfortable with coding. Students also commented that the smart greenhouse helped them visualize how programming can be used to control and automate plant growth conditions. Overall, our results suggested that physical computing, and especially this project with its many access points, is promising for engaging students of diverse backgrounds, supporting them in recognizing their capability for coding and in developing their STEM identity.

"A reason to do the coding": Teacher growth in fostering student interest across four years of an automated greenhouse project

David W. Jackson

To ensure equitable access to and participation in K-12 computation, scholars are working to embed computation in required courses for science, technology, engineering, and mathematics (STEM; Cateté et al., 2018; Lee et al., 2020; Vogel et al., 2017). While progress has been made, studies tend to focus on cognitive outcomes in monodisciplinary settings; more work is needed around affective outcomes in interdisciplinary or pluridisciplinary settings, especially for the sensitive period of young adolescence (Cateté et al., 2018; Jackson et al., 2022). Previous studies have focused on deep analysis of student *engagement* in a *single* iteration (e.g., Jackson et al., 2022); the current study considers student *interest* across *four* iterations. This study addresses the research questions, (1) In what ways did four iterations of an automated greenhouse project support student interest, within and across disciplines of computation, engineering, science, and technology?; (2) How were learning activities related to student interest?; and (3) How were knowledge and attitudes of both students and teachers related to student interest?

The research team of the Innovation in Urban Science Education lab (IUSE lab) at Boston College partnered with an urban-ring public school district in the Northeast US that we call "Mills City Public Schools". For four out of five years from 2018-2022, our research-practice partnership took a *social psychology* approach to design-based research (Bell, 2004), with professional development, co-design, and co-implementation of an eighth-grade automated tabletop greenhouse project, which we call the "smart greenhouse project". On average about 200 students per year participated in the project, and were diverse in terms of race and ethnicity, gender, culture and language, and socioeconomic status (e.g., about 45% students of color; 49% female, 49% male, and 2% identifying as non-binary; 50% speaking multiple languages at home; 35% classified as economically disadvantaged). The current phenomenological qualitative case study (Creswell, 2013) looks at lived experiences of both students and teachers. Data sources included representative sampling (Creswell, 2013) of mid- and post-interviews from the two teachers who most consistently participated at each of two middle schools, namely "Mr. Meloney" (2018, 2019, and 2022) and "Ms. Kade" (2021 and 2022). Our first round of coding was deductive per the four phases of interest from Hidi and Renninger (2006), the four major disciplines in the project (science, technology, engineering, and computing), and the 18 design considerations of its social infrastructure (Bielaczyc, 2006), alongside inductive coding. The second round of coding looked for trends and connections within and amongst the first-round codes, or *pattern* and *axial* coding, respectively (Saldaña, 2009).

The research team's analyses resulted in five themes across the four iterations of design-based research for the smart greenhouse project, of which we present three due to space constraints. Firstly, we found evidence of development of interest (Hidi & Renninger, 2006) that was flexible due to the pluridisciplinary nature of the project. For example, teachers emphasized technology such as LED light strips that stimulated triggered situational interest; teachers incorporated biology such as plant growth and environmental conditions, which supported maintained situational interest; teachers scaffolded experiences with computation, especially extra "challenge" activities or open-ended explorations, to foster emerging individual interest; and teachers sought to prime students for well-developed individual interest through recommendations of future clubs, camps, and classes. Secondly, we noticed teachers evolving in their adaptations of *the planned learning activities*, as well as the *social identities* and *participant structures* (Bielaczyc, 2006) of both themselves and the students. For instance, teachers grew in their repertoires for scaffolding of activities depending on students' prior and current experiences. In other words, over time teachers improved in their adjustments for students who initially had more coding proficiency *and* for students who mostly developed their proficiency during the project. Thirdly, we saw troubleshooting as a practice that could stimulate *or* stifle development of interest, depending on identities and participation of students and teachers. In general, students who had greater internal confidence and external encouragement tended to persist through troubleshooting their code, while the inverse also tended to be true. However, there were some exceptions to those trends, which teachers endorsed as a counterbalance to what they observed in their monodisciplinary science units (e.g., students who previously succeeded solving well-defined problems got needed practice in addressing ill-defined problems).

Our study confirms and extends much of the extant scholarly literature on embedding computation in required STEM courses. Honoring the tradition of research at the high-school level, our work highlights educational design considerations (Bielaczyc, 2006) that are most salient for the sensitive period of middle-school (Cateté et al., 2018). Rooted in cognitively intensive activities, and combining them with more affective concepts like social identities and more behavioral concepts like participant structures, we extend understandings toward more holistic conceptions of learning. In sum, our work has implications for the support of developing student interest in computing through required classes, using pluridisciplinary approaches to give each student and all students, in the words of Mr. Meloney, "a reason to do the coding".

Integrating math and science through CT in a 6th grade curriculum

Aditi Wagh, Emma Anderson, & Irene Lee

The development of reasoning about scientific processes relies heavily upon representational resources from mathematics (Weinberg, 2017). Mathematics underpins the computational modeling of scientific processes (Wilkerson & Fenwick, 2017). In other words, translating a target phenomenon of a scientific process into computational representations involves sense making of components/elements/concepts related to mathematics, science and computational thinking. The Making Sense of Models (MSM) project designed and tested an interdisciplinary curriculum that bridges Math and Earth Science through interactions with computer models of scientific phenomena. Our goal is to examine how attending explicitly to the links between math and science when negotiating the relationship between phenomena and their target computer models can impact student learning of math, science and computational thinking. The unit, "It's Getting Hot in Here", invited students to draw on their everyday lived experiences of hot summers in the Southwestern region of the United States; to conduct a physical experiment to measure the temperature of differently colored surfaces exposed to sunlight; to explore and manipulate the code embedding the cause and effect mechanism of an object's behavior upon collision with a surface within a math context; then to apply their understanding of that mechanism when reading and analyzing coded procedures in a scientific model of reflectance and absorption in solar heat gain. These experiences connect concepts in math and science to students' lives and environmental concerns.

In this paper, we report on the design of this unit and implementation of the unit in two 6th grade classrooms in the southwestern US. Our study examines whether and how this interdisciplinary approach contributes to students' understanding of science, math, and computational thinking as discrete yet connected subjects, as well as their ability to find and fix errors in coded representations of scientific processes. Data collected include pre- and post-surveys, classroom observations, and student interviews. We found that when fixing errors in a computer model, students run the model to produce a simulation, notice discrepancies, then interpret the math and science in the code, and reason about how to fix it. Encountering and fixing errors in models provides students opportunities to apply their understanding of the focal phenomenon and the mathematical and scientific bases of mechanisms that generate the phenomenon. The findings from this study contribute to research on how CT may support students' reasoning about scientific processes.

Assessment in interdisciplinary CS/ELA: Rhetorical analysis of student-produced computational texts

Chris Proctor

The US has made substantial progress over the past decade toward the goal of universal K-12 computing education, including state policy, curriculum standards, teacher preparation, and teacher professional development (Yadav et al., 2021). Following this progress, there is increasing interest in K-12 interdisciplinary computing, for principled reasons (e.g., literacy across the curriculum) as well as practical reasons (e.g., the difficulty of adding computer science coursework to full school schedules and the lack of qualified teachers). Unfortunately, many proposals for interdisciplinary computing pay more attention to epistemologies and learning goals in computing (computational thinking, CT) than to those of other disciplines. One common pattern – mapping problems from a non-computing domain into privileged computational representations – is exemplified in Wing's (2006) vision of a future in which other subjects are improved by turning them into computer science: "Computational thinking will have become ingrained in everyone's lives…when trees are drawn upside down" (p. 34).

In this paper, I specifically consider interdisciplinary computing in the context of English/Language Arts (ELA). Assessment practices drive pedagogy (Eisenhart, Finkel, & Marion, 1996), so I develop an approach to assessing student-produced computational artifacts that supports the assessment of CT while being grounded in epistemologies central to ELA. A literacy-based approach to computing would value the skills and knowledge required for effective programming, debugging, and reasoning about computational problems, but as prerequisites to participation in a computationally-mediated society, rather than as ends in themselves (Kafai & Proctor, 2021). If we want to support and assess students' CT development from a literacy perspective, where the terms of quality are themselves normative and community-defined, we need a way of understanding students' work in terms of the audience for which they were produced. This approach is likely to yield approaches to interdisciplinary computing which are more palatable to ELA educators, while also developing a more productive account of interdisciplinary epistemic practices drawing on CT and literary criticism.

This study presents several case studies analyzing student meaning-making in the context of interactive storytelling (Proctor & Garcia, 2020) using a programming language which offers affordances of both literary prose and code. These case studies were selected from a ten-week unit using interactive storytelling in a sixth-grade computer science classroom of a small city in the US midwest. I use a method of rhetorical analysis developed by Proctor and Blikstein (2019), which extends reader-response literary theory (Rosenblatt, 1968) to computational artifacts. Stories are qualitatively coded along four dimensions: (1) how they take up literary and computational affordances (e.g., characterization, point of view, manipulating state, manipulating of the story's graph structure); (2) rhetorical modes of meaning-making (e.g., suspense, granting or withholding agency, directing the reader's empathy); (3) figured meanings (e.g., school, the city, violence, gender); and (4) criticality (e.g., identity authorship, voice, worlding). Tracing the co-occurrence of codes across these four dimensions illustrates how the hybrid text-code medium supports emergent forms of social meaning-making, ultimately creating new opportunities for participants to discuss and reinterpret important experiences from in and out of school. For example, authors used emoji and SMS speech bubbles to model identities and discourse dynamics from text message communication; they combined first-person narration with nonlinear story structures to destabilize the idea of a unified sense of self; and they structured the user interface to strategically grant and withhold agency from the player to explore ideas of guilt, shame, and regret.

These case studies illustrate some of the ways in which CT learning and digital rhetoric can be mutually-supportive and point toward open-ended pedagogies of computational literacy in which we interpret the meanings of student-produced computational artifacts, rather than scouring them for expected representations of CT learning. The case studies ground a broader analysis of the 578 stories written by 49 study participants during the study, which will document the diffusion of practices through the classroom community as well as the emergence of genres and audiences that make room for new identities and voices.

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Reimagining the Future of Teaching and Learning Using Black Feminist-Womanist Storytelling Methodologies

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Abstract: In this symposium, four Black women learning scientists use Black feminist-womanist storytelling as an approach for restorying the future of education. Through sharing past and present learning and teaching experiences, each researcher will interrogate dominant narratives that often marginalize Black girls and women throughout their learning trajectories. Resisting these narratives, they will draw from missing or silenced perspectives to reimagine more liberatory futures for learners at the intersection of multiple systems of oppression. Through analyzing and theorizing their stories, the discussant (another Black woman education researcher) will review overarching themes across each story to demonstrate how centering the knowledge, experiences, and practices of Black women and girls offers unique epistemologies and methodologies for transforming education.

> *“Remember to imagine and craft the worlds you cannot live without, just as you dismantle the ones you cannot live within.” - Ruha Benjamin.*

Session summary

In this symposium, four Black women learning scientists use Black feminist-womanist storytelling as an approach for restorying the future of teaching and learning. Baker-Bell (2017) defined Black feminist-womanist storytelling as a methodology that blends autoethnography, Black women’s language and literacy practices, Black feminist and womanist theories, and storytelling to “create an approach that provides Black women with a method for collecting our stories, writing our stories, analyzing our stories, and theorizing our stories at the same time as healing from them” (p. 531). As opposed to foregrounding educational designs or empirical study, this symposium centers Black women’s collective storytelling as a method for not only addressing educational injustices, but also draws on their unique knowledge and histories of resistance to reimagine possible liberatory and dignifying futures.

Objectives of the session

The objectives of this symposium are to address the role narratives and everyday storytelling play in upholding oppressive power structures in educational spaces. As articulated by De Fina and Georgakopoulou (2012), narratives can act as “sites for the imposition of forms of domination by powerful individuals and institutions” and are “used to negotiate new roles and norms by members of society” (p. xii). Within learning environments in particular, learners employ narratives—which include sociohistorical and social constructs such as race, gender, and class (Nasir & Shah, 2011; Leyva, 2016)—to better make sense of themselves and others (Gresalfi & Hand, 2019). This symposium aims to leverage an intersectional praxis, Black feminist-womanist storytelling, to address the presence and impact of narratives in the experiences of learners, specifically Black girls and women. Through engaging in restorying practices (Stornaiuolo & Thomas, 2018), this symposium will demonstrate how collective storytelling rooted in Black feminist/womanist theories can become a site not for the imposition of domination, but for healing and transformation.

Significance of the session

While there has been recent enthusiasm within the learning sciences community for speculative approaches to education that critique intertwining systems of oppression, there also exists the need for innovative methodologies for creating speculative yet equitable learning environments within the field. Such methodologies would provide researchers with tools for not only examining our pasts and presents but also tools for imagining possible futures, particularly in the context of teaching and learning. As a qualitative method, autoethnography through Black feminist-womanist storytelling allows us as researchers to use our personal experiences to “describe and critique cultural beliefs, practices, and experiences” while also using deep reflexivity to “name and interrogate intersections between self and society, the particular, the general, the personal, and the political” (Adams, Holman

Jones, & Ellis, 2014, pp. 1-2). In this session, we combine autoethnography with the speculative literacy practice of restorying.

With deep roots in narrative scholarship (i.e., Clandinin & Connelly, 2000; Clandinin, 2006), restorying describes the ways marginalized communities reread and rewrite the world (Thomas & Stornaiuolo, 2016). Recent configurations offer youth of Color a conscious process for analyzing present and past realities to reimagine more just futures (Shaw & Kafai, 2020). Rooted in critical race theory, restorying offers a framework for collecting the stories of marginalized people through counternarratives, or narratives that present alternatives to dominant perspectives (Cooks & Dixson, 2013). Such a process involves educators and youth presenting the realities of their everyday worlds, situating those realities within historical practice and current discourses, and telling stories from missing or silenced perspectives to imagine alternate futures (Stornaiuolo & Thomas, 2018). Interrogating and reimagining dominant narratives about education—which can act as grand stories or myths that connect to broader societal ideologies, imaginaries, and stereotypes (e.g., Gresalfi & Hand, 2019)—not only reveals whose knowledge, experiences, and interests are most centered but also whose perspectives are most often less visible.

Evans-Winter and Esposito (2010) stated, “Girls of African descent are at the bottom of the social totem pole in society; thus, there is an urgent need for a theoretical framework that serves to expose, confront and eradicate race, class and gender oppression in our families, communities and schools” (p. 22). Black feminist and womanist epistemologies illuminate how the intersections of race, gender, sexuality, and class inform one another and assume that they cannot be analyzed as disparate phenomena (Baker-Bell, 2017; Collins, 1997). These ways of knowing recognize Black women as knowers and producers of knowledge and practices that are distinct from other groups based on their social position of being Black women. It is the group consciousness that comes from Black women’s historical position at the nexus of raced, gendered, and classed liminality that provides deep insight about the workings of structural power, privilege, and oppression (Collins, 1997). We are learning scientists who work towards creating expansive learning communities where Black women and girls can thrive. Therefore, we push back on dominant, White, cis-het-patriarchal perspectives that too often constitute conventional knowledge about educational practice. We leverage Black feminist and womanist epistemologies because “the existence of a self-defined Black women’s standpoint using Black feminist epistemology calls into question the content of what currently passes as truth and simultaneously challenges the process of arriving at that truth” (Collins, 2002, p. 221).

Weaved throughout the narratives of Black women writers like Octavia Butler, Toni Morrison, and Zora Neale Hurston exist a demand for the “seeing and knowing of Black girls and women’s lives in varied and heterogenous ways while at the same time calling for a collective vision and aspiration for their humanity” (Muhammad & Haddix, 2016, p. 303). We see significance in integrating Black women’s everyday knowledge, experiences, and histories as a theoretical contribution for addressing intersectional forms of oppression in education and the study of human learning. Not only does storytelling reflect one of Black women and girl’s most powerful language and literacy practices, but it also functions as a vehicle for Black women and girls to transmit our unique knowledge of the world in hopes that our narratives can promote societal change, as well as self- and communal healing (Baker-Bell, 2017; Richardson, 2003). This symposium offers restorying through Black feminist/womanist epistemologies as a framework for engaging researchers in critical race methodology—which offers researchers a space and the tools to challenge multiple systems of oppression by grounding research in the experiences of and knowledge of people of Color (Solórzano & Yosso, 2022.

Structure of the session

After a brief introduction by the chair to the theme and focus of the symposium, participants will be polled on whether they recognize the five dominant narratives from each presenter, which are displayed on the screen one at a time. Participants are then given ten minutes to reflect on and share a dominant, taken-for-granted narrative that creates a tension in the work that they do via another poll. Afterwards, each presenter will give a seven-minute story in which they share about their educational pasts and presents as Black women and girls and how they connect these experiences to their current work in reimagining the future of teaching and learning. Weaving in her own insights and experiences about teaching and learning as a Black woman, our discussant will review overarching themes and address the following research questions: (1) How might collecting, analyzing, and telling our educational stories provide Black women learning scientists the space for reimagining alternative futures for education and healing? (2) In efforts towards a more just future, what can the learning sciences research community learn from centering the knowledge, experiences, and practices of Black women? We will then open the symposium to Q&A with the audience.

Being soft and vulnerable makes you weak

Mia S. Shaw

For as long as I can remember, my family has described me as “soft” and “sensitive.” While I knew soft was a desired attribute when describing moisturized skin or mashed potatoes, growing up I perceived it as a character flaw when it came to succeeding in the real world. Having grown up in racist towns in the South and New England, my parents educated me about the insidious forms of racism I was experiencing throughout my private, religious schooling and taught me to remain strong in the face of challenges—lest I would be taken advantage of. When I was a child and teenager, I believed that strength came in the form of proving others wrong (in this case, it was my racist teachers and peers) about my abilities and hiding when I needed help. So even when I struggled emotionally throughout high school and college, I learned to redirect my pain into my academics and my work, wearing the badge of a “strong, Black woman,” one who was not “soft” and did not need anyone’s help.

Unlike visibly harmful stereotypes like the jezebel or mammy, the trope of the strong Black woman recharacterizes us as superhuman and immune to pain or suffering (Wyatt, 2008; Collins, 2000). In my case, I developed a habit throughout undergrad and my first years teaching of putting on a brave, level-headed face and not reaching out for help, despite my unawareness that I was struggling with anxiety and depression. My Black, Christian upbringing did not encourage therapy or sharing one’s issues and vulnerabilities with others outside of family, but when I observed my students struggling with similar issues, my approach as an educator shifted to one that emphasized care. Further, I became motivated to design learning environments that allowed Black and Brown youth to bring their full selves to the learning process, as well as reframe teaching and learning as a site for community and belonging. Growing up, education was a competitive endeavor, and to succeed financially in fields like medicine, I needed to learn how to be the best and the best “never lets others see them sweat.” However, I now see education as what bell hooks (1994) calls “the practice of freedom” and designing the worlds and relationships we want with each other—ones that allowed us to be whole and allowed us to be soft.

Anger isn’t ‘appropriate’ for classroom learning

Aireale J. Rodgers

> *“To my sisters of Color who like me still tremble their rage under harness, who sometimes question the expression of our rage as useless and disruptive…I want to speak about anger, my anger, and what I have learned from my travels through its dominions”* (Lorde, 1984, para 15).

From a young age, I was always confused about whether and how to express my emotions. My mother always kept her feelings concealed, like cards close to her chest. As I reflected on how I was socialized to act in schooling settings—both by educators and my most beloved family—I realized how large a role emotion management has played. In fact, it has been a deeply formative part of the hidden curriculum. As Black women and girls navigate formal schooling, we are often made keenly aware of the dangers of falling into the ‘angry Black woman’ stereotype. I learned that my emotions didn’t matter as much as others’ comfort. Surely, as a fat Black woman, any anger I felt had no place in the classroom and compromised my standing with my colleagues.

But the anger never went away. Instead, it has intensified over time. The more I was exposed to the inequities and violence embedded in educational policy and practice, the angrier I have become. I have tried to swallow the anger. I have tried to translate it into niceties. I have tried to make my anger palatable and deliver it with a smile. Ultimately, I treated my anger as anything other than what it was. I betrayed my anger, and it became grief.

Everything changed for me when I read Audre Lorde’s (1984) *The Uses of Anger: Women Responding to Racism.* I began to understand that my anger was not a liability. When I embrace my anger intentionally and meaningfully, it can be a powerful catalyst for transformative change in the world. My anger reminds me that I am neither despondent nor numb, and it calls me to act in ways that squash injustice and create something different. In this way, I have learned that anger can be pedagogical—an intellectual resource available to us. For example, I often ask students “how do you *feel* about what we are learning together? What is your anger teaching you?” Scholars in the learning sciences have recently pointed to the importance of emotions (e.g., Curnow & Vea, 2020; Vea, 2020), specifically anger and rage (e.g., Curnow et al., 2020), in learning. I work towards the cultivation of learning spaces where Black women and girls can bring their full selves—including their anger—to their learning and value it as a resource.

Separate yourself from your Blackness to be successful in academics and in life

Naomi Thompson

I didn’t have a Black teacher until college (see Madkins, 2011, for a discussion of the history of the Black teacher shortage). That didn’t mean I didn’t think Black people could be smart—I thought my mom and dad were smart. My dad’s job in telecommunications was so obscure and technical that my sisters and I just decided he was actually a spy and made up stories about his job to keep us off the scent. Sometimes we still think that. I knew my maternal grandmother had been a teacher in Jamaica. She lived with us while I was growing up, and she used to take me on walks around the neighborhood and quiz me on my multiplication tables. I imagine her spirit frowning (and laughing) every time I use a calculator to double-check 7 x 8. I still believe my mom is both the smartest and prettiest woman on the planet, I will not be taking questions about that at this time. So I knew Black people could be smart, could be teachers, could be engineers.

But even at home, that truth came with caveats. To this day, my mom tells stories about the Jamaican patois she sometimes spoke with friends but could never use at home lest she face the wrath of her own mother. They were proper Jamaicans who spoke proper English, nothing else was acceptable (Green, 2006). Similarly, I didn’t grow up speaking patois, or AAVE, or any dialect other than midwestern (white?) English. The very few other Black students at my school clocked that immediately. They teased me, asking why I talked like a white person? Surely at least one of my parents was white? No? Then why were we so different? I had no answer. I told my parents I was being teased at school. They told the school counselor I was being bullied. I also didn’t have a Black friend until college.

Of course, I know now that there are infinite ways to be Black, and that those students and I were both acting within a white supremacist system that wanted to constrain us, to make us smaller, to keep us apart (e.g., Shaw-Taylor & Tuch, 2007). But I didn’t have the language for that then. I continued to succeed in school, with no Black classmates in my honors or AP classes, no Black teachers, and no examples of what it might mean to hold my Blackness close, to let it take up space, to make me bigger. I made it through, but I have a lot to (re/un)learn. Today, I am lucky enough to bask in the presence of Black women and femme scholars, in my professional network and in my new home. I’m still figuring out how to let my Blackness take up more space in my research, but I’ve started by looking for examples and clinging to them. I have so many Black teacher.

“Maybe you’re not cut out for engineering”

Ti’Era Worsley

Learning opportunities are informed by one’s connections to specific places. How we come to know places is by the experiences that we associate with them; however, experiences are not static and can be (re)edited individually (Ma & Munter, 2014). Those experiences determine connections developed and can be informed by space/time spent in a place, types of learning that occur, or physical/mental boundaries. As I reflect on my own upbringing and experiences as an undergraduate in mechanical engineering, I wonder what the possibilities could have been if I had educators who created learning opportunities for me to engage in STEM in varied ways. As an informal STEM educator to predominantly Black youth within a Boys and Girls Club, I often reflect on how and who I want to be for youth. My pedagogical practices are in direct correlation to what I needed for myself during my upbringing. While I cannot revisit my childhood, I make it my goal to create spaces where youth have the supports they need.

When I was an undergraduate I was so excited, especially as a first-generation college student, to make myself and my family proud. However, within my second year, I struggled with a physics course. I was too resilient to give up so I searched for opportunities to overcome my struggle with passing the physics course. I spoke with the undergraduate advisor to see what resources were available and without a second glance, she said “If you can’t hack physics then you can’t hack engineering, so look into something else.” In that moment I felt that my career was being taken from me before I even started. *What was I supposed to do?* was the only thought that ran through my head. My mom encouraged me to look at other majors and said “you only fail if you give up.” After speaking with the coordinator of advising for the engineering department, I found a major that fit my interests and immediately switched. When I think back to this interaction, I realized that I was not as affected by switching my major. What stuck with me was how the conversation with the mechanical engineering undergraduate advisor left me feeling so dehumanized and belittled.

Because of this, I make it my priority to reauthor spaces for the Black youth I currently work with. I work to create space and community for them and myself. Almost as a form of self-healing, alongside these youth, I too, am provided learning opportunities to continue my own exploration of STEM. As a Black woman who loves to tinker, teach STEM in non-traditional ways, and discover my own rightful presence in STEM and STEM education, I work hard to ensure that the youth I work with and myself feel humanized when engaging in STEM. Instead of taking a deficit approach to determine who is able to engage and be a part of STEM, I disrupt the power dynamic to support youth in seeing themselves as doers of STEM

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Lifespans of Civic Engagement: Imagining and Enacting Justice-Centered Civic Learning Trajectories

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Abstract: This symposium widens the lens on "what counts" as civic engagement to include social movements, acts of dissent, and counter-narratives that center the voices and rights of BIPOC youth and elders, people without homes, and immigrants. The authors all share a commitment to learning that moves beyond the walls of a classroom, from immigrants members of decision-making bodies across the state of Oregon; to the streets and sidewalks of Seattle neighborhoods, to libraries and community walks in the Southeastern US; to the online political engagement of BIPOC undergraduate students during the 2021-2022 school year; and finally to an out of school design-build program for Black and Brown high-school-age girls of color. By bringing together these myriad learning environments in one symposium, we emphasize how civic learning trajectories are best supported by a diversity of settings which mutually reinforce individuals' and collective agencies, interests, and civic opportunities.

Focus of the symposium

Normative notions of "civics" in the United States assume all people have legitimate and equal rights to participation in public discourse (Mirra & Garcia, 2017) and place-making (Taylor et al., 2018). However, who (and what) counts as having rights has been constructed within the historical context of a nation developed on the enslavement of Black people, the land dispossession and attempted genocide of Indigenous Peoples, and the global militarization of predominantly Asian and Latin American countries (e.g., Mojab & Carpenter, 2011). Our symposium widens the lens on "what counts" as civic engagement to include social movements, acts of dissent, and counter-narratives that center the voices and rights of BIPOC youth and elders, people without homes, and immigrants. This parallax on civic engagement necessarily holds White folks and systems of White supremacy accountable for committing and upholding inequities and injustices across public spaces of learning (e.g., classrooms, parks, libraries, neighborhoods, online forums); what learning "interventions" do White people require to become better citizens? We believe seeing this version of civics and civic engagement anew could catalyze material redistributions of resources (a.k.a. wealth) to communities of historical disenfranchisement.

Education plays a crucial role in this new vision of civic engagement and development (Dabach et al., 2018)—particularly if education is understood expansively, as "a social process and function (that) has no definite meaning until we define the kind of society we have in mind" (Dewey, 2004 p. 93). Our imaginaries of society – heterogeneous (e.g., Rosebery et al., 2010), more equitable (studies cited in this symposium), and caring (Uttamchandani, 2021) – shape learning contexts that focus on civic engagement and responsibility. This learning, we argue, includes a diversity of practices that are life-long, life-wide, and life-deep (Banks et al., 2007).

Understanding trajectories of civic engagement through resistance efforts within the Learning Sciences can be traced to reimagining Chicago public schools for Black students (Lee, 1992); reimagining migrant intellectual citizenship in the University (Gutiérrez et al., 2009); organizing grassroot political campaigns with multiracial young people (Kirshner, 2008); BIPOC youth engaging city planners in reimagining transportation routes (Taylor & Hall, 2013); and creating solidarities in the march for science (Bang et al., 2018). These acts of civic organizing worked at the edges of school contexts or through community-led efforts to support greater justice for BIPOC youth and communities. Building on this work in the Learning Sciences, Jurow and Shea (2015) developed an argument for the field to expand notions of learning by studying social movements where community members were organizing for greater justice within their neighborhood. These efforts support a movement within the field to see sites of civic resistance or social movements "as productive sites where people work together to critique, re-imagine, strategize, and re-make how we can engage with one another now and in the future" (Curnow & Jurow, 2021, p. 14). Learning and civic engagement recast through social movement organizing allow the field to theorize learning with the efforts of immigrants engaged in participatory budgeting (Meléndez, 2021), youth activism both in South Africa (Tivaringe & Kirshner, 2021) and in US LGBTQ+ youth groups (Uttamchandani, 2021), as well as with migrant women intervening for human rights in Japan (Takeuchi & Ishihara, 2021). In these examples, the range of ages, the central organizers for learning, and the contexts for where learning takes place all offer the potential to reimagine civic learning to be based on heterogeneity, equity, and care. This symposium furthers these efforts by attending to a wider scope of practices that "count" as civic engagement and developing our collective imagination for how resistance and counter-narratives offer new possibilities for understanding civic learning.

Our session interrogates processes that privilege and reproduce certain kinds of civic engagement, while foregrounding techniques to unsettle the status quo (including processes to define "civic engagement"), opening new possibilities to develop a more just society. The authors all share a commitment to learning that moves beyond the walls of a classroom, from immigrant members of decision-making bodies' across the state of Oregon; to the streets and sidewalks of Seattle neighborhoods, to libraries and community walks in the Southeastern US; to the online political engagement of BIPOC undergraduate students during the 2021-2022 school year; and finally to an out of school design-build program for Black and Brown high-school-age girls of color. By bringing together these myriad learning environments in one symposium, we emphasize how civic learning trajectories are best supported by a diversity of settings which mutually reinforce individuals' and collective agencies, interests, and civic opportunities (Ito et al., 2015). Through this dialogue we invite learning scientists to ask how existing or developing learning environments support or constrain intersectional civic identities across generations and settings, and to develop design principles which could help forge supportive civic learning trajectories, particularly with historically marginalized people to disrupt White hegemony. In this way, we hope learning scientists can participate in these trajectories so we, as a society, can live up to our ideals of justice and equity.

Themes explored by the collective work

Trajectories that best support civic engagement in its multi-dimensional complexity

The global *reflexive turn of citizenship* began in the 1970s and 1980s, as communities that had previously been excluded from civic forms of participation started demanding recognition in response to social, political, and economic turmoil (Ellison, 1997, p. 698). "This resulted in expanded citizenship, civic identity, and public participation in civil society, and participants previously barred from making claims to democratic activity began to voice their needs as rights" (Meléndez, 2021, p.3). In the United States, this reflexive turn of citizenship has been taken up in the literature on cultural citizenship, becoming associated with "the process of claiming space and rights" (Flores, 2003, p. 89). This formulation has been especially meaningful in developing the identities of communities that have traditionally been excluded—either legally or socially—from state-sponsored forms of citizenship (Appadurai, 2001; Dabach, 2015; Ellison, 1997). Therefore, by centering underrepresented groups in public-sphere activities, such as the ones highlighted in this symposium's papers, the conversation around important issues expands, creating the potential for more informal and local modes of civic engagement to happen and take their rightful place in the civic engagement landscape.

Political and civic imaginaries to reconceptualize society and develop practices and identities of civic engagement

Imaginaries are ways to see the past, present, and future, connecting individual or collective historical experiences with new insights that transcend previously understood structural restrictions with expansive possibilities for new ways of action and being (Gutiérrez & Calabrese Barton, 2015). Through imaginaries, participants become "*historical actors* who can become designers of their own futures" (Gutiérrez & Jurow, 2016, p. 3). The participants in the various papers in this symposium move towards imagining or social dreaming (Freire, 1972) as a step towards *conscientizacion*, (1973). The process of "acquiring critical consciousness and becoming political subjects" (Flores, 2003, p. 93) mediates the "political imaginary," of under-represented communities and individuals in the public sphere (Meléndez, 2021). As Meléndez has argued, these are specific types of *citizen imaginaries*, where individuals move into a position of critically questioning what is possible in relation to structural and institutional limitations. This symposium highlights the role of heterogeneous, equitable, and caring imaginaries; for if democratic ideals are to be actualized or embodied, civic spaces—whether created for, by, or with—people from underrepresented communities, these spaces must be intentionally designed and actualized for said communities to sustain agency over their participation.

Consequential learning: Developing an identity in practice while serving on decision-making bodies across the state of Oregon

José W Meléndez

The use of public decision-making bodies to inform policymakers is common governance practice in the U.S. (Bryson et al., 2013). Whether required by law or as a strategy for both gathering information and securing public buy-in around decisions that impact communities directly (Ibid), these bodies should be representative of the demographic makeup of their communities. Yet, civic engagement by and of immigrants is a contested topic in the public sphere since it challenges normative definitions of citizenship. It raises the fundamental question on what voice immigrants should have in decisions that impact their communities, given that the diversification of who participates holds the potential to alter systems of governance that up to now have been designed to preserve the benefits of White supremacy to more privileged communities. Studying the public involvement of immigrants in decision-making bodies that advise and/or govern across levels of government is a gap in the literature on civic engagement and learning. This paper applies socio-cultural-historical theories of learning (Engeström, & Sannino, 2021; Vygotsky, 2012) to government practices that are idealized in democratic theory.

In this paper, I present findings related to a multi-phased, cross-sectional study entitled, "Oregon's Decision-Making Bodies: Diverse and Equitable Representation" (Meléndez, et. al., 2021). Using a discourse analysis approach, we analyzed 46 interviews of immigrant members on Oregon's decision-making bodies that were conducted between the fall of 2019 and March of 2020. Framing immigrants' board service as a third type of civic engagement, the study created an inventory of members across the 503 bodies at the city, county, and state levels in our study and determined how many self-identified as first-generation or second-generation immigrants. The interview analysis focused on how immigrant participants reflected on what they learned thought participation and what roles they began to take on or were inhibited from doing so while serving on these bodies. I highlight findings related to the development of an identity in practice (Lave, 2012), that supplement and sometimes contradict the findings related to learning of professional development skills and how government works. I argue that through our analysis, I found evidence of what Vygotsky referred to as the *microcosm of consciousness* (Collins, 2011), or an awareness of how one's behaviors are in relation to the environment one is acting in and how they are generatively interrelated. In so doing, I discovered that for participants developing an identity in practice, it was geared towards achieving or changing what they understood the policy purposes (the object of activity) for their respected body was. We discovered that for many participants the object of activity was grounded in concerns over representation and how they could be a representative of and for their community—both within the inner practice of their respective bodies and beyond—that centered on achieving tangible policy changes for their communities.

Analytically, I found that claims related to representation were connected to participants' reported learning and its impact on their participation. Three distinct types of learning were identified: professional development; government; and dispositions. For professional development, participants reported learning how to collaborate, manage processes and differences, and "see the big picture. Across types of bodies, those who discussed learning about local government indicated learning about how resources were distributed and that learning the lifespan of policy development from conception to implementation was instrumental to making sense of their role on the boards. When analyzing how board service changed participants' dispositions, three outcomes emerged: building self-esteem; increasing agency; and enhancing self-efficacy. One participant on the state's Commission on Hispanic Affairs reflected: "As I mentioned in the beginning…we need to be in those spaces. We can't shy away from that—it's happened too many times before. At a minimum … by doing that we enter the record. And we are stating the case."

I argue that in the current political climate, when immigrant enters the public sphere, it is a revolutionary act that confronts normative expectations of who is meant to engage and how. As such, for immigrants sitting on these bodies, their participation helped connect local/cultural civic acts to more explicit political ones along the continuum of civic engagement trajectories by providing the opportunity to develop an identity in practice. Learning how to identify as a commissioner, or a board member, requires citizen imaginaries (Meléndez, 2021), especially for immigrant members in such a racially homogenous state as Oregon, which is so by design given the state's White supremacy history (Tichenor, 2021). Subsequently, the ability to imagine and identify with one's public service role may be a key variable to explaining how sitting on decision-making bodies is in fact a prerequisite experience that many elected officials share (Meléndez et al., 2021). Yet, this "middle type" of civic engagement has received little scholarly attention, particularly in the literature on immigrants. As a form of consequential learning across scales of time and activity systems (Hall & Jurow, 2015), our interview participants wrestled with key concepts of governance, such as representation. What it means to enact representation, both as a practice while serving on decision-making bodies and for their respective communities is a complex question needing further research.

Yet, this study's findings on consequential learning for immigrants serving on these bodies are generative, since each of these decision-making bodies constitute but one activity system within a network of activity systems (Engeström, & Sannino, 2021) that form the backbone of governance in the U.S. Therefore, engagement in any one of these systems holds the potential for immigrant participants to learn about government and the topical content focus of each body (e.g., transportation, budget, education, etc.). Just as critical, they also learn what social identities are validated in practice (Lave, 2012), that can be expanded beyond White rational modes of participation (Meléndez & Hoff, 2022; Renirie & Meléndez, 2022). The findings reported in this paper support the link between participants' identity development and their ability to express those identities meaningfully in deliberative democratic spaces.

Neighborhood visions coalesce in a collaborative filmmaking project

Ari Hock

Civic learning is often conceived as the development of a particular kind of engaged citizen (Hope, 2022). This logic tends to reinforce normative developmental trajectories which locate the impetus of and responsibility for sociopolitical transformation within the individual. In contrast, Gert Biesta suggests a conception of public pedagogy, in which "becoming public *is* the creation of (a) public sphere," (Biesta, 2012, p. 693). This processual, collective understanding is particularly important when considering civic learning related to the interconnected socio-ecological challenges that many cities are facing: rising housing prices, physical and cultural displacement, and environmental racism.

To overcome these complex challenges, learning scientists are looking beyond civic learning as a discipline and seeking to understand the ways in which civic learning is supported, constrained, and accomplished in practice. To that end, some researchers have used ethnographic methods to theorize participatory budgeting meetings as sites for learning (Meléndez, 2021); and have engaged in design research to connect young residents' spatial epistemologies with grid epistemologies employed in planning meetings (Taylor, 2020). Both examples demonstrate how learning scientists can work with community members to design civic infrastructure which fosters better dialogue across stakeholder groups.

The present study, *Visions of Wallingford*, builds on these efforts through a critical place inquiry (Tuck & McKenzie, 2014) in a predominantly White Seattle neighborhood. Wallingford has been a lightning rod for recent debates, with competing interests around historic preservation, affordable housing, and "livability." Community members share a common concern about the rising costs of housing but competing discourses around neighborhood change have manifested (Eliason, 2021; McNichols, 2022). Meanwhile, the infrastructure to support civic engagement around these issues (e.g., civic groups, social media) have proven ineffectual, with many residents reporting feelings of distrust and exhaustion during interviews.

Visions of Wallingford is working to develop civic infrastructure that allows for a public sphere to emerge, by asking how neighbors can learn to create a collaborative place-story (Blood et al., 2012) through a collaborative filmmaking project (e.g., Baumann, Lhaki & Burke, 2020). The author began by conducting in-depth interviews in which participants mapped out personally significant locations. These maps informed themes for a series of guided walking tours (e.g., housing, plants, waterways, mosaic art), in which tour leaders, discussants, and other participants shared their own place-stories. Community members also helped to film the walking tours, content log the footage, and – with the help of a professional editor – assemble it into a documentary film. Throughout the entire process, families, retirees, people experiencing homelessness, construction workers, librarians, and myriad others were engaged as creative collaborators and encouraged to consider their own positionality with respect to the land they inhabit. The author is currently organizing public screenings, during which the film will serve as a catalyst for conversations about the future of the neighborhood.

Videos collected from the walking tours, the film assembly meetings, and the screenings are being treated as resources for data to be interactionally analyzed (Jordan & Henderson, 1995; Jones & Norris, 2005) as well as resources for the ongoing production of the film itself. In this way, the construction of educational theory is a parallel process to the construction of the film. For these dual goals, the project aims to stimulate citizen imaginaries by provoking self-reflection, challenging assumptions, creating beauty, entertaining, and giving pleasure for and with the publics that form throughout (Tobin & Hsueh, 2014).

Emerging findings suggest that participants are learning to see new possibilities with their neighborhood as they establish *polyoptic attunement*, or the multimodal, ecological coordination of attention (Marin & Bang, 2018) as visions are overlaid and hybridized. For example, during one of the film assembly meetings, a resident presented her summary of the plant-themed tour, based on her experience reviewing the footage. She was "kind of disturbed" that parents encouraged their kids to pick fruit from a cherry tree growing in a traffic circle, "but there wasn't any mention of, oh, somebody planted this tree." Another member at the meeting—who had been on that tour—responded, "I feel like I pay attention to that stuff. And I never even thought about that." This exchange led to a group visualization of possibilities for community care among humans and more-than-human life. In this instance, participants achieved polyoptic attunement as they engaged in public pedagogy.

Visions of Wallingford disrupts institutionalized civic engagement processes, which tend to perpetuate inequitable resource allocation in neighborhoods by amplifying voices of those with the material and identity resources which afford fuller participation (Fraser, 1990). Community members of different identities and ideologies engage in moments of dialogue, debate, and negotiation (Forester, 2012). In doing so, visions coalesce in both the film and throughout the filmmaking process, as the neighborhood expresses new possibilities for development. The project invites those interested in creating justice-oriented learning environments to similarly imagine how shared creative endeavors could stimulate new conversations and thinking about the challenges and opportunities that are closest to home.

Undoing acts of historical erasure: Breaking from dominant frames of White supremacy as civic engagement

Katie Headrick Taylor

Undoing acts of historical erasure is a form of civic engagement in which, especially White young people and adults, rarely participate. Instead, civics and social studies curricula (e.g., Sabzalian, Shear, & Snyder, 2021), as well as public spaces, too often *perpetuate* the historical erasure of Black, Indigenous, and People of Color in accounts of community and national development. How, then, might interactions and digitally mediated learning activities, that are intergenerational, interracial, and interinstitutional (e.g., public schools, public library, liberal arts college, and city government), restore/re-story the heterogeneity and pain of how places came to be? What new modes of community engagement are revealed and legitimated from such a learning context?

In a community-based project called Off the Map (OtM), mostly White high school students worked with Black and White retirees, librarians, and teachers to uncover and digitally preserve stories of school desegregation in an area of the Southeastern United States (Taylor, 2022). In the process, Black retirees described their memories of being made to attend all-White high schools and colleges; White retirees described their memories of being in schools with (very few) Black students. Present day high schoolers asked questions and documented these conversations for thematic leads into the public library's local archives. Synthesizing conversations and archival research, as well as observations from guided walking tours, young people created digital place-stories (Blood et al., 2012) for other residents of the area to experience via their mobile devices.

In this study, I begin with a grounded theoretical understanding that breaking from and reimagining dominant frames of White supremacy requires (predominantly White) people learning across lines of difference, be they racial, generational, gendered, and/or socioeconomic. Looking at video data and student-created artifacts, I used methods of video-based interaction analysis (e.g., Derry et al., 2010), as well as multimodal discourse analysis (e.g., Norris, 2004). These analytic methods further supported an interest in representational forms like mapping and app design: how do available tools and technologies also perpetuate the myth of a "single story" (Adichie, 2009)? The analysis followed the contestation, negotiation, and (re)construction of place-stories across the lifespan of the project (approximately six weeks).

Conversations with retirees represented for White students the first step toward undoing acts of historical erasure, especially in regards to students' preconceptions about the benevolence of school-based racial integration. In response to White students' provocations that "being able to attend [their] high school," must have been an "amazing opportunity" for Black students of the 1960s, Black retirees countered; they described being one of four or five Black teenagers in White high schools in the 1960s as "preparation for battle in Vietnam," "isolating," and learning that the "anticipation of violence can cause more stress than the actual violence does." White retirees described willfully ignoring the presence of Black peers in their high schools, downplaying any threat of violence remembered by Black elders. These exchanges unearthed so much pain, embarrassment, and outrage that one retiree said, "nobody wanted to talk about it."

Currently, some White students received alternate accounts of school desegregation as not just "acts of dissent" in the service of a community project, but—perhaps for the first time—a centering of being a Black person in a predominantly White community that has until recently only told (and taught) stories of White people in the curricula of civics and public space. Their digital place-stories represent a first attempt at circulating for public comment accounts of community development that acknowledge heterogeneity, violence, and pain. In this way, this project invites us to consider if civic engagement for White people might be about divesting from the myth of the “single story” and grasping stories about a nation “founded upon a triumvirate of horrors” (Castillo, 2022; p. 100).

Educating, coming out, and bringing hope: The online sociopolitical lives of undergraduate BIPOC youth

Molly Shea, Emma Elliott, & Christina Guevara

This study explores the intersection of learning, civic engagement, and wellbeing for eight undergraduate students during the 2021-2022 school year, which took place during an ongoing racial reckoning, a global pandemic, and online schooling. Thus, this study explored how students narrated their civic engagement and its relationship to their well-being during a heightened socio-political moment. Undergraduates in our study used social media to expand their understanding of themselves, create communities to support school-related struggles, and refigured their social media communities to better support their wellbeing. We found that young people were engaged in a political education online and in-person (through protests and community care actions) that shaped their understanding of the political moment and had implications for their sense of wellbeing.

This year-long, mixed methods study involved the development of a survey on students’ overall wellbeing and learning in an undergraduate lecture course (n=98). From the respondents we selected 8 participants and conducted 3 hour-long, semi-structured interviews with each participant throughout the year. We selected interview participants with a purposeful sampling strategy (Merriam, 2009). Preference was given to students from historically underrepresented communities and/or students who reported the largest changes in stress levels. Sample interview questions included, “How are you maintaining your health and well-being during this time?”, “How is your chosen community supporting you?”, and “How did your civic engagement detract from, support, or expand your sense of wellbeing?”. We then coded for themes and conducted a grounded analysis of how wellbeing, civic engagement, and learning informed one another.

We found that students engaged in online communities to teach, mentor and support others who may have been struggling with their sense of belonging in college settings. These activities were often done as part of a voluntary engagement with social media and took place outside of incentives from college coursework. For example, Sherria, a biracial Black student who grew up in predominantly White communities, was engaged in several in-person protests and helped create mutual aid pages for those in need. However, the activity she spent the most time supporting was using social media to educate people about racism. Here is one excerpt from our first of three interviews where she discussed taking action on a topic she cared about:

> I went to protests, but my biggest impact... was having... probably 100 conversations with people [online] over the past year about racism and how it impacts me and my family... educating people or trying to educate people sometimes just having like straight up arguments with people who I was close with but are no longer friends with... I'm having those hard conversations.

These “hard conversations” were taxing, and in her next interview, Sherria shared how she ended up “purge[ing]” many of the people from social media to preserve her wellbeing. The activity of educating others became a place of learning to take care of herself by shifting her social support systems. She found support from online communities of people who identified as People of Color, neurodivergent, and/or polyamorous. Sherria’s experience was unique, but mirrored how other students were learning about racism (to some degree) in classes but were also teaching and learning from others and reorganizing their online communities as issues of race became central conversations online.

A second example came from Dani, a college student who identified as a non-binary and biracial (Mexican and White). Just after the pandemic began, Dani became an online tutor at a local community college, Table Mountain, where they used to be a student. The tutoring group was struggling with engagement as courses moved online. The group was concerned that some students may not feeling welcomed. Dani decided to do something new for them and “come out” online. When Shea asked Dani how their civic activities changed during the pandemic, they cited their role as a tutor where they “came out” on the tutoring Discord page. Dani stated:

> Something I did as a tutor was I re-introduced myself in a very long post where I was basically coming out as all of my individual identities and trying to bring hope to anyone who might be like me or might see some of themselves in me… you know, I was once just like them, and now I’m here and I’m here to help as well” (interview, 12/9/21).

Dani shifted their sociopolitical engagement to “bring hope” and to reconceptualize a more caring pedagogy. Although Dani and their family were experiencing financial hardship and were immunocompromised, they were able to engage in sociopolitical activities through work. Dani had previously been “timid about community engagement” but through their work as a tutor and an employee at an interfaith synagogue, they realized that engaging with the community “felt good.” These experiences shifted Dani’s practices and solidified a sociopolitical engagement that spanned in-person and online activities.

The connections between sociopolitical discussions online and how undergraduate students develop civically engaged identities often remains invisible to researchers studying civic learning in school. The political importance of engaging with racism and gender politics online may have implications for constructions of civic life across contexts. These online spaces preserved social connections, deepened sociopolitical engagement, and often led to different forms of engagement that spanned online and in-person civic activities.

Developing a culture of place: Belonging, identity and socio-spatial learning

Kaleb Germinaro

Collaborative place-making fosters a sense of *identity-in-place* at the scale of the individual and the collective. Following Black Geographers like Katherine McKittrick (2020), this paper examines identity-in-place by asking “where we know *from*” and “how we come to know *where* we know from?” To consider these questions, this study follows a group of Black and Brown high-school-age girls developing identities-in-place during an out of school design-build program run by a local nonprofit organization called Sawhorse Revolution. Through a design process to build youth- and disability-friendly spaces, young participants learned architecture principles (e.g., accessible design and storying a space) and carpentry techniques. The design process also focused on developing young people’s sense of belonging and identification with specific Seattle-area locations and structures through field trips, arts-based design activities, and workshops about disability spatial justice.

As young people made sense of their belonging, they incorporated their individual and collective place-based identities related to becoming/being a spatial producer in the design process for a client group—Deaf Spotlight. This client represents the Deaf community while making space and advocating for those in the disability community. They center Deaf artists, filmmakers and performers through annual events and a film festival. The first 4 weeks included individual and collective identity-focused design sessions. Deaf Spotlight was picked by the youth within the middle of the 10-week program. The client picked activities for week 5, and subsequent weeks were focused on designing the space for the client by applying identity-focused design sessions. After distributing an RFP, Deaf Spotlight was selected as a means of disrupting spatial inequities, since the youth realized that both the organization and the Deaf community at large lacked a physical space in the city. Therefore, this study’s central question was: How do disciplinary-based spatial practices (e.g., designing and building) support the development of intersectional individual and collective identities?

Data consisted of participant observations, interviews, and video data of design sessions; thematic coding revealed three components of youth learning to build their own belonging that they took up in their own design process. These three components were: Memory, and resisting forgetting, to express un/belonging; relationality as a process for making space for their individual and collective space-making processes; and learning to story a space through design as detailed through pedagogical techniques. Using a grounded theory approach and thematic analysis (Glaser and Strauss, 1967; Harry et al., 2005), I identified identity narratives in the learning environment and analyzed how youth within the study learned their own belonging as they cultivated and understood their identities in relation across spaces (Gholson and Wilkes, 2017; Nasir, 2011). The youth within the study use their identity development as a cyclical everyday activity to design alternative futures individually and collectively (Gutiérrez et al., 2019) as they learn about the components of their belonging. In so doing, my analysis identified that as youth understood their identity-in-place across the individual and collective scales, they learned how and where they know from. They then extended this identity-in-place concept to the client through their design of a physical space. Further, their identities and cultivation of identities were actualized through a civic engagement process that connected to local movements of spatial justice and design activism for larger social movements that aimed to disrupt hegemonic power structures through space, a form of design activism.

Design activism is the process of positioning designers and their practices as central to activist work to address social injustices. The design activist approach also centers and emphasizes the needs of those receiving said design, rather than centering an aesthetic. In this study, young people went from engaging in activities that illuminated their individual design principles and desires, to negotiating a collective design as spatial re/producers and designers of a physical space for a group of people. Their efforts showcase that design activism is a mechanism that responds to the needs of those within a city, resisting luxury and exclusive design innovations that further render those within the margins as placeless (Summers et al., 2022). The development of their collective design was possible through the design principle of belonging. Belonging as a design principle allows for more equitable and just spaces that resist belonging to spaces not built for those who are othered and rendered placeless. Identity un/belonging is a political, challenged, and inextricably linked process to understand ways of knowing and being in the world. Supporting students in perspective taking and reasoning through a sense of identity-in-place requires multiple and diverse stories to be told, centered, and promoted in learning. Through design activism, young people wrestled with issues of power, historicity, and ethical responsibility to disrupt spatial hegemony.

We need more understandings of design activism and its relation to learning for how we engage and think about space. Design then serves as an activist tool that mediates learning on civic and spatial imaginaries of/for belonging. In this study, youth build their imagined futures of where/how they want to belong in real time. Throughout the program, youth moved their imaginary belonging through designing and building their imagined physical futures, informed by their sense of *identity-in-place*. Through this learning process, youth produced infrastructure that activated previously uninhabited space, activating public space in a way that works to repair unbelonging through design. This form of learning is consequential, employing learning as action to engage civic imaginaries and shift material conditions. As such, this paper's findings position youth as legitimate space- and decision-makers as they extend their belonging far past themselves. There is a need for more identity-centered inquiry as a means of deepening place relations and promoting identities connected across time and space.

Significance of contribution

This symposium's set of papers pushes on the notion of civic engagement to consider the multiple publics that communities engage in, how they do so, where they take place, and how this can shape our designs of learning environments that move beyond normative constructions of civic participation to a more generative one that supports the imagining of a more socially just future. Moreover, through the dialogue between papers, we hope the reader can wonder how those who are not invited into some normative notion of "civics" can speak and act powerfully to reimagine community values and practices. How are immigrants, Black and Brown youth, queer folx, and people experiencing houselessness claiming space, creating civic imaginaries, and fighting for dignity and belonging across contexts? And how does the field develop learning environments where White people learn to divest from the myth of the "single story" of civic identity to reimagine rightful presence (Calabrese Barton & Tan, 2020) in communities? Collectively, the studies in this symposium either design or interrogate learning environments where citizen imaginaries form, where individuals are driven to imagine answers that remove structural limitations and enable them to act as fully human and in solidarity with others. In the learning environments highlighted in these papers, a sense of belonging and agency are a central component of citizens' imagining or dreaming within their civic engagement trajectories. Together these papers offer new insight into civic engagement that suggests democratic ideals are not set in stone but instead should be in constant expansive development geared at more socially just communities and societies.

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Playful and Creative Assessment for Learning: Examples and Analyses From the Field

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Abstract: While research has shown the value of learning through play and creative production, less is known about the use of playful and creative assessment for ongoing learning. We therefore use this symposium to address the following questions: how can educators use creative and playful assessment techniques and tools to engage students in processes of learning? And what types of learning do students encounter in these experiences? Additionally, how can researchers engage educators in creating playful assessments that address the needs of their students' learning context? In response, we present findings from four separate research projects that engage these intertwined forms of assessment in different contexts. In doing so, we produce a holistic understanding of designing and using creative and playful assessment for learning, one that positions this approach to learning design as a valuable and far reaching tool within learning processes.

Symposium focus: Constructing playful and creative assessments

Although common conceptions of educational assessment frame this process as a means for evaluating student achievement, Pellegrino et al. (2001) and multiple other scholars also argue that educators can and should use assessment as a tool for continued learning. While this assertion produces a binary distinction within the literature, with certain forms of assessment being labeled as formative (focused on learning) or summative (focused on evaluation), researchers also assert that the barrier between the two remains blurry and more accurately rests on the intentions of educators, evaluators, and students (Black et al., 2004; Knight, 2002; Shepard, 2000). Moreover, Kumpulainen & Wray (2001) argue that summative assessments of students' final tasks or products do not provide a full picture of learning. Researchers and educators should therefore look towards the processes of learning, such as play and creative exploration, as potential tools in a holistic approach to assessment (Kumpulainen & Wray, 2001). In doing so, the field can continue to explore how various assessment tools contribute to the ongoing learning of students and how educators can employ those tools for that outcome.

With this broad framing in mind, we use this symposium to address the following questions: how can educators use creative and playful assessment techniques and tools to engage students in the processes of learning? What challenges do they face in implementation and design? And what types of learning do students encounter in these experiences? Drawing on multiple bodies of literature (including game-based and arts-based learning), we focus on assessment through creative production and play for multiple reasons. First, both forms of (overlapping) assessment contain embedded and authentic assessment processes, allowing students to learn as they continue to engage in playful and creative practices (Halverson, 2021; Howard et al., 2022; Kim & Ifenthaler, 2019; Norris, 2008; Shute & Ke, 2012). Second, playful and creative assessment allows students to both develop and demonstrate learning beyond the intended curriculum, including the construction of agency, creativity, autonomy, collaboration, and other crucial skills within the contemporary moment (Díaz-Lefebvre, 2006; Halverson & Sawyer, 2022; Kim & Rosenheck, 2020; Pavlou, 2020). Finally, while numerous scholars have advocated for playful and creative approaches to learning for years (Gee, 2007; Papert, 1980), others have argued that further research into game-based and arts-based assessments in particular needs to occur (Halverson, 2022; Halverson & Sawyer, 2022; Kim & Ifenthaler, 2019; Sawyer, 2015). Scholars have only begun to scratch the surface of what creative and playful assessment can offer students. Further investigations into (a) the various forms of creative and playful assessment employed by educators and (b) what and how students learn within those experiences will contribute to our growing understanding of how these intertwined approaches to assessment can help students.

Taking this call for further research to heart, our symposium addresses this need by providing robust examples of playful and creative assessment for learning in a variety of US based contexts. While we draw on research from international scholars throughout, we situate this work within the US because of the growing divide between assessment and forms of play or creative exploration within formal learning settings (Zosh et al., 2017). Our work therefore explicitly challenges this distinction and provides opportunities to think with these two interrelated components of education in tandem. Across the four papers in this symposium, the panelists highlight the essential purpose of assessment–making students' thinking and learning visible–and the necessary conditions, including a mindset shift in the educational macrosystem, that will enable the success of assessments that go beyond ranking students' performances. Taking an ethnographic approach, Saplan opens by discussing the assessment approaches in out-of-school time arts education and the pain-points brought about by the traditional assessment mindset, even in this setting. Stoiber and Kim further illustrate the barriers to embedded, playful assessments by providing two concrete examples of assessment tools–one adopted and the other neglected, potentially due to their differential alignment with traditional assessment beliefs–in an inclusive artificial intelligence (AI) literacy curriculum. Lin, Anderson, and Woods follow-up with a potential approach–co-designing with teachers and educators through multiple design iterations, even in the early stages of this process–in an effort to strike a balance between playful assessments and practical constraints in high school geometry classrooms. Finally, Tofel-Grehl, Feldon, Searle, and Suarez demonstrate the powerful impact of creative assessments in a makerspace, where elusive constructs such as identity development can be made visible through authentic activities with maker materials. From theoretical insights to findings from different moments of the design and implementation process, this rich set of examples builds towards a holistic understanding of playful and creative assessment.

In presenting this symposium, we begin with a brief overview statement from the symposium co-chairs and individual statements from representative authors. From there, we move into a more informal style of presentation where audience members can try some of the assessment tools described in the papers and discuss empirical findings from the research conducted by participants. The symposium will then conclude with a discussion that will include comments from our discussant, pre-planned questions for the presenters, and an open question and answer session where audience members and authors can further explore playful and creative assessment together.

Promises and pain-points for creative and playful assessment in out-of-school arts learning environments

Kailea Saplan

Purpose and theoretical framework

Students across the United States are becoming increasingly diverse and entering the education system with rich cultural backgrounds and funds of knowledge that lay the foundation for how they learn (González et al., 2005; Llopart & Esteban-Guitart, 2018). Unfortunately, our current assessments do little to integrate or honor each student's unique ways of knowing and sense making. Exploring the nascent world of creative and playful assessment offers solutions for how to assess students in such a way that empowers them to equitably demonstrate what they know (Díaz-Lefebvre, 2006; Kim & Miklasz, 2021). Since American schools rarely afford opportunities for creative and playful learning, let alone creative and playful assessment, I sought to investigate the assessment practices of various non-school environments. In a secondary analysis of a qualitative research study, I explored creative and playful assessment in highly creative and playful learning environments, namely out-of-school time (OST) youth arts programs. The main research question guiding this analysis was: How do OST youth arts organizations integrate creative and playful assessment, if at all?

Methods, data sources, and analysis

Data sources for this study include: nine semi-structured interviews with educators and organization leaders of OST programs across the United States, and 12 focus group conversations featuring a combination of at least 3 types of stakeholders (e.g., arts educators, organization leaders, policy makers, researchers, or youth artists). This study was nested within a larger project about OST arts education and marginalized youth (Halverson et al., 2023), and is the result of multiple rounds of qualitative analysis including: (A) a round of emic, open-coding strategies (descriptive, concept, and in vivo coding) and memo writing to make sense of how the organizations generally operate and what promising practices and challenges they share; and (B) a round of more detailed analysis focused on how these organizations implement and describe assessment, using analysis matrices, memo writing, and concept and pattern coding (Merriam & Tisdell, 2016; Saldaña, 2016).

Specific to this study, I conducted a secondary analysis of stakeholders' discussions about assessment using both emic and etic coding strategies. Etic codes were drawn from literature on creative and playful assessment, and included concepts like the authenticity of the situations in which youth are assessed, the degree to which assessment proved flexible to youth's learning processes as they unfold, and the degree to which assessment allows a learner to demonstrate their competency in multiple ways depending on their own goals (Díaz-Lefebvre, 2004; Kim & Miklasz, 2021).

Findings

In this symposium, I highlight approaches to creative assessment that stakeholders identified, including approaches that are common in formal arts education assessment literature, like final showcases or performances and informal, formative critique (Deutsch, 2016). I also introduce approaches to assessment worth further exploration in OST arts learning, like stealth observations of youth building their public presence as an artist, and the use of stories as evidence of success. Additionally, I share two other notable findings that emerged in analysis. First, despite the creative environment of OST arts organizations, educators identified many obstacles to engaging in assessment that they found meaningful and authentic to arts practice. Second, although arts educators and organization leaders implement assessments that share many features of playful or ludic assessment (Kim and Miklasz, 2021), the assessments are rarely playful in terms of being fun for learners. These findings represent opportunities for assessment in OST arts organizations moving forward.

Discussion

Overall, my analysis revealed that while some OST arts organizations relied on creative praxes to assess youth in OST arts programs, stakeholders also revealed barriers to integrating less traditional assessments. Kim and Miklasz (2021) wrote that classroom educators sometimes experience pain-points when they attempt to integrate playful pedagogy that is incompatible with familiar assessment methods. This study suggests that pain-points also exist for OST arts leaders and educators, who feel constrained by certain notions about how assessment is "supposed" to function (e.g., assessment should function in a one-size-fits-all capacity; the core purpose of assessment is to compare youth). While creative and playful assessment in informal learning environments may hold promising solutions for equitable assessment, the pain-points that emerge in implementing those assessments must be understood and mitigated.

Examining barriers teachers face when adopting playful assessments for a middle school AI curriculum

Andy Stoiber & YJ Kim

Purpose

Playful assessments are a dramatic counterpoint for most classroom educators trained and experienced in teaching during a regime of standardized testing. Playful assessment centers and empowers learners to display what they know via modalities which are designed to leverage students' own interests and allow multiple paths to demonstrate progress.

This work examines playful assessments embedded in a middle school Artificial Intelligence (AI) curriculum, including: Computational Thinking, Design Thinking, Ethical Thinking, and AI domain knowledge. This paper focuses on challenges encountered during the implementation of our new assessment tools, and discusses barriers teachers face to embrace playful assessments.

Theoretical framework

In the wake of No Child Left Behind, educational psychologists found an improvement in learning when, instead of studying, students take tests and practice retrieval (Roediger & Karpicke, 2006; Karpicke & Roediger, 2008). This suggests that more opportunities for learners to reflect on their experiences and synthesize their thinking throughout a curricular unit significantly impacts student learning (Penuel & Watkins, 2019). Playful assessments diverge from this approach on principle, as Kim & Miklasz (2021) outline four dimensions of freedom playful assessments ought to embody: Freedom to (1) Experiment, (2) Fail, (3) Try on Identities, and (4) Freedom of Effort.

Methods, data sources, and analysis

Following these principles, we designed two playful assessment tools: 1) Game Cards + Profiles, inspired by Pokemon trading cards and Dungeons & Dragons character sheets, and 2) Kanban (a project management process popular across industries). These tools were introduced to teachers at five of our implementation schools to be used with the four-week-long AI curriculum. We present findings from this, our first design-implementation-iteration cycle of a design-based research study. We include four data sources: co-design sessions with two teachers, teachers' reflection videos, student responses to assessments, and classroom observations; data and transcriptions were analyzed using Grounded Theory (Strauss & Corbin, 1994).

Findings

The Kanban boards were adopted in some form by most teachers, while Game Cards + Profile were all but neglected. We speculate this cleavage flows from teachers' routines and value systems. Whereas the Kanban boards were modified into a set of worksheets due to teacher preference and classroom constraints, Game Cards + Profiles' concept and mechanics were perhaps too divergent from what teachers expect and are comfortable with when conducting assessment. This bias, perhaps rooted in the conditions of standardized testing, may impact their evaluation of how helpful playful tools can be; whereas tools described/designed in terms a teacher can relate to may make them more likely to adopt playful assessments. We will further describe our tools and the affordances and constraints of playful assessment and the significance of how teachers perceive them in the context of a project-based AI curriculum.

Discussion

Our work provides useful design insights for how to help teachers adopt playful assessment for middle school students. Despite teachers' recognition of its affordances, playful assessment requires teachers to actively challenge existing and familiar assumptions for conventional assessment approaches. This paper highlights these challenges and offers perspective for how we can support teachers with this innovative approach.

Situated experiences to assess new thinking: A puzzling approach to playful assessment

Grace C. Lin, Emma Anderson, & Peter J. Woods

Purpose and theoretical framework

While extant research advocates for gamification as an effective approach for developing assessments and learning contexts beyond traditional tests (López-Belmonte et al., 2020; Piñero Charlo et al., 2021; Sailer & Homner, 2020; Sakai & Shiota, 2016; Sun-Lin & Chiou, 2019), others have amplified the challenges of gamifying education without sacrificing the game's authenticity (Laato et al., 2020). A related tension exists within the complexities of assessment within project-based learning (PBL) (Wilson, 2021), as educators navigate the tensions between authentic projects and targeted assessment tasks (Fields et al., 2021; Grover et al., 2018; Lui et al., 2020). In this presentation, we argue that the integration of gamified assessments within PBL can attend to the issues of both, imbuing assessment games with a sense of authenticity while providing new tools for targeted yet contextual assessment within PBL curricula. To further explore this connection, we draw on Kim and Miklasz's (2021) framework for ludic assessment that sits at the intersection of learning sciences, assessment science, and game design. The playfulness of such assessments would engage students while supporting their learning and growth. They call attention to the pain points of educators and urge a broader, flexible view of assessments. In this presentation, we dive deeper into educator pain points, attempting to bridge the gap of traditional assessment and a truly ludic assessment.

Methods, data sources, and analysis

To more fully investigate the design of puzzle based assessments within PBL curricula, we draw on design-based research (DBR) as an overarching methodology (Anderson & Shattuck, 2012; Barab & Squire, 2004) with an emphasis on co-design (Roschelle et al., 2006) and rapid prototyping (Desrosier, 2011; Tripp & Bichelmeyer, 1990). This ongoing research initiative began when we formed a design collaborative by recruiting high school math teachers as design partners to help develop PBL Geometry curricula through monthly co-design sessions. We also worked with the collaborative to create the Situated Experiences to Assess New Thinking (SExTANT) materials, a series of puzzles designed for targeted assessment within our curricula that draw on the benefits of both PBL and gamification. For this presentation, we focus on the design of a tangram-based puzzle assessment of knowledge related to rigid transformations. The puzzle involves students using translations, rotations, and reflections to transform a letter or number made of tangram shapes into another letter as a means to decipher a secret message.

Data sources include collaborative meeting video recordings, teacher comments on design artifacts, teacher interviews, and researcher meeting notes and memos. As the primary objective of this phase of the project is to create the assessment (as opposed to theory building), we rely on a rapid qualitative analysis approach via the lightning report method (Brown-Johnson et al., 2020) wherein we organized notes (often in real-time) taken during meeting or interviews, synthesized feedback, decided on new modifications, and proceeded to enact design changes. In turn, our findings stem from our process-based methodology and provide insight both into our co-design process and the creation of puzzle based assessments.

Findings

Throughout our iterative process, the researchers, designers, and teacher co-designers (both the consultants and the implementation partners) collectively attempted to balance practical constraints and needs of the classroom while maintaining the playful, fun, and engaging aspects of the puzzle designs. In doing so, we uncovered the following tensions within the design process. First, designers and educators routinely iterated between playful designs and assessment efficacy. As seen in Puzzle Iterations 2 and 3 listed in Table 1, which outlines our meeting notes and design choices, collaborative members regularly debated how to balance the ability to recognize "individual understanding and contribution" with "the 'fun' and the magical" elements of puzzle design. Second, our team regularly navigated the tensions related to format, aesthetics, and materials. This tension clearly exists in Puzzle Iteration 4 and 5 (see Table 1), with the desire to move to a digital platform creating the need for a physical backup while simultaneously producing translation challenges within the design of the puzzle itself.

Table 1

Major Iterations in the Transformation of the Puzzle Assessment Design

Puzzle Iteration	Design Collaborative Feedback	Design Team Response
0	Expressed assessment needs and interest in puzzle as assessment	Conceptualized assessment ideas for Transformation module
1 – Tangram cipher puzzle where students first solve transformation steps to obtain cipher, use cipher to decode secret message, and then create their own cipher and message. The starting puzzle may be a letter (e.g., E) or a number (e.g., 4) formed by the seven tangram pieces. The steps of transformation will move the shapes to form another symbol.	Positive response toward puzzle; Timing may be an issue; Group work (small group or class level would work better, depending on class proficiency) Create your own would be ideal, but may work better as enrichment	Reconfigured puzzle so that student groups will be able to solve the puzzle within 1 class period. Created explicit group work instruction Removed the "create your own" activity as part of the assessment.
2 – Shortened tangram *group* puzzle embedded in a narrative where the transformed symbols would spell the solution to the narrative.	Concerns surfaced regarding how to tell individual understanding and contribution when the puzzle is meant to be solved as a group. The sentiment was that students may be able to spell the word without having solved all of the tangram pieces.	Reconfigured puzzles to make various pieces more individualized, resulting in the "blasted to pieces" version where each student only sees one piece of tangram shape at a time.
3 – Blasted to pieces version: each panel includes only one piece of the tangram shape. Students will have to transform each piece individually and then work together to materialize the transformed symbol.	The pendulum swung too far the other way. When you see only one piece with the instructions at a time, you lose sight of the "fun" and the magical. The resulting "puzzle"looks and feels similar to a traditional assessment.	Revert back to the shortened group puzzle. Re-emphasize the narrative as well as the group work instruction. Polish the tangram pieces to align with the narrative (i.e., tavern theme).
4 – Tangram *anagram* version. Students would each solve 1-2 symbols depending on class level.	Desire to move to a digital space	Explored and started building a puzzle version on Mathigon.

(More advanced class, groups of 3 where each student solves 2 puzzles.) The solved tangrams would each show a letter. The students would have to unscramble the anagram to get the solution to the narrative.		Physical print version relegated as "back-up." Updated facilitation notes for teachers.
5 – Digital Mathigon prototype	Difficulty level of puzzles and the resulting shape locations need to be adjusted.	Rewrote the mathematical instructions to address difficulty level and differing scales between initial prototype and Mathigon's tangram shape defaults.

Discussion

Though our study is still underway, we zoom in here on our co-design and rapid prototyping (Jones & Richey, 2000) process, one that helped teachers and researchers navigate the tensions between design puzzle assessments to formatively gauge student understanding of content materials and keeping students engaged in a PBL module. Our emergent findings thus provide a glimpse into the inner workings of a diverse team and shed light on the design tensions, challenges, and adaptations that emerged as we attempt to balance playful assessment with the needs of our teacher partners. In doing so, we offer an approach to co-design that can embody the gradual change needed to shift stakeholder mindset from the traditional to the ideal, flexible view of ludic assessments called for by Kim and Miklasz (2021).

The authentic maker assessment: Staying true to the spirit of making with a constructionist measure

Colby Tofel-Grehl, David Feldon, Kristin Searle, & Mario Suarez

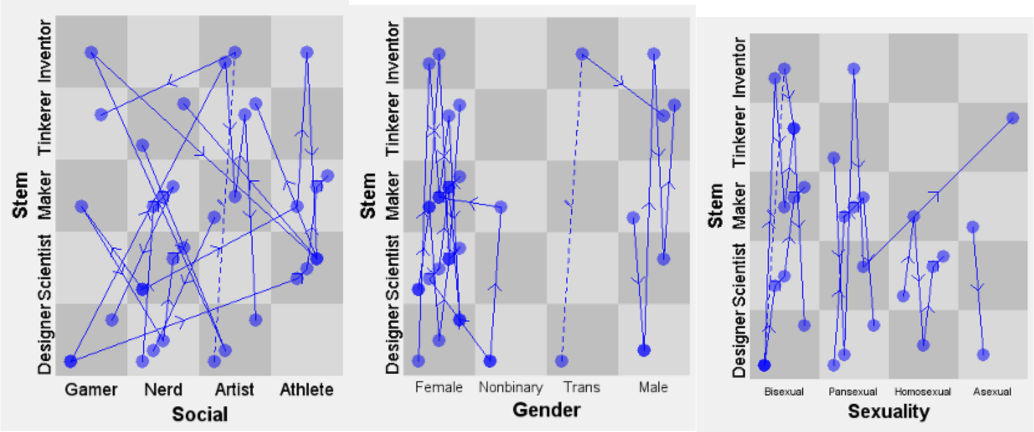
Purpose and theoretical framework

Making is a powerful tool for engaging historically marginalized peoples in STEM learning by creating an inclusive space for identities to be visible and actively incorporated into projects (Shaw et al, 2019; Peppler et al, 2016). Use of unconventional STEM materials (e.g., electronic textiles, recycled materials) and individuated designs also creates opportunities for diverse funds of knowledge to become a part of how STEM is perceived and enacted, linking developing knowledge to the values and needs of communities (Tofel-Grehl, 2022; Tofel-Grehl et al., 2017). However, measurement of the shifts that occur in the relationships between personal, cultural, and STEM identities have historically used methodologies at odds with the ethos of the maker movement, frequently relying on static categories of identity framed by the authors of validated surveys. Existing quantitative instruments are limited because 1) their unidimensional and non-intersectional conceptions of identity (e.g., targeting exclusively gender or race, but not both), 2) their stylistic incompatibility with Maker environments (i.e., hands-on, loosely structured Maker projects followed by a multi-page Likert instrument), and 3) their inability to incorporate locally meaningful identity constructs salient to specific cohorts of participants.

Methods, data sources, and analysis

Authentic Maker Assessment deliberately utilizes materials consistent with Maker activities to capture and quantify shifts in intersectional identities that occur through maker activities. Using a phenomenographic approach (Åkerlind, 2005; Marton & Pong, 2005) to collect qualitative data from groups of students and develop locally meaningful and emergent categories of identity, these locally constructed categories are then represented by pony beads of different colors. Each day, participating youth add beads they select from categories that best reflect how they are experiencing their identity at that time with remarkable variance from day to day (see Figure 1; Feldon et al., 2020). As participants construct these bracelets, they inherently provide longitudinal, multidimensional records of shifting identity facets meaningful to them. The cumulative results yield co-evolving and interacting categories of identity that are quantifiable through mixed-methods phenomenography (Feldon & Tofel-Grehl, 2018).

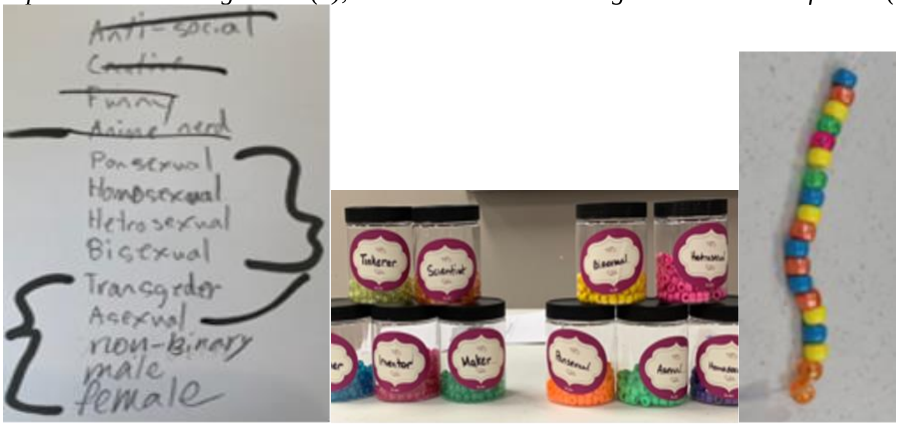
Figure 1
Pairwise mapping STEM identity to social identity, gender, and sexuality



Findings and discussion

In this paper, we share analytic strategies, evidence of measurement validity, and participants' views of communicating their identities using this approach based on multiple samples of youth participants across diverse geographies, affinity groups, and ages. Participants in summer schools and camps brainstormed different aspects of their identities that they wanted to think about and share. Facilitated discussion yielded aggregation of articulated identities into larger categories (e.g., gender identity, sexuality, social identity) with specific subcategories for each. The beads selected from each of the four broad categories and strung onto participants' identity bracelets acted as a running log of shifting identities and identity emphases throughout the camp, as well as a physical artifact for the student to display their identity within the group (see Figure 2). Daily photographs were taken of each participant's bracelet to allow for tracking of the dynamic identity shifts students experienced while attending the Maker camp. Metrics based on dispersion and duration of category selections over time yielded higher level integrated constructs suitable for statistical analysis of change and stability over time.

Figure 2
Qualitative development of identity categories by participants (a), examples of their representations using beads (b), and data shown in a longitudinal bracelet format (c)



(a) (b) (c)

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Moving Towards Critical Pedagogy for Transformative Action: Learnings From Research Partnerships

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Abstract: This structured poster session brings together seven presentations from middle and low-income countries around the world. While research in the field of learning sciences provides some guidance as to how to design learning environments for transformative action, most of this research is conducted in economically wealthy parts of the world (United States, Europe, Australia). This session focuses on different approaches to critical pedagogy that lead to transformative action in unique cultural contexts across low and middle-income countries in the world. It also highlights the need for equitable partnership building between researchers, practitioners and community members that are engaged in transformative action.

Introduction

This structured poster session brings together seven research projects that have investigated the role of critical pedagogy in supporting transformative action within local communities in low and middle-income nations around the world. *The focus of this symposium* is the importance of transformative action as a framework to design learning environments for youth, so as to help them apply their knowledge to urgent problems faced by society (Curnow & Jurow, 2021; Gutiérrez & Jurow 2016; Kirshner, 2015). We present a set of papers committed to transformative action, in the tradition of Freirean pedagogy. Learning environments designed within the framework of transformative action challenge educators and students to critically think about issues such as: how can all voices and contributions in the learning environment be heard and honored; how can issues discussed in the learning environment center around social justice; how can knowledge generated in the learning environment be used by local communities so that the knowledge generation process has relevance to everyday life issues faced by the learners and their communities (Bangs & Davis, 2015; Jemal & Bussey, 2018). This work also builds on Freire's (1970) assertion that the educational process must interweave theory, reflection, and action as a means to advance the broader society towards social change and justice. This approach to the design of learning environments is particularly relevant in a moment in which the world is experiencing a series of concurrent crises—environmental, geopolitical, civilizational, economic, health—each with direct and profound effect on students. To respond to these challenges, school curriculum should not only give voice to students, but empower them as transformative agents in the face of political, racial, economic or cultural oppressions. Such curriculum can take the form of participatory action, service learning, arts-based learning, critical making, or others. The role of educators is a challenging one, as they must be agents who can help students parse through different sources of knowledge. The transformative action approach responds to research that suggests that emotional responses to situations perceived as oppressive and overpowering (e.g., systemic racism and other forms of discrimination, war, poverty, etc) might be alleviated by engaging students in some form of committed action (Charlés, 2010; Ridley et al., 2020).

While research in the field of learning sciences provides some guidance as to how to design learning environments for transformative action, most of this research is conducted in economically wealthy parts of the world (United States, Europe, Australia). There is a need and a responsibility for learning scientists to address learning in all of its forms and contexts, which can inform our deeper understanding of how learning occurs in diverse contexts and situations. We can also advance on the work of Freire and others in critical pedagogy, by examining these ideas in a set of studies. Putting such pedagogy into practice has been recognized as a great challenge, in part because of the need to engage student voice meaningfully and establish a democratic learning environment (Braa & Callero, 2006; Wink, 2005). These forms of engagement have proven to be a challenge even in high-income nations (Basu & Calabrese-Barton, 2010), with some hard-won advances made by educational researchers. But to succeed, teachers require substantial professional development, in order to engage students in autonomous, personally relevant forms of learning while still connecting with disciplinary content and practices, as well as critical thinking, inquiry, and creative expression. Lower and middle-income settings introduce an additional set of challenges, varying greatly in terms of their educational systems, local cultures, languages, and the specific issues that may be oppressive to students and local communities. The learning sciences bring a wealth of understanding about how to engage such diversity and sustain deeply situated learning, and the researchers in this symposium will present an array of studies that deliver on that promise. As a part of this structured poster session we provide examples of how critical action approaches were facilitated by teachers in Bengaluru, India; how educators at a tinkering lab in rural India connected materials and learning experiences in the tinkering lab to community problems; how science teachers in Guyana brought their socio-political identities to their classroom settings; how podcasting was used by youth in the Coeur D Alene nation to understand community based environmental problem solving; how education approaches in India need to include voices of marginalized (Dalit) students and their communities; how a youth led organization (Equal Education) creates powerful learning experiences for youth in South Africa; how education approaches in Brazil create a culturally relevant learning experience for learner.

Structure of the session

This session will be a structured poster event, with short (2-minute) presentations given by each project at the outset, followed by three 15-minute visiting rounds, where audience members choose one poster where they will join a discussion, and everyone switches to a new poster with each round. Each poster will include information about the partnership, relevant research, and findings about transformative action. At the end, the audience will return to a plenary mode for a 20-minute discussion led by Professor Chris Hoadley, from University at Buffalo. The audience will be engaged with a set of questions derived from our innovation sessions, described below.

This will be an innovative session, responding to the criteria listed in the Call for Papers. To *allow a wider level of hybrid activity* in support of all time zones, and *to allow for protracted discussion before and after the session,* we will engage all those registered for the conference (i.e., including those who signed up for online access) in a knowledge building activity before the session.

CALE: Empowering teachers in southern India in a professional learning community

Renato Carvalho, Preeti Raman, Jim Slotta, & Khyathi Vinay

This study was conducted in the context of a project called the Critical Action Learning Exchange (CALE). CALE is an international professional learning community (PLC) for educators dedicated to designing, enacting and sharing critical action curriculum that empowers students in responding to pressing, complex socio-environmental issues such as climate change, social justice, pandemics, and more. CALE draws upon the theoretical perspective of Critical Pedagogy, which is based on a philosophy of praxis that stresses the importance of an educative process that interweaves theory, action, and reflection as a means to advance the broader society toward social change and justice (Freire, 1970; Kincheloe, 2004; McLaren, 2000). This perspective is grounded on the concept of *conscientização*, which is described as “The process whereby people achieve an illuminating awareness of the socioeconomic and cultural circumstances that shape their lives and their capacity to transform that reality” (Freire, 1975). *Conscientização*, therefore, aims beyond “critical thinking” to include a sense of critical consciousness that enables students to make judgements on their current and ideal realities, and empowers them as agents for positive change. CALE applies Critical Pedagogy within a modern context of empowering teachers to help students overcome the sense of powerlessness regarding overwhelming socio-environmental issues, and feel empowered as agents capable of responding to those problems. Within CALE, teachers participate in professional development activities to develop understandings of Critical Pedagogy and collaboratively develop new critical action curricula. Over the past three years, we have designed the CALE activities, resources, and technology environments to support our programs, tested our design ideas through cycles of implementation with teachers, and continuously improved our various frameworks and design guides to help CALE become a sustainable community of practitioners (Authors, 2021).

In Summer 2022, we organized a workshop in Bangalore, India, with the participation of 15 educators. Participants explored four “critical action approaches” using carefully curated materials and exemplars. Teachers’ curriculum designs were guided by the CALE design framework for critical action curricula. This framework includes six components, divided into two axes. The "vertical" axis includes components intended to help students move deeper toward action—from knowledge, to criticality, to action. The “horizontal” axis increasingly expands the scope of the students' critical action—from the individual to the community and finally to the globe. Participants worked in small design groups and engaged in two cycles of peer review. This paper presents the specific features of our workshop, including materials and activities, as well as the pedagogical elements of provocation/activation and engagement through design. We investigate the efficacy of our model in supporting teachers' development of understandings of critical action pedagogy, as captured through teacher discourse, document and interaction analysis. We surveyed participants regarding their beliefs about professional development and their own practices, as well as their understandings of active learning and 21st-century competencies. Our data include teachers’ survey responses and products of their design work.

We start from the hypothesis that some factors make it difficult for teachers to implement this change, such as the curricular expectations, which demand that teachers cover a broad range of topics and discourage the time-consuming deep exploration of topics needed for critical inquiry. The CALE workshop model provides a series of pedagogical and technological supports to help teachers overcome those barriers. These include the exploration of pedagogical approaches, the CALE curriculum design framework, and a curriculum design template. While “lack of time” and “fear of change” continue to be barriers to the implementation of CALE curricula in classrooms in India, teachers in our study were hopeful and motivated to integrate critical action into their curriculum. We look forward to sharing teachers’ experiences and outcomes of enacting their curriculum designs in their classrooms.

Community based problem solving through technology design and collaboration in rural western India

Akshay Kedari & Devayani Tirthali

Rural students across the world find it challenging to develop interests and motivation in science and technology related topics (Harris & Hodges, 2018). Research focusing on students in rural schools showed that students, irrespective of their actual ability, tended to have weaker beliefs in their own academic ability and did not pursue additional educational opportunities compared to their suburban and urban peers (Young, 2000, Gilbert & Yerrick, 2001). In rural western India school is often perceived as an agent that introduces the youth to outside knowledge that is very different from the existing culture and tradition in the region (Jackson, 2003; Shiva, 2000; Goonatilake, 2001). As Pande (2001, pp 48) points out, “In their haste to run away from the village, the young men and women do not seem to have the time to understand their own village and their own people, nor do they receive any orientation towards this in school.” For example, in Maichun Village in the Kumaon region of India, Palta was a community activity that involved the entire village coming together and making compost for their agricultural fields. The practice not only strengthened community bonds but also provided quality fertilizer for agriculture. Jackson (2004, pp 96) observes that “The young youth in the village do not see compost as a resource for sustainable agriculture. In fact, they are ashamed of working on the land: the girls for aesthetic reasons (nail paint would be spoiled and the compost stinks- were some instant remarks from girls) and the boys for livelihood (what will we do in the village? We go to the city, earn money and live comfortably- the boys say). Several families in the village now complain of declining agricultural yields, so much so that “food is not even enough for six months in a year.” The example clearly points out that since most of the formal educational system does not focus on traditional practices, the sustainable livelihood in the village is impacted. Pande (2001, pp 51) also adds, “These impacts were too small to be noticed in the village in the early stages and when they became apparent and obvious for everyone to notice them, it requires resources, the time and knowledge to regenerate or improve them- a task that nobody in the village can do alone.” Therefore, it is an important undertaking to design a curriculum that focuses on connecting school related work with community-based practices. In this paper we discuss a project that was conducted in rural western India that focused on how to make science and technology relevant to students' everyday lives and how to increase student interest in science and technology related topics. The study was built around the recognition that scientific expertise resides not only within school walls but also within the community itself. The project started with asking students to work collaboratively in groups so as to select a problem in their community which they could solve by designing a technology based solution. The students were asked to work for about a duration of 6-months as a part of the tinkering lab they had in their school. The students were instructed to use as many tools as possible from the tinkering lab to design their prototypes. This project was carried out during the COVID-19 pandemic and therefore the curriculum that was implemented was designed taking into consideration that student attendance would not be consistent. The school shut down twice during the pandemic and a lot of the students did not have access to technology tools which made remote learning an impossible task. The project design reflected these concerns and designed a program that the students could attend face to face.

We measured student interest in science and technology related topics using a survey before and after the program. We also kept field notes during the 6-month period in order to document the process of how the students went about choosing, understanding and solving the problem that they perceived existed in their community. There were 13 students from 9th grade who participated in this project (4 girls and 9 boys). The topics that the groups chose were as follows: Group 1: The four girls decided to design an incinerator for disposal of used sanitary pads. This topic was chosen by the girls as availability and access to sanitary pads and a system for disposal of the pads is an urgent issue in rural India. The girls imagined this incinerator would be used in their community. Group 2: This group had 3 boys in it and they discussed the need to design a face lock system for doors in the community that they wanted to live in. The lock in the door would have a facial recognition software which would then provide optimal security for members of the community. Group 3: This group also had three boys and they worked on creating an automatic water tap in all the households so that there is less waste of water along with the convenience of having a water tap in the home. Group 4: The three boys involved in this group decided to design an electricity generator through the use of sewage water. The idea was to direct the sewage into a micro-turbine system that would then generate electricity. While most of the groups worked steadily towards their projects, group 4 struggled with conflict. The students in group 4 were not very interested in working on a project that involved community issues. The teacher had to step in several times so as to make sure the conflicts between the group members was at a manageable level. As mentioned above we administered a pre and post STEM interest survey. The STEM interest survey was adopted from a validated and reliable instrument designed to measure STEM interests among middle school students (Christensen & Knezek, 2017). We also used field notes to understand how students engaged with each of their projects.

Our findings suggest that we do not see significant shifts in terms of students' interests in STEM. While some students in the groups (n = 4) showed positive changes in their interest toward science in particular the shifts observed are not significant. However, our field notes suggest that the students were engaged throughout the process of the project. The COVID-19 pandemic also made it difficult for students to have steady engagement with the projects and may have contributed to showing no significant change in the interest levels. Given that this was our first attempt to make the ATAL tinkering lab relevant to the students' everyday lives we have several findings that will help us with our next attempt toward making the tinkering lab relevant to students' lives. Given that patience and perseverance are key factors to any kind of STEM work, in our next iteration we will emphasize that in any kind of STEM related work collaboration is a key aspect. Collaboration requires building trust, creating spaces for listening and being vulnerable. We will emphasize these important aspects of STEM related work. We are also in the process of thinking about how to emphasize patience and perseverance in our next version of making the ATAL tinkering lab relevant to students' everyday life.

The impact of the sociopolitical landscape on science teacher identity and science classroom discourse in Guyana, South America

Shakuntala Devi Gopal

Science education has historically had a tendency to call itself apolitical or neutral and consequently been unwelcoming to conversations surrounding injustice (Bazzul and Tolbert, 2019). However, funding agendas, cultural lobbies, and personal bias not only influence the direction and quality of science, but also what we teach about that science and then how that science is received by learners. This point is emphasized by Rodriguez (2017) who describes his own experience teaching students about the damage deforestation is causing to ecosystems and then later receiving angry phone calls from parents who worked in the forest industry. While he uses his story to examine the emotional demands of teachers who have social justice agendas, this research explores similar teacher narratives in Guyana in South America to highlight how teacher identity plays a significant role in how and what science is taught in the classroom, especially that with significant sociopolitical dimensions. This work specifically examines the sociopolitical factors that shape science teacher identity and how that identity informs pedagogical practices and classroom decision-making. Research on science teacher identity has established how identity can influence science teaching practices and pedagogical commitments (e.g., Helms, 1998); however, the relationship between science teacher identity and the increasingly sociopolitical nature of science education remains under-examined (Kokka, 2018). This relationship requires deep exploration given how important connecting science to society has become in order to prepare youth for the complicated world they will inherit. Youth must not only learn to decipher scientific complexities, but also the social, economic, and political factors that influence decision-making. For example, learning how dams can generate hydroelectric power in lieu of burning fossil fuels is not enough to make informed dam-related decisions as dams also disrupt marine ecosystems (Scheer & Moss, 2012) and can impair the livelihood of marginalized communities (e.g., Mapes, 2020). So, this research asks whether science teachers see themselves as responsible for developing youth "critical consciousness" (Freire, 1970) i.e., the ability to recognize social realities that perpetuate inequities (Jemal, 2017), and why not if not. Conclusions drawn rest on the stance that a) science education plays a significant role in cultivating critical thinking skills in youth (Bybee, 2013) and b) teachers effectively serve as "agents of political socialization" (Bar-Tal & Harel, 2001, p. 122) in terms of how they choose to frame issues in the classroom, and what kind of learning ecologies they sustain (Authors, 2015). Using a qualitative research design, this study examines whether secondary school science teachers (1) position themselves as responsible for engaging student criticality in the classroom, (2) see a direct connection between their work in the classroom and national socio-scientific challenges such as climate change i.e., see themselves as sociopolitical actors, and (3) see science education as supportive of activism. Holland et al.'s (2001) concept of figured worlds and Davies and Harré's (1990) conception of positioning theory were employed to explore the social reality that Guyanese secondary school teachers are embedded within that shapes and informs how teachers position themselves in relation to this sociopolitical work of science teaching. 25 secondary school science teachers participated in a three-part semi-structured interview design (Seidman, 2013) where they were asked about their teaching practices, commitments, and history, and also the connections they saw between politics and their work in the classroom. Data analysis took the form of coding and thematic analysis (Saldaña, 2016) in order to locate structures, or moral orders (van Langenhove, 2017) that characterize and shape figured worlds (Holland et al., 2001). Initial analysis has revealed unique social, political, and historical context that shape tensions science teachers must then navigate. For example, one science teacher reflected on her struggle to use the color green when designing her classroom during a science unit that focuses on environmentalism because this color has historically been associated with a particular political party. Her use of this color risks asserting a false political allegiance which could alienate students along political lines. Furthermore, because political parties in Guyana are ethnically divided, she risks stoking pre-existing ethnic tensions within her classroom. This paper will share similar stories that highlight the social and political complexities that must be considered in science learning environments that aim to develop youth critical consciousness.

Voices to hear: Telling stories, listening to the present, and imagining the future

Sameer Honwad

Voices to Hear (V2H), a design-based research project that utilized oral traditions of storytelling, engaged Native American youth ages 12-25 in learning about complex environmental challenges faced by the Coeur d'Alene (CDA) nation. We believe that by asking students to reflect on environmental decision-making processes in their communities they, and we, will advance the practice of merging two different knowledge systems (Eurocentric-mainstream/dominant science perspective, and Indigenous – traditional knowledge) to resolve environmental problems, and enable sustainable decisions in their everyday lives.

Research has shown that successful environmental decision-making in Indigenous communities across the world involves combining both traditional and Eurocentric science knowledge (Penashue, 2006). This project aimed to spotlight the historical atrocities that have led to several environmental, social, and political consequences, and also embolden students to consider the ways they can be activists and community leaders (Ginder & Kelly, 2013). By the end of a multi-week summer program hosted by the CDA Department of Education, students create podcasts about environmental issues affecting their community that are direct consequences of colonization and exploitative practices by non-Natives on Native land. Podcasts topics included exploration of the heavy metal waste in the Coeur d'Alene (CdA) river due to extensive gold and silver mining, and the absence of salmon, a culturally important food source, because of the construction of a dam by Western corporations.

We used making high quality radio podcasts as a pedagogical approach to help youth understand how to engage with complex environmental problems in their communities. The use of high-quality radio podcasts was the chosen storytelling mechanism for two key reasons. The first is accessibility—podcast production and distribution is inexpensive and an almost universal medium. The second reason is that podcast making connects deeply with Native oral traditions. Of the modern media, podcasting comes closest to the original form of human storytelling: stories told "in the dark" with the pictures formed in the listeners' imagination. At the same time, podcasts still uses the latest digital technology. While podcasting resonates strongly with oral story telling traditions, it also provides a mechanism for conducting scientific inquiry. The production of a five- or ten-minute high-quality audio documentary is a multilayered, labor-intensive process that emphasizes scientific inquiry, patience, and perseverance, requiring observation, data collection, analysis, and building a summary.

Through the podcasting process, students learned about environmental issues through the lens of different knowledge systems (Indigenous and Eurocentric) by hearing stories told by CDA Elders, explanations provided by natural resource scientists, and observations made by other community members. While the strength of podcast making is in resonance with Native American oral storytelling traditions for learning about and sharing with the rest of their community, the V2H process also provided a mechanism for conducting scientific inquiry and reflection on the inherent complexities of socio-scientific challenges. The podcasting process allowed youth to think about, ask questions about, and discuss the social and political dimensions of the environmental problems they explored. Podcasts were published on the CdA Department of Education website. This research examined student ability to systems think through the analysis of interviews, concept maps, and podcasts. Pre- and post-program data included student analysis of a pre-designed problem-based environmental story and concept maps as visual representation of the social, political, and scientific components that they saw as integral to solving the problem at hand. Data from podcasts focused on how students chose to represent local socio-scientific issues that are grounded in real-world complex systems.

We used the Core Values (CV), which draws on five core values (stewardship, membership, guardianship, scholarship, and spirituality) that reflect the worldview and heart of the CDA Tribal people, as the analytic framework. The core values as defined by the tribe are as follows: Stewardship: To care for all things with integrity, responsibility, accountability and social awareness in all spheres of life. Membership: Capable, decent, moral, ‘a good person’, a good citizen in your family, tribal, local and world community. Guardianship: Protecting tribal ways of knowing and being through the protection, care and responsibility for people, natural resources, culture, history, traditions, language and spirituality. Scholarship: Life-long, holistic learning with ideas rooted in tribal values, self-determination, self-government and sovereignty. Spirituality: Faith from which the Creator reveals the connection between all life.

The core values provide a culturally relevant framework to help us analyze and understand how CdA youth think and understand complex problems. Given the ways student participants were already embedded in a community with a rich cultural and environmental history, we aimed to leverage sociocultural worldviews and utilize pre-existing student schemas as cultural capital for systems thinking through our use of the CV framework. Framing the analysis within these core values highlights relationship, protection, and care. The V2H program enabled students to realize the interconnections within systems, as revealed in their interviews, stories, and the podcast narratives. The data showed that students value (1) caring that emphasizes responsibility, accountability, and social awareness in all spheres of life, (2) learning to understand the world by applying knowledge meaningfully in the community, and (3) care, responsibility, and protection for fellow people and natural resources. Meadows, Randers & Meadows (2004) posit that our increasing obsession with growth has resulted in the persistence of unsustainable environmental decision-making. We assert that CV, as a teaching framework, offers an ideal ideology approach to living that works to reinforce the notion that environmental systems are in a delicate balance which must be maintained in order for them to remain sustainable.

Making waves from the margins: Agency of students marginalized by caste in india

Ishita Pradhan & A. Susan Jurow

To design equitable learning environments, it is important to listen or read about the lived experiences in the voices of the people who are at the receiving end of oppressive practices. Educational experiences of students marginalized by caste system (Dalits) in Indian higher education have been documented well (Deshpande, 2006; Maurya, 2018; Pathania & Tierney, 2019; Singh, 2013), predominantly, these narratives did not include Dalit students’ voices. The narratives, especially those presented by privileged caste researchers, advance deficit views of students from marginalized caste backgrounds. In contrast, we center Dalit students’ voices to present their everyday experiences and interpretations of being in a space enduringly dominated by and imagined as a stronghold of privileged caste communities. Our initial question considered what it meant to engage with the dominant narratives about what it means to be a Dalit in spaces of higher education in India. As we gained insight into their everyday experiences of humiliation and marginalization, our research question shifted to ask: How does Dalit students’ agency manifest in everyday actions and towards what ends?

The study was conducted virtually in Spring 2021 due to the COVID-19 pandemic. It was initially designed as an interview study, where Authors conducted online interviews (~80 minutes) with 6 participants, who were a mixed group of Dalit students pursuing undergraduate, master's and doctoral studies in state and central universities across India, along with supplemental information from a focus group discussion (~90 minutes). Framing the participants as agentic individuals aware and in-charge of their voices (Trouillot, 1995), in control of their narrative, we approached the interviews as a co-constructive space where the participants recounted their experiences in their own words and Authors engaged in storying with the participants while reflecting on her personal experience of being a student in the Indian higher education belonging to the middle rung of the caste hierarchy.

The co-constructive nature of the interviews allowed Authors to listen to the participants deeply that helped Authors in discovering connections, reconsidering assumptions, develop and assess new ideas and pursue new directions in the inquiry of humiliation and agency manifested in the everyday campus life of Dalit students (Lareau, 2021). As a result of this deep listening, Authors identified a remarkable event during interviews, when one of the student participants spoke about a half naked protest at their university which received media attention from the local media channels. Authors subsequently searched through the YouTube channel of the local media outlet and identified publicly available videos where the student participant, along with fellow Dalit student activists, can be seen staging half naked protest for their rights. Therefore, for our research question, we use data from interviews, relevant information from the focus group discussions and YouTube videos to understand how Dalit students claim and articulate their community's humiliation (Nandy, 2009; Rawat & Satyanarayana, 2016) and use agency in everyday actions and towards multiple ends against the indignity and marginalization. The interpretive video analysis helps "seeing" frame by frame, gestures and actions to decode the social interaction (Knoblauch, 2012) among students, how they position themselves, each other and the institution in the act of protest and leverage embodied use of agency to transform the campus environment – implementing a university wide dress code, in this case. Using the framework of transformative agency (Engeström, 2015), initial analysis based on the interviews shows that Dalit students used their agency to organize change across multiple spaces and times. They strategically critiqued their everyday oppression and humiliation, and pushed the imposing limits of the institution to drive change in their learning ecology. Their bold actions brought awareness to caste-based atrocities and drove policy changes in their colleges. Students leveraged resources and tools such as, writing about caste inequalities and publishing in local magazines, collectively organizing events to celebrate lives of famous Dalit personalities, running study groups to discuss caste-based issues, use law (SC/ST Act) and access to local media outlets to challenge discrimination on campus. Their personal stories of organizing involved shifts in their sense of what was possible, what they were learning about higher education systems, and who they were becoming as historical actors (Authors, 2016).

The politics of "waithood" and designing for transformation: Learning to organize while confronting liminality in south africa

Tafadzwa Tivaringe & Ben Kirshner

Youth in South Africa have (re)emerged as powerful actors at the center of educational transformation. From organizing groups, such as Equal Education, to fallist movements, such as #RhodeMustFall and #FeesMustFall, young people are challenging unequal social structures and leading efforts to reimagine just and equitable education. While there is a growing body of research that documents such transformational efforts, less scholarly has attended to the kinds of learning environments that have (re)ignited political activism among this cohort of youth as well as their contemporaries in the global South, such as Nigeria, Brazil, Chile, and India (Espinoza & González, 2016; Kirshner et al, 2021; Tivaringe & Kirshner, 2021; Strong, 2018). Further, the scant body of work on designing transformative learning environments within the learning sciences has largely been situated in the global North, and is therefore yet to sufficiently grapple with the unique structural dynamics, cultural, economic, and political, that characterize the global South (Espinoza and González, 2016; Honwana, 2014; Honwana & De Boeck, 2005). This paper draws on ethnographic data of a South African youth-led organizing group, Equal Education (EE), which influenced the country's educational system by effectively compelling the government to adopt an equity-focused education policy. Building on our previous work that documented young people's framing strategies and learning trajectories (Kirshner et al, 2021; Tivaringe & Kirshner, 2021), we use this opportunity to carry out a focused analysis of the learning environment for a subset of the EE movement: post-secondary youth, here defined as high school graduates who are typically between 18-24 years. We exclusively focus on post-secondary youth because, as much literature on youth in the global South has shown, this cohort is often confronted with high levels of liminality, precarity, and marginality relative to peers in the global North. Conceptualized as "waithood" because so many post-secondary youth experience barriers to full employment, education, and economic independence (Honwana, 2014), this life stage and structural position presents unique opportunities and challenges for the design of learning environments that advance Frerian approaches to social change. Confronted with a common challenge of shifting governance and leadership from founders to local actors, we observed that EE created transformative learning environments for political education, called “youth groups”, in which post-secondary youth served as facilitators and community leaders. Youth groups, and indeed EE’s broader learning ecology, were characterized by pedagogical practices that emphasized distributed forms of authority, embraced equity-centered spatial arrangements (e.g., reading circles), and drew on the legacy of the anti-apartheid movement and everyday practices to resist inequality in the education system. The youth-led movement developed a specific cohort model for post-secondary youth that combined political education, skill development in facilitation and youth organizing, and community building. Given the effectiveness of these features in empowering youth to navigate liminality, transform EE into a more democratic organization, and advance justice in the country’s educational system, we argue that such a model has important implications on designing transformative learning environments across the globe.

Making as empowerment and community-building in the brazilian amazon

Paulo Blikstein, Raquel Coelho, José Valente, Eliton Moura, Joana Corrêa, & Romaro A. Silva

Despite Maker Education’s numerous contributions to education, such as the rekindling of constructionist, project-based STEM learning in mainstream systems, recent research has drawn attention to the fact that a considerable part of what happens in makerspaces reflect North American ideas, views, and epistemologies, having objectives implicitly rooted in the experiences of dominant populations (Buechley et al., 2008; Buechley, 2013; Vossoughi et al., 2016). Anthropologists, sociologists and historians have long documented varied and globally dispersed manufacturing and craft practices (e.g., Eglash et al., 2006; Mukhopadhyay, 2009). Inspired by works that merge such studies with considerations of making in education (e.g., Cavallo, 2000), and recent conceptualizations of cultural making, we designed a project in Brazil to engage with multiple communities to research their making practices and the diverse perspectives that underlie them. A team of 6 researchers was assembled, with deep ties to six Brazilian communities. The locations include two indigenous tribes, two *quilombola* communities (formerly enslaved people), a community of Afro-Brazilian weavers, and a Samba school. Our analysis for the symposium will focus on two communities of *quilombola* origin.

In the first community (clay pot makers in the Northeastern Amazon), the production of clay objects was deeply intertwined with spirituality. The collection of clay could only be done once a year under strict religious rules dating decades back. The interviews revealed that those rules served a variety of goals, from the practical (making sure the clay was collected exactly before the rainy season) to the political (assuring that the elders and the women remained protagonists in the process). The data also showed that the production of the clay pots was anything but routine or prescribed: despite the “official” production routine, each of the pot makers (“louceiras”) reported having their own set of steps, innovations, and new ideas to optimize the process or make it more interesting--and reported strong self-efficacy in the process. For example, some devised a technique to leave the clay sun dry for several hours, while others swore by a different procedure based on fire drying. The clay pot making process was just one cog in a much more complex set of practices that were a key component in the well-being of the “louceiras,” in which empiricism and religiosity were tightly connected: the spiritually-inspired procedures were seamlessly connected to highly empirical procedures. In a second quilombola community, a few hours away, women made cosmetics from native seeds. We also found seamlessly-integrated spiritual and empirical practices here with an additional and vital political component. The community leader reported that they had to organize and create an association to optimize production, which made them realize something entirely unrelated to cosmetics. Once they had an association, their voices coalesced into an amplified and powerful one. They were surprised to realize that, as a women's association, they could demand better local healthcare, transportation, and education from the local government. In this case, thus, the collective making of cosmetics indirectly empowered women to organize, find their voice and demand their rights. In the symposium, we will expand on such topics and discuss how making -- in its unsequestered version -- goes much beyond the creation of exciting objects, but is enmeshed in the spiritual and political realms of community life. However, the making that happens in most schools largely ignores that the production of artifacts in the world is connected to psychological, economic, and political aspects. We will discuss ways by which the creation of artifacts by diverse communities can inform and inspire how maker education is organized and conceptualized in our schools.

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Expansive Lenses to Examine Interventions (of) Moving Across Contexts

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Abstract: Learning sciences researchers, in correspondence with the increasing usage of design-based research, increasingly tend to implement similar theories, curricula, tools, and even learners across different contexts like schools and out-of-school settings. Successfully navigating these movements and transitions involves understanding the dynamic relationship between our (researchers') imagined design's learning goals, and the goals and constraints of learners, educators, and other stakeholders mediating any implementation. In this symposium, we present a diverse breadth of work which highlight different design, analytic, and theoretical lenses to examine these transitions. This symposium aims to encourage researchers to consider such extensions of their work, and surface grammars of analyses that can help researchers involved in such work, through shared discussion across five different projects implementing and analyzing their different implementations in contrasting ways.

Introduction

As researchers and designers, we are often re-adapting similar activities for in-school and out-of-school settings. This is uniquely relevant to the learning sciences community for our inclination towards design-based research (Barab, 2006), and navigating and understanding the dynamic relationship between our (researchers') imagined design's learning goals, and the goals and constraints of learners, educators, and other stakeholders mediating any implementation (Fishman & Penuel, 2018).

We are especially interested in the journeys and challenges underlying projects that aim to implement similar designs, goals, or even concepts – broadly conceived of as any intervention (or reform) – in school settings as well as out-of-school settings. Building on Engeström's argumentative grammar for formative interventions (2011) – "(a) activity system as a unit of analysis, (b) contradictions as a source of change and development, (c) agency as a layer of causality, and (d) transformation of practice as a form of expansive concept formation" – we want to collate how this can provide an analytic lens to examine transforming the same intervention across different settings. In this symposium, we want to discuss different instances of interventions or developments that are conceived for, or repurposed across settings, and the different ways this adaptation is done.

This aims to build on prior work around how different out of school spaces are in general recognized for their affordances and limitations. In the span of work in this symposium we discuss a breadth of different agents and phenomena that can be noticed and inform our understanding of how moving across settings changes learning.

We present these submissions in a particular order which build upon and vary from each other in the scale and kind of trans-context phenomena they highlight, especially through the lens of Engeström's argumentative grammar (a, b, c, d) for formative interventions and activity systems (2009).

Tools

Our first entry highlights the design variations as enacted in *tools and materials* that are necessitated through the variations in *rules* imposed across different settings. This work also highlights how the division of roles (in terms of informal educators, teachers, and other enactors of curricula) remixes materials in ways that we should anticipate and design for. This analysis shows signs of thinking about interventions as serving and being transformed in different activity systems, and especially surfaces how (grammar feature b) contradictions in settings can be a source of change and development.

Learners

Our second submission focuses on the learning that is enacted as learners themselves move across settings – and how their participation in creative activities in out-of-school spaces is often rooted in and initiates from identities rooted in the more familiar school settings. This is not seen as a drawback but provides a lens to pay attention to how learners' movement and increasing familiarity with different identities itself is a productive form of learning. This piece surfaces a valuable lens of (grammar feature c) agency as a layer of causality, centering *youth/learner subjectivity*, but as always constituted through features of the new and old settings like overt and implicit community and rules present across these spaces.

Teachers and Families

Our third submission highlights a critical way of deepening the traditional *divisions of roles and labor* across *community* members. Providing out of school events that allow teachers to connect with their students' families helps teachers gain new lenses to consider their students' broader ecosystems, recognizing a fuller *agency* from their *parents*, and also engaging in these activities with parents – a peer group that they typically see as disconnected from their contexts – also deepens how they are able to perceive the disciplinary practices relevant to their instruction and teaching.

Institutions and Materials as Bridges

Mirroring and extending our first entry, the fourth submission presents a focus on materials as constructed in response to different components of activity system(s) (like institutional rules, community members and division of roles) but as a bridge across contexts as learners move between and across settings (grammar feature a). At an overt intersection of the different lenses highlighted above, this work aims to support learners moving across settings and focuses on how to enable productive movements of the same in response to the complex interconnected and interacting networks that bridge these different settings.

Expansive conceptual development and transformation

Our last submission presents a heavily community centered re-adaptation of broad learning principles and ideas with varying amounts of similarity and connection between the same (including very adjacent and connected settings as well as completely distal and disconnected re-adaptations). This work surfaces how we as researchers can pay attention to community grounded translations and interpretations of our own ideas as a source of learning and transformation for our understandings and identities.

Structure of Symposium

Given this surfaced progression and contrast of ideas and analytical lenses across our works, we imagine presenting our works in short presentations of less than 7 minutes each (35 minutes). Following this, we aim to do a collective brainstorm including symposium participants and the discussant on how these different lenses can be applied to the other projects (approximately 25 minutes), and if there is a productive shared synthesis of these lenses that can be a product for all presenters as well as other learning science researchers to use in their projects considering cross-context learning experiences. Our discussant Nichole Pinkard brings tremendous experience to the space and discussion of creating and studying ecologies of learning for (marginalized) youth across a wide variety of contexts, which can powerfully enhance this discussion through surfacing many other practical concerns from the field, as well as theoretical perspectives which can enhance our analyses. We imagine the last 10 minutes for open-ended question and answer between the audience and the panelists.

Intersecting Sports and Technology Across Schools, Parks, and Community Centers

Vishesh Kumar & Marcelo Worsley

Our work aims to design culturally sustaining computing education experiences for youth engaged in sports and physical activity, through the use of various sports technologies and physical computing tools (Kapor Center, 2021). This work is rooted in enabling richer exposure and access to technology as users as well as manipulators and producers to youth involved in athletics spaces which are often seen as disconnected from most academic endeavors (Hodge et al., 2008). Relatedly, this also connects to expanding conceptions of computing practices and learning experiences – enabling youth to see competence in technology and computing as possible within the context of their sports practices, as well consider computing itself as a domain not exclusively for people with academic competence (Kendall, 2007).

Our implementations of these activities have spanned a variety of contexts including schools, parks, community centers, and a variety of other pop-up summer and afterschool programs. Our curricular activity design tends to span a variety of modalities including discussions about sports activities and related technologies familiar to youth; engaging in familiar physical activities (like running laps around a track, or shooting hoops on a basketball court); repeating these activities with technological tools (like step counting wearables, or automatic sensor embedded score tracking balls); and then recreating these tools using programmable modules (like creating step counters using easy to program microcontrollers like micro:bits). Implementing such activity sequences in different settings has posed a variety of contrasting design constraints leading to minor and major variations in our curricula.

In Schools

Space: While finding classrooms and *spaces* to engage in conversations about and with different computing technologies *which also support free movement* for learners in a cross-contextual challenge, it is a more pressing constraint in schools. Schools tend to make stronger divisions between regular classroom spaces and educational conversation being engaged with “sitting down” learners, and physical education conducted in a dedicated gym space which is minimally oriented for extended discussions and conversations, and mostly centered around following drills and exercises or engaging in free play.

Time: This separation of space and practices also adds to the additional challenge of moving between different kinds of activities. For instance, schools would rarely allow students to access their laptops in a gym space, and moving large groups of students from a classroom to the gym takes a significant amount of time. This immediately affects the shape of our original curricular designs. Additionally, the nature of “dedicated discipline centered time periods” (while not unique to school and similar to many other educational programs) also poses a challenge in implementing deeply multidisciplinary curricula in schools.

Capacity: Additionally, being able to find *partner teachers*, specifically a library teacher who already engaged in computing exercises with her students, and a PE teacher willing to adapt her classes while also deeply collaborating with the library teacher at the same school – mediated through our researcher support – was an extremely critical component of a successful school implementation of our activities. Since the ideas of using such sports technologies as well as wearable computing tools for programming are unfamiliar in traditional PE or computer science teaching professional development, it is key to recognize and prepare for in-classroom small scale innovations being impossible without constant correspondence and partnership with teachers, as well as great flexibility in the expectations around the material covered since school teachers need to prioritize the requirements of the district, of their own school, and also their own prior expertises and preferences.

Assessment: Relatedly, these systemic requirements also frequently constraint or reshape the kinds of assessment and data collection made possible to identify student learning. While our partner teachers went above and beyond in responding to classroom survey and assessment design alongside us, we found it important to prioritize centering teachers’ professional goals and requirements to also contain student participation around assessment through modalities and language that they are more familiar with and often presented with. These modalities help the assessment serve the teacher first, and also respond to other structural constraints like the time allotted and available, and student orientations to classroom activities in the spans they are asked to complete assessments.

Out-of-Schools

Moving these curricula to out of school contexts showed how the features described saliently above vary in out of school settings. Also, this transition also surfaced the role of *interest*, or learner *engagement* as a much stronger affecting factor that we did not directly or overtly experience in our work at schools.

Space: In informal settings, while our unique needs of a gym-like space alongside technological resources and tools presents a key constraint regarding the spaces we partner with, we have experienced fewer challenges rooted in the separation of space (for instance bringing laptops or tablets on the basketball courts) across out of school spaces.

Capacity: Not dissimilar to the nature of overworked teachers with limited capacity for adaptation and novel implementations, most programs and out of school spaces catering to under resourced youth (a primary goal and design constraint in an equity and justice centered project like ours) have a lack of access to well-equipped facilitators and mentors to implement curricula, especially for extended periods of time. While this varies, many out of school spaces also have a lesser capacity than teachers to have sustained relationships with students and a recognition of their broader contexts. We do not have any specific response to this difference and are currently considering different ways of building deeper relationships in these spaces (Thompson et al., 2021) with youth, their families, facilitators in the space, and the activities they experience.

Interest (and assessment): Tied to the nature of formal assessments in schools, youth interest and engagement in out-of-school settings is often significantly changed through the different nature of assessments with significant stakes. School grades tend to often be valued as a social authentic marker of learning and competence from youth, which necessitates most school students to pay attention to the teacher in a way that is rarely induced in out of school settings. Here, some youth are extremely intrinsically driven to some specific activities that they attend for (for instance passion about specific sports at a sports after school program), and some are socially driven either through peers or parental decisions; or are intrinsically demotivated regarding any specific activity (for instance talking about STEM at a sports camp which can continue to excite some learners but also polarize and induce disinterest in others). So far we respond to this diversity of youth participation by including space for prolonged participation in any of the intermediate activities for whichever youth have strongest affinity for. For instance, if some youth are strongly engaged with their favored sports experience augmented through our sports technology, and indicate disinterest from the following activity of programming the same technology, we try to let those learners continue playing the sport they are more interested in. This often creates a tension between other learners not wanting to sit down and code while their friends are still playing, but also creates space for and draws learners who might be particularly excited about the programming exercise after having used a technology.

Dreaming Beyond the Specter of Schooling in Expansive Co-Design Spaces

Michael Alan Chang & Thomas M. Philip

Towards dismantling dominant power hierarchies in schooling, researchers have sought to engage youth as key actors in re-imagining schools (Cammarota & Fine, 2008; Flores, 2008). Despite researchers taking critical approaches to participatory design, youth commonly advocate proposals that ultimately bolster standardized academic outcomes (Kirshner, 2010). In this paper, we share our journey running an out-of-school *Learning Futures Workshops* (LFW) with high-school aged youth of color. The LFW supported youth in dreaming expansively about schools and identifying how emergent artificial intelligence (AI) technologies could make those expansive dreams a reality. In this work, we frame co-design spaces as figured worlds (Holland et al., 2001) in order to better understand how youth conceive of new interventions and reforms for *ideal schools* based on identities situated in well-established cultural contexts, such as *existing schools*. Over the course of our workshop, we altered our co-design figured world to offer youth an expansive set of identities to draw from, and show how this created opportunities for youth to author new possibilities for schooling beyond the grammar of schooling. The conceptual exercise of moving from existing settings to the ideal settings posed challenges and opportunities that we detail here.

Figured worlds are described by Holland et al. as “a socially and culturally constructed realm of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others” (2001). We conceptualize out-of-school co-design spaces as a particular kind of figured world where the valued goal is to construct new figured worlds. Because co-design spaces are unfamiliar for most youth, where participants actively try on identities, including established identities practiced in *existing* figured worlds. These identities practiced within existing figured worlds exist within the context of a *space of authoring*, or a toolbox of practices and discourses that participants are constantly orchestrating. These spaces of authoring open and constrain possibilities around how actors respond to events within existing figured worlds; it is in this way that co-design participants develop their identities as agents of change, and determine how and in what ways existing figured worlds can be transformed to realize their hopes and dreams.

Early in our LFW, we found that youth primarily drew from their well-established, durable identities from the figured world of schooling. The figured world of schooling, sometimes described as a grammar of schooling (Tyack and Tobin, 1994), is characterized by a series of historically robust instructional practices that serve to reinforce a hierarchy amongst students. Drawing from their identities as high achieving students, youth conceived of an AI-based agent that keeps “other” (e.g., lower-performing) students on-task, thus reinforcing the existing systems of authority that are common within the figured world of schooling. These AI possibilities initially advocated by youth were strongly in tension with our critical goals, where we hoped to create a space where young people could re-imagine powered relationships within classrooms.

In an effort to surface expansive possibilities, we brought youth to a number of relatable sites of everyday collaboration, including a cooperative house occupied by seventy university students. In the cooperative house, youth were introduced to *community agreements*, where all house members collectively constructed a set of beliefs about how they would occupy a shared space. By making the figured world of the cooperative house salient to the co-design space, facilitators opened up a variety of tools and practices that youth could deploy to author novel, liminal identities within ideal imagined figured worlds. Youth subsequently imagined a new AI-based technology that supported them in classroom conflicts, where the norms for the conflict would be jointly constructed and agreed upon by the members of the classroom community. In this manner, we demonstrate how imagining within co-design spaces is deeply shaped by identities in practice that youth invoke across a large swathe of figured worlds. While the specter of schooling looms large over this process of re-imagining schools, we demonstrate how broadening the imagined spaces of authoring can open expansive possibilities for dreaming across disparate worlds.

“They Are Whole People”: Consequential Transitions for Pre-Service Teachers Participating in a Family Creative Computing Program

Melissa Braaten, Ronni Hayden, & Ricarose Roque

Introduction

Our design work focused on the different roles in a learning ecology and the consequential transitions of roles and practices across settings. In this particular case, we focus on pre-service teachers (PSTs) as they participated as facilitators in a culturally expansive and creative computing environment within an intergenerational, out-of-school setting. This paper presents findings from a project that documented the experiences of PSTs as they prepared for, facilitated, and reflected on their practices to support families from non-dominant communities in an implementation of the Family Creative Learning (FCL) program, a series of workshops that engaged families to create projects based on their families’ stories. We use the concept of “consequential transitions” which emphasizes that “transitions are consequential when they are consciously reflected on, often struggled with, and the eventual outcome changes one’s sense of self and social positioning” (Beach, 1999, p.114).

Data sources and analysis

We recruited PSTs from an elementary science education course taught by one of the authors at a school of education at a university in the Mountain West region of the US. Two PSTs signed up, Christine and Esmeralda (pseudonyms), who were completing their final semester of student teaching in local elementary schools in an urban area. Both Christina and Esmeralda grew up in the same urban area. Prior to the workshops, we supported PSTs in preparatory sessions where they engaged in case studies of past facilitator experiences, documentation practices, and activities with the computational tools that families would be using.

The FCL workshops were hosted at a public library in the same urban area and families were recruited from the local neighborhood by library staff. During the workshops, we collected ethnographic data that included observation through written field notes, photo and video documentation, and project artifacts. Our design team, including PSTs, recorded debriefs following each workshop that included discussions of facilitation practices and suggested design improvements for the next workshop. We also conducted post-workshop interviews with pre-service teachers and family members who had participated through the last workshop.

Findings

Through reflections in their field notes and post-workshop interviews, both Christine and Esmeralda came to understand families’ identities and their own identities as teachers in more expansive ways than what was available in school settings. They voiced how in school opportunities to build relationships with adult caregivers and families were very limited (e.g. brief parent-teacher conferences to discuss children’s progress). At best, teachers get to know parents as “so-and-so’s mom or so-and-so’s dad” rather than full people. Within FCL workshops, PSTs were engaging with children and parents across various activities and working with family members to create projects based on their family stories. Both PSTs shared a shift in perspectives in how they saw parents and families. For example, after observing and later supporting a father-daughter pair to negotiate ideas for their project, Christine shared her realizations that parents were fully human, people who have their own interests and identities and who need to be seen and heard too by their children. Esmeralda noticed the structures and facilitation practices within FCL that supported families to “come as they are” with their values, stories, and languages appreciated and welcomed. These structures included meaningful activities that allowed younger children to participate, facilitators like herself who spoke the families' languages, and activities that supported parents to explore their own ideas and curiosities with the tools.

In addition to developing more expansive views of families, teachers also engaged in STEM and tech-related identity work. Christine shared she felt a sense of accomplishment, not about a specific moment of coding, but about envisioning how a whole creative computing experience could be used to reconfigure relationships between teachers, families, and STEM-centric school activity. Esmeralda reflected on the power of seeing "so many smiling faces when it came to coding" and shared "personally my feelings towards coding have changed and it's really cool that I get to see families…producing some really beautiful projects that have to do with coding."

Implications and contributions

We found the concept of "consequential transitions" in noting the powerful shifts experienced by PSTs when reflecting on: (1) their perspectives of families as "whole people," not just knowledge about family engagement; (2) their own selves in STEM and computing; (3) their ability to name and identify what structural features of FCL supported them in their engagement with families. Our inclusion of pre-service teachers has implications for the kinds of experiences that are provided for PSTs during their education, especially experiences with families and with out-of-school organizations to engage in alternate possibilities, perspectives, and roles as educators. In our next steps, we plan to document the pre-service teachers' experiences as they move back and forth between their field experiences in classrooms and move onto their professional careers as teachers. Despite these powerful transitions, after they completed their SoE program, Christine and Esmeralda reflected having a hard time imagining what they could implement in practice in their school experiences from their FCL experiences. We recognize PSTs themselves are in less powerful positions as newcomers to systems and structures that dominate interactions between teachers and families. We plan to design scaffolding experiences for PSTs as they transition into school experiences from FCL.

Connecting OST and In-School Settings to Support Learning Transitions

Kylie Peppler, Maggie Dahn, & Mizuko Ito

Introduction

Learning sciences research often views learning ecosystems as a constellation of in- and out-of-school partners. Less frequently do we theorize or design for transitions between in- and out-of-school experiences. In the example of STEM learning, considerable interest is placed in learning experiences that spark STEM interest. But, once interest is sparked, how do we design and develop sustainable ecosystems (which necessarily must span in- and out-of-school experiences) to support learning across a lifetime? This paper examines the work of an interdisciplinary team of educators and learning scientists leveraging the research-based connected learning framework (Ito et al., 2013, 2020) to identify effective community-based strategies for STEM transitions across settings, and using design based research to amplify and spread effective practices across coordinated state networks.

A key element of connected learning environments is how educators and program leaders make connections across settings so that youth can build on their interests to access additional programming, interest-driven communities, and future learning pathways. Through specific design principles and strategies, including (a) coordinating learning between settings, (b) brokering new learning opportunities, (c) using openly networked infrastructures, and (d) making learning visible, this project iteratively co-designed and developed strategies for educators and program leaders to more effectively support youth in connecting their early interests into lifelong and lifewide learning. These design principles for connecting learning across settings take shape through specific choices educators, program leaders, and youth make to support learning in and across their respective settings, whether or not those choices are an explicit part of a program's design. Examining the transitions between learning experiences provides the field with a more equity-oriented and learner-centered approach to supporting young people's learning across settings and over time.

Data sources and analysis

This project examined the transition between learning experiences within the context of middle school girls' learning trajectories across STEM learning settings. In partnership with STEM Next-affiliated Afterschool State Network alliance (which includes in- and out-of-school partners) and the coordinated initiative, Million Girls Moonshot (MGM), we were able to view coordination across settings and the broader ecosystem and trajectory of STEM learning. We systematically studied how five state networks (i.e., Nebraska, Alabama, Pennsylvania, Florida, and Massachusetts) built upon and improved girls' transitions between STEM experiences, which involved interviews with 25 field leaders and youth from across the network, and multiple cycles of iterative co-design with network and program partners. At the start of the project, networks identified strategies they would like to use to connect youth to future learning opportunities. Partners iteratively worked with the research team over the course of a year to refine and implement strategies for making STEM transitions between settings. Two exit and interest surveys with over 70 network members helped capture the impacts of this work on over 5,000 youth.

Findings

Eight initial examples for successfully promoting STEM connections surfaced within the network as a result of our DBR approach to community-engaged design, falling across the four design principles of the *making connections* area of the connected learning framework: (1) a wraparound model to bring together cross-sector organizations; (2) coordinating between out-of-school (OST) and school programs; (3) coordinating between community and OST programs to support community-based STEM projects; (4) supporting brokering work of near-peer mentors; (5) helping adults broker connections to STEM-based entrepreneurship opportunities; (6) helping adults get family and youth buy-in into STEM programs; (7) developing an openly networked infrastructure to help youth find STEM programs; and (8) supporting youth in using an open portfolio for STEM work.

Key findings included: (1) Through implementation and refinement of these making connection efforts, the state networks reported gains in connections to future STEM learning. Networks reported a 37% increase in the number of new connections made to future STEM learning during Phase 1 of the project–over 864 connections to future STEM learning opportunities. (2) The participating state networks saw a marked increase in capacity. While deploying these new and refined approaches, networks reported a 39% (n =+1,235) increase in youth participants, drawing in over 51% (n = +647) more girls. (3) The national MGM networks and programs employ a wide range of nascent practices for making connections that can be leveraged for higher impact. Practices are interconnected and mutually reinforcing, and network administrators self-reported intense motivation (i.e., each strategy is of interest to more than 75% of the state network) to adopt and/or refine one or more ways for making connections highlighted in this project.

Implications and contributions

This paper centers on advancement of theory and knowledge of how connecting learning across settings can broaden access and deepen engagement with STEM for girls. As the field continues to make progress on how to design culturally relevant STEM learning environments for historically marginalized groups, what has received less attention is how to effectively connect and coordinate between these efforts. Typically, STEM programs, both in and out of school, lack connections and coordination across programs and settings. This study offers critical insights and models for how to support inclusive and equitable STEM ecosystems that knit together culturally relevant approaches, focusing specifically on the connections between programs and settings. It also contributes to theory and evidence for how to build effective alliances, networks, and initiatives that serve educational equity and inclusion goals.

Constructionism through the Prism: A Spectrum of Education Implementations in Thailand

Deborah Fields & Paulo Blikstein

Sometimes an educational reform is not a specific technology, activity, or curriculum but rather a philosophy. Such is the case in our study of the implementation of constructionism in Thailand. In the late 1990s, an emerging organization in Thailand, the Suksapattana Foundation (meaning “study and development” in Thai), initiated four years of collaborative work with Seymour Papert in an effort to learn and apply constructionism in their country. While they partnered with Papert and leaders visiting from MIT for four years, they continued implementing constructionism in creative ways across many local sites for the next 20 years and continuing.

In this paper we consider the range of implementations of constructionism specifically in education contexts: public and private, formal and informal. Pizmony-Levy (2011) provides a useful metaphor for considering the ways that local implementations can vary: educational reforms are refracted through the “prism” of individual nation-states, local ministries, and institutions (p. 604). Applied to implementation of constructionism in Thailand, we ask, *how was the educational philosophy of constructionism refracted through local institutions in developing different “colors” of implementation? What, if anything, was held in common across implementations? What institutional and individual factors shaped each implementation?*

Part of a larger study of the Suksapattana Foundation's (SF) implementation of constructionism since 1997, we draw on interviews with 23 people (several more than once) from five sites along with several leaders of the foundation, totalling 47 hours of interview data gathered in-person from 2017-2020. Analysis focused on each individual institutional case of implementation of constructionism, attending to origins, endings, transition points, leaders, influences of various institutions (school, educational ministry), and explicit and tacit applied values of constructionism. Below we briefly describe diverse, 6-20 year long constructionism interventions across different areas of Thailand.

Primary School 1: "Traditional" constructionism implementation

One teacher who attended some constructionism workshops using Microworlds was inspired to implement it in her classroom. With some used computers provided by the SF, she began to teach units on Microworlds (and later Scratch) with her 5th grade class. Over time the entire school slowly adopted the idea and embraced the idea of doing creative projects under the ethos of "constructionism." We call this the traditional model because it most mirrors constructionism implementations around the world which tend to focus on students using digital technology to create interest-driven projects (Holbert et al., 2020).

Primary School 2: Teacher Agency

Here the main instigator was a principal who took to heart the idea of learner agency and met with her teachers to engage in conversation about how to implement constructionism. The teachers chose to group by grade level and work together to do an implementation each year. For instance, the third grade decided to use one month to focus on student projects around cooking traditional foods. When the principal left, constructionism implementation ended, but at least one teacher deeply internalized it and has applied it in other work.

Primary School 3: Indigenous Knowing

A leader of the SF was visiting a school in the Hill Tribe area of Northern Thailand, one locus of the country's indigenous population. Here he met a teacher who had self-developed a beautiful pedagogy where students learned math and Thai (a second language for most students) by studying rice fields and other local work. The leader recognized constructionism in this teacher's work and simply celebrated and acknowledged it, helping the teacher win some awards that led to local recognition and acceptance of his unusual pedagogy.

Summer Technology Workshops

A former principal created a small foundation to support teachers and students in Southern Thailand by sponsoring summer workshops. These focus on creative uses of digital technology, such as maker education, and do not require changing the school curriculum since they take place over the summer. The SF helps provide or connect leaders for some of these workshops.

Private School: Radical Constructionism

Frustrated by the resistance of many schools to providing time and flexibility for teachers to implement constructionism, some SF leaders created their own private school where learner interests and student-created projects were the entire focus of all learning. Teachers were hired from other careers (not from teaching colleges) to disrupt traditional norms of top-down, hierarchical teaching models. As the school grew, it moderated some of this radical implementation through interactions with parents' college entrance worries and school certifications, but as of 2020 still reserved at least 3 days a week for student projects.

Across these implementations we see a great deal of flexibility and innovation. The pioneers of constructionism might be a teacher, a principal, or foundation leaders. Leaders met resistance from existing school models, policies, curricula, and traditions. They each found different niches of application, from what would easily be recognized elsewhere as "constructionist" with digital tools to more ground-up approaches that focused not just on learner agency but teacher agency and tapping into local and traditional knowledge. Researchers were not a part of any of these implementations, though the SF played a variety of roles, from introducing leaders to the constructionist philosophy, to providing materials, to connecting people with resources, to simply celebrating and publicly acknowledging good pedagogy that defied local norms. Perhaps what stands out the most is that nowhere did SF tell leaders what constructionism was or how it should be implemented. Like Papert and Harel (1991), they instead engaged leaders in developing their own (constructionist) projects and valued leaders as learners with agency, interests, and local needs. The Thai constructionist community provides a provocative case of culturally responsive revision and application of an educational reform by people from across the society of a Global South, developing country.

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Posters

Engaging With Glucose Equilibrium Mechanistic Accounts: Type 1 Diabetes Case Study

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Abstract: Reasoning about mechanisms is a core of science education, however, more research is needed into the degree of mechanistic details that should be unpacked to support learning. In this study, we analyze two case studies of laypersons with diabetes engaging with agent-based models that represent glucose-equilibrium processes. Our analysis revealed that incomplete mechanistic representations triggered a sense of dissonance but involved strong emotional engagement. Implementations are discussed.

Introduction

Type 1 diabetes mellitus (T1DM) is one of the most common chronic diseases and is caused by the destruction of the pancreas's ability to naturally produce insulin. To what degree laypersons who are diagnosed with T1DM engage in mechanistic reasoning is not fully understood. Mechanistic reasoning focuses on the process that underlines cause-effect relationships and thereby takes into account *how* the activities of components of a constituent system affect one another. Koslowski (1996) proposed that mechanistic reasoning "explains the process by which a cause brings about an effect" (p. 13). Russ et al. (2008) distinguished between causal inferences of input-output relations, the "causal intuitions", which emerge very early during the course of human development, and the mechanistic conception of a specific process within particular domains (p 422). For instance, in relation to glucose equilibrium and T1DM, the effect of insulin injections upon reduced blood glucose levels would be a causal intuition. While a particular explanation of how insulin mediates the glucose uptake into the muscle cell, which in turn goes through a breakdown process (glycolysis) to produce energy, would be a deep mechanistic explanation that identifies the causes and *how* they are processed. Unpacking mechanistic accounts and their causal interactions is extremely important to learning and teaching (NGSS Lead States, 2013), however, more research is needed as to how many "black boxes" should be unpacked (Haskel-Ittah, 2022), namely, how much mechanistic detail is required. The current study, therefore, explored the mechanistic reasoning structures by studying the learning processes of T1DM patients who used computerized agent-based models which simulate glucose-equilibrium processes (Dubovi et al., 2020). The aim was to outline how laypersons with T1DM who are experiencing bodily diabetes "episodic feelings" engage with mechanistic accounts of their medical condition and to what extent (Nemirovsky, 2011).

Methods

Two male adult patients were recruited during their routine visits to the diabetic clinic. The first participant (P1) was 38 years old and diagnosed with T1DM since the age of 8. The second participant (P2) was 41 years old and diagnosed with diabetes since 14 years of age.

To explore how T1DM patients engage with mechanistic accounts related to their disease, they were introduced to computerized agent-based models which represent the main organelles and molecules that participate in the metabolic processes and insulin mechanisms that maintain blood glucose levels. The models were developed by Dubovi et al. (2020) with NetLogo (Willensky, 1999). The learning process was video recorded and lasted on average for 56 minutes. While exploring the models, participants were asked to apply the "think-aloud" protocol (Ericsson & Simon, 1998) by talking through their step-by-step interaction with the models. Their think-alouds were transcribed and coded for their learning practices, the difficulties they encountered, and their areas of individual interest.

The video recordings were analyzed for facial expressions, using the Affectiva Affdex algorithm provided by iMotions 9.0 (https://imotions.com) to obtain in real-time the 7 basic emotion likelihoods for joy, anger, surprise, contempt, fear, sadness, and disgust.

Results & discussion

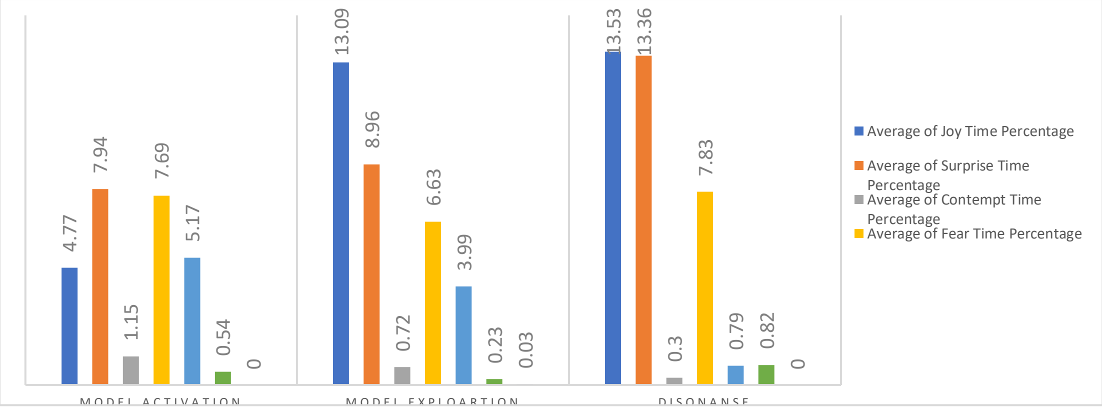
The following exploration practices were identified: (1) The agent-based models integrated three main representations: the microworld, the graphs/plots, and buttons to manipulate the models. P1 attended mainly to the microworld of the agent-based models, while P2 mainly observed the graph representations. (2) While each screen included an agent-based model and the instructions beside it, both participants attended first to model manipulation and exploration, and only when they had finished did they proceed to reading the instructions and scaffolds.

The think-alouds analysis revealed that the participants experienced a strong sense of dissonance between the model visualizations compared to their own mental models which were grounded mainly on their individual embodied experiences. For example, P2 outlined that in the model the impact of the short-acting insulin injection “felt” too fast with a too small impact on blood glucose levels; in contrast, the effect of physical activity on the glucose levels “felt” too strong. This sense of dissonance might be explained by incomplete mechanistic details that were represented in the models which in turn revealed a gap between P2's embodied experiences and the visualized processes. It should be noted that during those moments of dissonance, an emotional engagement that was measured by facial expressions extraction (see Figure 1) demonstrated a relatively high frequency of emotions such as surprise and joy. Surprise is included in a notable list of basic emotions, which has been related to triggering cognitive mechanisms, fostering attention and improving learning processes (Brod et al., 2018).

Overall, it can be suggested that moments of dissonance can be reduced by tuning the degree of mechanistic information details to the learner’s previous experiences with the phenomena. For example, to help learners understand better why physical activity bring a such strong impact on glucose levels, the models should include more complete mechanisms on how physical activity increases the expression of GLUT4 transporters on the cell membrane which in turn enhances cellular glucose transport into muscle cells. On another hand, further research should explore to what extent these moments of dissonance should be mediated, because as we show, moments of dissonance are important to emotional of joy and surprise, which in turn might promote deeper learning.

Figure 1

Changes in participants’ emotional engagement across different phases of the agent-based models.



Note. The figure shows the percentage amount of time the participants displayed each emotion.

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Designing Worked Examples for Dynamic Learning Technologies: The Effects of Action and Self-Explanation

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Abstract: The worked example (WE) effect has predominantly been explained by cognitive load theory. Less research has considered how embodiment may inform the design of WEs. We present a pilot study on the effects of *viewing* versus *mirroring* WEs in a dynamic online environment. A total of 64 ninth-grade Algebra I students were randomly assigned to a condition in which they viewed or mirrored WEs and were or were not prompted to provide explanations. Students showed learning gains with the largest gains among students prompted to give explanations. These findings support the worked example effect and provide preliminary evidence that may inform how WE s are designed for online math environments.

Introduction and theoretical perspective

Worked examples (WEs) provide a step-by-step solution to a problem. Studying WEs in algebra increases learning more than solely problem solving (Barbieri & Booth, 2020), known as the worked example effect (Sweller, 2006).

Prior research has explained the worked example effect through cognitive load theory and shown the effectiveness of providing WEs with self-explanation prompts on learning in algebra (Renkl, 2014). Such WEs provide minimal content that avoids redundant information, splitting attention, or unnecessary elements that do not contribute to learning. Alternatively, theories of embodied cognition posit that students' physical experiences and interactions influence their cognitive processes, including mathematical thinking and learning (Nathan, 2021). In this vein, *interacting* with, instead of just studying, WEs may better support learning.

We present a pilot study testing how principles of cognitive load theory and embodied cognition may extend to WEs with and without self-explanation prompts in Graspable Math (GM: Weitnauer et al., 2016), an online, interactive algebra notation tool. GM was developed from theories of embodied cognition to allow users to physically manipulate notation through gesture-actions that emulate mathematical properties in a physical-to-virtual embodied experience with mathematical terms. To identify effective ways to present algebraic WEs in dynamic online learning environments like GM, we ask: 1) *Do students learn more from viewing or mirroring WEs in an online learning environment?* 2) *Do students learn more from studying WEs with or without self-explanation prompts?* 3) *Is there an interaction between WE presentation and self-explanation prompts?*

Methods

The sample included 64 ninth-grade Algebra I students (M = 14.2 years of age, SD = .5) who participated in the intervention and completed at least half of the pretest and posttest. Our sample included: 34 (53%) female, 27 (42%) male, two (3%) non-binary students, and one student not reporting gender.

We used a 2 (Presentation: view or mirror) × 2 (Self-explanation: prompt or no prompt) between-subjects design. Teachers assigned the study as three 30-minute in-class activities. On Day One, students completed an eight-item pretest to measure their algebra knowledge (e.g., $5 - 4(2b - 5) + 3b = 15$). The pretest and posttest were used in a previous study with a similar population (Smith et al., 2022). Here, the reliability coefficient was KR-20 = .74 (pretest) and KR-20 = .77 (posttest), showing acceptable reliability. On Day Two, students were randomized to a condition in GM. Students completed a brief training tutorial on GM followed by four pairs of WEs and practice problems on equation solving. The WE presentations and instructions varied across conditions but the problems were consistent. The WEs and paired practice problems were presented in the same order across the four conditions with each WE followed by a paired practice problem. On Day 3, students completed a posttest that matched the pretest structure (e.g., $30 - 4(b - 5) + 1b = 20$).

Conditions

Students were randomly assigned to one of four conditions in which they would: 1) *view* WEs, 2) *view-and-explain* WEs, 3) *mirror* WEs, or 4) *mirror-and-explain* WEs. Students in the *view* condition saw two presentations of each WE on-screen. The WE on the left side of the screen showed the major problem derivations in a static image. The right side of the screen showed a looping video of the problem being transformed in GM. The looping video ensured that students in all conditions saw the dynamic problem-solving process; however, students in view conditions watched the video whereas students in the mirror conditions generated the process themselves through GM gesture-actions. Students in the *view* condition were prompted to "*Study the worked example. Once you feel comfortable with the steps taken to solve for the variable, select the solution below as your answer*." Similarly, students in the *view-and-explain* condition were prompted to study the same WEs and select the solution. They were also prompted to provide an explanation: "*Study the worked example. Use the box below to explain each step in the worked example. Once you have explained the steps, select the solution to the equation*."

Students in the *mirror* condition saw a static image of a WE at the top of the screen, and an interactive problem equation presented below. They were instructed to manipulate the equation using GM to match their solution steps with the WE: "*Use the worked example as a guide to complete the problem below using the Graspable Math Canvas. You may reset the problem as needed*." Students in the *mirror-and-explain* condition were also prompted to provide an explanation: "*Use the box below to explain each step in the worked example*."

Results

A 2 (Time: Pretest vs Posttest) × 2 (Presentation: View vs Mirror) × 2 (Self-Explanation: Prompt or No Prompt) repeated measures ANOVA revealed a main effect of time ($F[1,60]= 56.93$, $p < .001$, $\eta_p^2 = .487$): students improved from pretest ($M = .39$, $SD = .25$) to posttest ($M = .60$, $SD = .30$). There was no main effect of mirroring vs. viewing worked examples ($F[1,60]= 0.82$, $p = .37$, $\eta_p^2 = .013$). There was a marginal effect of self-explanation prompts ($F[1,60]= 2.80$, $p = .10$, $\eta^2 = .045$). There was also a marginal Time × Self-explanation prompt interaction ($F[1,60]= 3.74$, $p = .06$, $\eta_p^2 = .059$). Post hoc comparisons with Bonferroni corrections revealed that all students performed comparably at pretest and significantly improved from pretest to posttest ($p < .001$); however, this effect was larger for students in the self-explanation prompt conditions. Students who received self-explanation prompts demonstrated larger growth (pretest: $M = .41$, $SD = .26$; posttest: $M = .68$, $SD = .25$; $p < .001$) than those who did not receive self-explanation prompts (pretest: $M = .36$, $SD = .24$; posttest: $M = .52$, $SD =.32$; $p = .001$).

Discussion

This pilot study investigated how features of WEs impact learning in a brief randomized controlled trial. On average, students improved from pretest to posttest, demonstrating learning gains across conditions. There was no evidence to suggest that viewing or mirroring WEs was more effective; however, students who studied WEs with self-explanation prompts learned more than those who studied WEs without self-explanation prompts.

Students improved about 20% from pretest to posttest, supporting the worked example effect. Similarly, Smith et al. (2022) saw comparable learning gains after students studied one of six WE presentations. These findings suggest the WE format may not matter as much as just engaging in WE practice. As such, researchers and educators may have more flexibility in designing WEs for online contexts. Further, the results support prior research on self-explanations in WEs (e.g., Renkl, 2014): self-explanations are helpful regardless of the WE format. Looking ahead, we will conduct the experiment with a larger sample. While the small sample size renders the results somewhat inconclusive, this pilot study demonstrates how educational technologies open new doors to designing WEs. As K-12 education increasingly uses online tools, it is essential to consider how we can leverage multiple theoretical perspectives to design materials that support student learning and online practice.

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Synchronous Brain Activities in Mathematical Task Processing

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Abstract: Neuroscientific studies in educational contexts increasingly reveal insights into mathematical cognition. However, means for, and results from, group-wide brain activation synchrony analyses when engaging in mathematical reasoning are absent. Thus, we developed a method to investigate population-wide brain activation synchrony and applied this function to examine expertise-dependent differences when interacting with geometric or symbolic math demonstrations. The results revealed greater synchrony when interacting with geometric than symbolic demonstrations, and for students with less formal math education. This indicates the presence of group-wide expertise-dependent brain activation pattern differences upon interacting with different math demonstrations. Furthermore, the results demonstrate the functional validity of a novel method for brain activation synchrony analysis.

Introduction

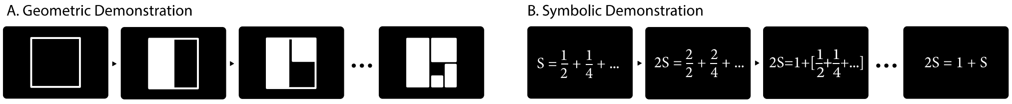
Neuroscientific approaches to investigating cognitive mechanisms of learning in laboratory and classroom settings constitute an essential part of the learning sciences research. At present, there is a lack of neuroscientific studies of group-wide brain activation patterns to shed light on (mathematical) cognition. In other contexts, whole-brain analyses revealed the importance of theta synchrony for memory encoding and retrieval (Solomon et al., 2017), and brain-to-brain group synchrony analyses were shown to be a predictor for classroom engagement (Dikker et al., 2017). However, these studies mainly consider isolated electrodes or individual brain waves, whereas approaches tackling the whole picture of electrode activation, including various locations, brain wave frequencies, and group-wide pattern similarity comparisons, are missing.

This paper reports participant-overarching EEG-based brain-synchrony patterns of students with different levels of math education interacting with geometric or math symbolic demonstrations. We propose and describe a new method to explore EEG-based estimations of brain activation patterns over large population samples. Additionally, we provide an open-source *R*-package to apply this function to other datasets.

Methods

The study participants were 46 university students (26% female, 74% male, 0% non-binary; Age: $M = 22.3$ years, $SD = 2.4$ years). They were grouped into novices and experts based on their educational background (i.e., the number of math courses in their study discipline). All participants were right-handed and did not report hearing difficulties or neurological disorders. The study was approved by the local ethics commission. The stimuli shown during the study consisted of geometric (i.e., figurative) and symbolic math demonstrations. The latter depicted step-by-step explanations of mathematical calculations of variable difficulty. The participants were asked to attentively follow eight randomly and vicariously solved math demonstrations (four symbolic, four geometric) on a screen (Figure 1). Meanwhile, their brain activation levels were measured by EEG (ANT NEURO EEGO MYLAB electrode cap with 128 EEG channels).

Figure 1
Exemplary geometric (A) or symbolic (B) math demonstrations consisting of consecutive slides



A participant's average frequency signal of all electrodes was used as a reference to standardize the recorded signals. Artifacts related to eye movements were removed by conducting an independent component analysis decomposition. Welch's analysis was conducted upon high- and low-pass filtering to assess the signal power at the different frequencies, serving as the basis for investigating between-participant brain synchrony. The novel brain-synchrony function's underlying idea combines clustering algorithms and correlation analyses. First, within-participant correlation scores are calculated for each EEG channel as the basis for *k*-means clustering. Applying the Kelley-Gardner-Sutcliffe penalty function, the channels are hierarchically grouped in clusters.

Repeating this procedure for all participants results in multitudes of specific sets of channel clusters. In the next step, all channel combinations are summarized over all participants in a contingency table, revealing how often two specific channels are assigned to the same cluster in all individual participants. Lastly, a *p*-value-corrected χ^2-square test for each channel comparison is conducted to examine which channels' recorded brain waves consistently correlate over the population. The specifically-for-this developed function is openly available as *R*-package under https://github.com/samueltobler/brainwavesync.

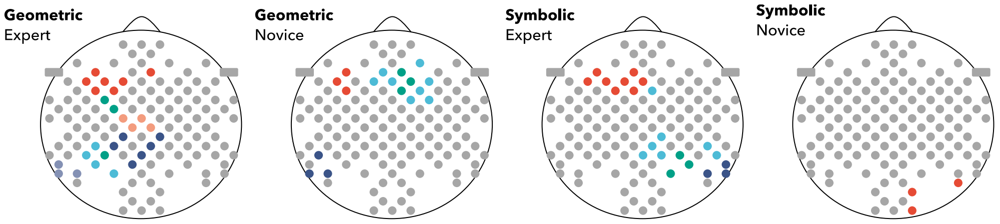
Applying this *brainsync* function (described above) to the priorly Welch-transformed data sets, we obtained brain-synchrony patterns for the four conditions of brain wave frequencies between 0 and 50 Hz (α = 0.001 with FDR-adjusted *p*-values). The results of the analysis were descriptively analyzed.

Results

The analysis revealed four very distinct patterns of brain activation synchronies in the four different conditions (Figure 2). Looking at all experts with geometric demonstrations indicated several electrode clusters of similarly recorded brain activation patterns, primarily found in the left prefrontal and parietal brain regions. In contrast, novices seeing the same demonstrations showed the largest brain activation synchrony in prefrontal and right frontal brain regions. When viewing symbolic math demonstrations, all participants shared fewer brain activation patterns. Furthermore, experts displayed the most brain activation synchrony in prefrontal brain regions, whereas nearly no synchronous activity was found among the novice participants.

Figure 2

Brain activation synchrony clustered in the different experimental conditions and sub-groups



Note. Different colors indicate condition-related cluster-belongings.

Discussion and conclusion

Prior research suggested the feasibility of population-wide brain synchrony analyses for identifying cognitive mechanisms associated with learning in various conditions. Regrettably, previous approaches to examine such synchronous activities are lacking. In contrast, the present novel function identified several electrode clusters of brain activity synchronies in various subgroups. The synchrony pattern with geometric demonstrations in prefrontal regions indicates commonly shared synchrony in brain regions associated with working memory tasks (e.g., Sauseng et al., 2010), and those in the parietal areas related to the more regulated activation of regions necessary for low-dimensional structure generalization and object interpretation (cf. Summerfield et al., 2020). The activation synchrony that is only present in the expert group might be attributable to different prior knowledge influencing the processing of the geometric demonstrations. In contrast, insufficient prior knowledge might constitute an additional challenge for generalizing structural information. The lack of identifiable brain activation synchronies might be caused by the variability of activation patterns, also stemming from diverse behavioral reactions. Future work should investigate whether such cluster analyses can reveal additional insights when considering various moderating factors, including math anxiety or prior knowledge. The study's primary limitation is the lack of prior mathematical knowledge assessment. Comparing individual students based on actual performance instead of inscribed courses may result in more precise results.

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How and for Whom Does DragonBox12+ Support Math Learning? The Relation Between In-Game Progress and Math Performance

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Abstract: Using data from 183 U.S. seventh graders, we examined whether students' DragonBox12+ progress related to their later mathematics achievement, and whether students' prior achievement moderated this relation. Higher in-game progress was associated with higher end-of-year mathematics achievement, and this association was stronger among students with lower prior mathematics achievement. These findings advance research on how and for whom DragonBox12+ supports mathematical learning, and have implications for practices using game-based technologies to supplement instruction.

Introduction and methods

Grounded in theories of game-based learning (Plass et al., 2015), DragonBox12+ (hereafter DragonBox) is a commercially available application that allows students to dynamically manipulate engaging characters on-screen as they learn algebraic principles in a playful context. Aligned with seventh grade math standards in Common Core, students isolate a box containing a dragon, similar to solving for *x* in algebraic equations. Although developers of DragonBox claim that it may help students improve their algebraic performance (Siew et al., 2016), the empirical findings are mixed (Long & Aleven, 2017). Recent analyses in a year-long randomized controlled trial (RCT) suggested that DragonBox positively impacted seventh graders' algebraic performance (Decker-Woodrow et al., in press). However, it is unclear whether the positive effect was associated with, or independent of, students' progress within DragonBox. Further, prior work has focused on students' algebraic performance (e.g., Long & Aleven, 2017; Siew et al., 2016), but the broader impacts of playing DragonBox on students' general math achievement remains unknown. Here, we investigate the effect of students' DragonBox progress as well as the moderating effect of prior achievement on later math achievement. Our research questions (RQs) and their corresponding hypotheses are as follow:

1. Does students' progress in DragonBox predict their later math achievement? Based on relevant research (e.g., Hulse et al., 2019), students who solve more problems in DragonBox may score higher on the end-of-year math achievement.
2. Does the relation between progress and end-of-year math achievement vary by students' prior achievement? We explore this relation, and do not have an a priori hypothesis.

The data were collected as a part of an RCT involving a pretest, nine 30-minute intervention sessions, and a posttest during the 2020-2021 academic year amidst the COVID-19 pandemic. The RCT was conducted in collaboration with a large, suburban school district in the Southeastern U.S. to test the efficacy of three educational technology interventions on seventh graders' algebraic performance (Decker-Woodrow et al., in press). Using this dataset, our current analyses included 183 students (male=52%, female=48%; White=60%, Hispanic=25%, other=15%) who played DragonBox and had math achievement scores from the end of fifth and seventh grade.

DragonBox has ten chapters, each with 20 problems. DragonBox progress was measured as the total number of problems students completed in the game throughout the full intervention (*M*=103, *SD*=49). This measure of in-game progress was the focal predictor for RQ1.

The end-of-year assessment measured students' mathematical understanding in a broad range of topics, including ratios, equations, geometry, and statistics. The assessment included a variety of tasks (e.g., computation, word problems) and answer formats (e.g., multiple-choice, graphing). The assessment scores ranged between 265 and 740. We used students' seventh-grade scores (*M*=549, *SD*=56) as the outcome variable for both RQs. The interaction between fifth-grade scores (*M*=561, *SD*=58) and in-game progress was the focal predictor for RQ2.

Results and discussion

We found that students' in-game progress predicted their seventh-grade scores above and beyond the covariates (e.g., biological sex, race, fifth-grade score), *B*=0.17, *p*=.012. For students with average in-game progress, increasing their progress by one problem was associated with a 0.17-point increase in their seventh-grade scores. Adding the Fifth-grade Score × In-game Progress interaction revealed that the effect of in-game progress varied by students' fifth-grade score, *B*=-.002, *p*=.035. Specifically, the positive association between in-game progress and seventh-grade scores was stronger among students with lower vs. higher fifth-grade scores.

Given that prior studies on DragonBox focused on students' algebraic performance (Decker-Woodrow et al., in press; Long & Aleven, 2017; Siew et al., 2016), the current study was the first to report DragonBox's impacts on general math achievement. We found that on average, students' end-of-year math achievement scores decreased over time, potentially owing to the negative impacts associated with educational disruptions during the COVID-19 pandemic (Engzell et al., 2021; Kuhfeld et al., 2022). Despite the learning loss, we found a positive effect of in-game progress; solving more problems in DragonBox might have mitigated the decrease in students' math achievement. Further, this positive effect was stronger among students with lower math achievement.

One explanation of this finding is that simply engaging students in math through playing DragonBox may help foster a positive attitude towards math and support their later performance, especially among students with lower math achievement. Prior work has shown that the game-based approach can increase students' engagement with learning (Mora et al., 2015), and that playing DragonBox fosters students' positive attitudes towards math (Dolonen & Kluge, 2015; Long & Aleven, 2017; Siew et al., 2016). Future work should replicate the current finding and delineate the mechanisms through which in-game progress and prior achievement influence students' math attitudes and performance. Doing so will help identify ways that game-based approaches support different aspects of mathematical learning and inform practices that maximize their benefits across students at varying levels of achievement.

In sum, understanding how and for whom game-based tools are beneficial can help researchers and educators effectively support students' mathematical learning. Game-based tools may be one way to engage students in math and help decrease learning gaps from pandemic-related disruptions in education. Our findings contribute to the research on when and how to use game-based tools to support mathematical learning during the pandemic and beyond.

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Teachers Using Perspective-Taking to Develop Deeper Understanding of Their Emotions and Informed Views of Teaching and Learning in a Knowledge Building Environment

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Abstract: This study explores how in-service teachers worked collaboratively to discuss their views of teaching/learning while reflecting on teaching-related emotions via perspective-taking (PT) in a knowledge building (KB) environment. Data mainly came from online activity logs and discussion. The main findings from mixed-methods analysis indicate that after engaging in PT in a KB environment for a semester, teachers were able to develop more positive emotions towards their teaching practices, while also developing more informed pedagogical views.

Introduction

Facing the challenge of the 21st century education that responds to the economical, technological, and societal shifts at an ever-increasing pace, teachers play a key role in improving students' capabilities. This challenge requires them to perform increasingly more complex teaching tasks that demands high cognitive and emotional load (Buchanan, 2020). Currently, as often seen from formal teacher training and development, the main trend of teacher development still tends to employ an outside-in approach that focuses on how to develop teachers' professional expertise via enhancing their teaching knowledge and skills (Grainger, 2020). There is a general lack of studies focusing on inquiring into how to help teachers develop their expertise from an inside-out approach, such as reflecting on their own practice to better understand their own pedagogical views and the related emotions derived from the conflicting views of teaching and learning (Korthagen, 2017). To this end, this study is interested in examining a reflective approach, called perspective-taking (PT), to help teachers look at the inner-side of their teaching experience, by reflecting on their own pedagogical views while developing deeper self-understanding and more positive teaching emotions (Jaber, 2021).

Perspective-taking (PT) is a way of viewing experience from differing stances (e.g., 1st-, 2nd-, & 3rd-person PT). PT helps people to form some self-distance (Orvell, et al., 2022) when looking at themselves, so as to critique and revise their experience. So, PT may be used to help teachers reflect inwardly and facilitate their professional growth via self-awareness and emotional clarity. Unfortunately, when reviewing existing literature about PT and educational studies, PT is mostly used as a strategy to build students' multiple views and cultural understanding, and rarely used as a tool to help teachers' professional development. PT, however, can be useful for effective professional development as it provides an opportunity for re-thinking teachers' own teaching concerns, personal strengths and mission, emotional fluctuation, within an authentic teaching context (Fullan, 2007). Many studies also showed that teachers' emotions affected their pedagogy and the students' performance, and their views of learning also influenced their practice, and that teachers' emotions, learning perspectives, and practice are related and important for teacher growth (Buchanan, 2020; Jaber, 2021). Consequently, we intend to apply PT to help teachers engage in self-reflection and self-exploration regarding teaching views and emotions. This study also intends to engage teachers in community-based professional development by means of a collaborative knowledge building (KB), which is defined as sustained production and improvement of ideas of value to a community (Scardamalia, 2002) and it is posited that engaging participants in PT in a KB environment would help them rethink about their psychological well-being, while building collective knowledge for public good, and developing a deeper understanding of the conceptions of knowledge creation. A computer-supported KB platform called Knowledge Forum (KF) is employed in this study to foster online discussion and to provide a virtual place for teachers to practice their PT via exploratory and self-distanciating discourse. Building on the above review, the main research question is: Does engaging participants in PT while discussing critical teaching incidents (CTIs) in an online knowledge building environment help them develop more informed views of teaching and learning and more positive teaching emotions?

Method

Participants were 51 in-service teachers enrolled in a master degree program in a national university in Taiwan. The duration of the study was a semester (18 weeks). We introduced PT as a means for participants to engage in reflective discussion about CTIs occurred within their teaching practices. Knowledge Forum (KF)--a knowledge building environment—was used to record all online activity and content. The course was divided into three stages to guide participants to shift their perspectives, from I-PT, to Other-PT, to Back-to-I-PT, when discussing CTIs.

Four KB principles (Scardamalia,2002) was used as teaching guidance: (1) “Authentic problems, real ideas” was applied to help participants identify their target critical incidents for discussion; (2) “Idea diversity” was used to encourage participants to read and respond each other’s online notes and to promote social collaboration; (3) “Rise above“ was used to guide participants to review all the self-reflections and peer-responses; (4) “Knowledge Building discourse” was employed to encourage constructive and collaborative discourse with partners. Data mainly came from online discussion notes, and analysis focused on: (1) online activities which examine the number of notes contributed, read, and modified in KF, as well as the number of words written per note; (2) content of discussion that reveals participants’ views of teaching and learning, and related teaching emotions (using key concepts in notes as unit of analysis). Cohen’s Kappa (k) was used to compute inter-coder reliability (= 0.74). Wilcoxon signed-rank test was employed for analysis of above three views from the three stages.

Findings, discussion, conclusions and implications

According to the analysis of online activity logs and discussion notes in KF, we found the following four main findings: (1) There is an increasing trend from stage 1 to 3 in terms of number of words written per-note, indicating that under principled guidance, participants progressively became more thoughtful and reflective on their critical teaching incidents during discussion. (2) In terms of participants’ teaching emotions, z-test showed that from I-PT to Back-to-I-PT (stage 1 to 3), there was a significant increase in more positive emotions ($z=-5.592^{**}$, $p<0.01$), but no significant change in negative emotions. This suggests that PT activity in a KB environment was effective to cause emotional reflection among teachers. The persisting negative emotions only imply that there were still conflicting views between teaching and student learning that requires further deeper thinking. (3) In terms of teaching views, from stage 1-3, there showed a significant increase in student-centered view ($z = -7.472^{*}$, $p < 0.05$), while there was a significant decrease in teacher-directed view ($z = 5.119^{**}$, $p < 0.01$). This suggests that the participating teachers are exploring possibilities for student-directed learning, thereby implying the development of a more informed teaching views. (4) In terms of the learning views, from stage 1-3, there showed a significant increase in creation-oriented learning view that is deemed essential for the 21st century education ($z = -2.428^{*}$, $p < 0.05$); and, in contrast, there showed a significant decrease in acquisition-oriented learning view ($z = 5.064^{**}$, $p < 0.01$), while there was no significant difference in terms of participation-oriented view. As creation-oriented learning view is more compatible with a student-centered teaching view, this may explain why there is an increasing trend of positive epistemic emotions as well from stage 1 to 3.

To sum up, this study used KB principles to guide and engage the participants in taking different perspectives to discuss some past teaching critical incidents in a KB environment (i.e. KF). The study intends to shift the focus of teachers’ professional development from externally acquiring core teaching knowledge, to internally reflecting on one’s epistemic views and emotions. The main finding suggests that incorporating PT activities to discuss critical incidents in a KB environment seems effective. Accordingly, we conclude that PT as a pedagogical means can help enable teachers to form some self-distanced perspectives to reflect deeply on their teaching experience as tacit knowledge with a more objective, holistic, and diverse views. At the same time, our finding also suggests that the application of KB principles can help the participating teachers more effectively engage in the collective discussion and reflection activities online to better understand themselves as teachers and integrate differently teaching and learning perspectives more coherently and deeply. In addition, KF provides a computer-supported collaborative environment that helps engaged the participants in community-oriented (rather than individual-based) PT reflection. Future research could explore the integrated use of PT and KB in greater depth by including a control group to better validate that this is an effective way of promoting teacher professional development.

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Figured Worlds of Emerging STEM Education Researchers

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Abstract: Various experiences bring STEM (Science, Technology, Engineering, and Math) researchers to discipline-based education research (DBER), but there is little research on their conceptualization of and navigation into this new area of research. Pairing phenomenography with the figured worlds framework, we discuss how emerging STEM education researchers identify within DBER and negotiate how this new research field fits with their primary one. Our findings highlight salient negotiations they are encountering in their DBER engagement, which provides us with insights into the opportunities needed to better support their professional development.

Introduction

DBER, discipline-based education research, is an interdisciplinary field that investigates discipline-specific learning and teaching that is often paired with more general research on human learning and cognition (National Research Council (U.S.) et al., 2012) and has substantial overlap with the learning sciences. DBER draws from learning practices from disciplinary science, whereas learning sciences provides a complementary perspective by drawing from the psychology of learning, cognition, and development. Our work investigates how emerging STEM education researchers, particularly classically trained STEM faculty transitioning to DBER, identify and/or imagine their positioning in DBER. Their positioning has not been examined before; rather, prior work focuses on the way emerging STEM education researchers' projects evolve. Taking an identity and positioning frame to better understand the adjustment of new DBER scholars, we address the following research question: How do emerging STEM education researchers currently perceive their DBER role? We interview emerging STEM education researchers and present a preliminary analysis that focuses on how they negotiate DBER into their professional lives.

Theoretical framework: Figured worlds

Figured worlds is a theory that captures how individuals imagine or identify their identity and position within a particular context that is social, cultural, and historical (Holland et al., 1998). Figured worlds allow us to examine identity formation as an evolving narrative or storyline constructed due to interactions within a sociocultural space. The identity formed within a figured world comes from participation in its activities and from processing the meaning of one's identity in a given socio-cultural context. The framework draws attention to how people process entry and growth as learners in a new sociocultural space; how they make sense of the space's norms; how they situate themselves and the contributions they bring; and how they perceive the power dynamics at play (Urrieta, 2007).

Context and methodology

A significant portion of our study data was collected in a professional development program named "Professional Development for Emerging Education Researchers" (PEER), which was designed to help STEM faculty, postdocs, and graduate students jumpstart their transition into DBER (Franklin et al., 2018). Our 28 interview participants included researchers with a disciplinary emphasis in mathematics, physics, and biology. We analyzed our data using a phenomenographic approach, which is a research methodology examining how individuals experience a phenomenon (Marton, 1986). Through the repeated reading of the interviews, categories of experiences were identified, followed by the creation of definitions and codes. The first author gathered all the categories, codes, and quotes, refining definitions and codes continuously. The analysis was collaboratively discussed until consensus developed among the project's research team.

Analysis: Central theme of negotiation

A significant theme identified is how emerging STEM education researchers negotiate their position and identity in DBER vis-à-vis their home discipline.

Negotiating positioning in DBER and DBER collaborations

Some negotiators seek to balance improving their teaching and engaging in DBER. A full professor of mathematics at a regional undergraduate serving US institution reflects on the ways to position himself in DBER as a collaborative field. He wonders, *"What's the way to work with education research or what's the overlap"* between doing DBER himself or collaborating with DBER researchers as an engaged instructor, and how he can be *"part of that community."* He is trying to figure out how to collaborate with education researchers in productive ways but is unsure of what expertise DBER values and what a classically trained STEM researcher can contribute. This navigation of norms of collaboration and scholarship in an interdisciplinary field is daunting to emerging scholars in the field, even for experienced researchers in other areas, which impacts how this negotiator positions themselves in DBER and how they see it as a figured world.

Negotiating identity in DBER

This type of STEM education researcher is negotiating which aspects of their professional life drive their DBER engagement. One of the participants who is a math instructor at a US public research institution reflects on her professional identity as having tension between mathematics and mathematics education research: "*I was a mathematician, but no, I'm not a mathematician anymore. Oh, and maybe I'll be a math ed researcher? No, I'm not really a math ed researcher either."* This researcher no longer identifies with her past experiences, which influences her lack of identification as a mathematics education researcher. Her DBER identity becomes a mediating force that causes her to reconsider and renegotiate her professional identity**.**

Negotiating tension between DBER and traditional STEM disciplines

This type of negotiator highlights how some STEM faculty are skeptical of DBER results. One tenured math professor in a mainly undergraduate US institution stresses that some senior mathematicians and faculty *"don't value math education research."* She imagines senior mathematicians saying "*you can't possibly capture what I know from my decades of experience. Like, math education researchers just can't do it."* Part of her mathematics figured world includes devaluing education research results, as embodied in these imaginary-yet-powerful experienced mathematicians. As this type of negotiator imagines herself engaging more in DBER, she highlights the challenge of navigating tensions between DBER and classical STEM disciplines.

Discussion and conclusions

This analysis of interview data examines how STEM education researchers conceptualize themselves as they negotiate their DBER figured world. They imagine how they can integrate their expertise into this collaborative and interdisciplinary space, as they take up new research identities. They experience a tension between education research and practitioner expertise, which highlights the challenge of committing to DBER as a classically trained scientist. To help build capacity and acclimate new researchers, support could include explicit discussions about these negotiations to help researchers imagine their figured worlds. Helping STEM education researchers manage the tensions between DBER and classical research fields can promote persistence and strengthen ties. In turn, knowledge-sharing around these challenges can help researchers transition smoothly.

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Finding a Sense of Belonging: Linguistic and Social Marginalization in Education in Rural India

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Abstract: In India, significant challenges exist in education for students from marginalized language communities. India is incredibly linguistically diverse but education is offered in only twenty-three languages. We explore the case of Banjara students, a marginalized Tribe in Maharashtra, who speak a different language at home than their non-Banjara peers. This study examines Banjara experiences of the language gap between school and broader communities to develop ways to address closing the gap in the future.

Introduction

India is the world's largest democracy and socio-culturally one of the most diverse nations in the world, with 122 official regional languages spoken across approximately 1.3 billion people (Guha, 2017). The diversity comes with challenges related to socio-linguistic inequities. One of the ways in which social inequities get perpetuated is through language use in classrooms (Mohanty, 2019). In India, school-based curriculum is often taught in one of the twenty-two official state languages or in English (Annamalai, 2001). Even after the recent emphasis on Indian languages to 'decolonize' education, the use of official state languages as language of instruction, recreates the colonial power structures that prioritize monolingual monocultural practices, suppressing the marginalized communities and their languages (Panda, 2023). Students who do not speak the regional or state language at home and in their communities find the learning process challenging when they attend school (Groff, 2017). In Maharashtra, a western Indian state, Marathi is the dominant regional language used for official transactions and education in addition to English. Students from marginalized communities who do not speak the dominant regional language at home or in their communities often do not find a sense of belonging in the classrooms. In this study, we explore the case of Banjara students, a socially marginalized Tribe in Osmanabad District in Maharashtra. Banjara students speak a different language at home (Banjara) than their peers who use Marathi, Maharashtra's state language and language of instruction in government-funded schools in the region. Banjara communities across India were previously branded as "Criminal Tribes" during the British colonial period due to the notion that their nomadic lifestyle and occupations were socially deviant. The community continues to face marginalization and social, economic, and educational disenfranchisement which is compounded by Banjara youth's inability to communicate in the state language when entering school (Ramaswamy & Bhukya, 2002l; Schwarz, 2010). As they progress through their schooling, Banjara-speaking students distance themselves from their language because learning Marathi in school is both a means to assimilate to educational norms and mediate their experiences of social marginalization and stigma.

In the Osmanabad District in Maharashtra, Banjara children attend schools in or near their home communities, called tandas, where teachers are non-Banjara speaking. Students therefore must adapt from their mother tongue at home to Marathi in school, even if they attend school with their Banjara-speaking peers. This poster describes the learning challenges Banjara students face where there is no formal or official support provided to help them bridge the gap between the language spoken at home and the language of instruction in school. The poster details findings from a first phase of a broader research project on how Banjara students (6th through 10th grade), and community members understand the problem that Banjara students face. Future phases of the study will progress to understand what solutions community members, teachers, school administrators and students themselves think to close the language gap between schools and communities.

Theoretical background

We ground this work in learning sciences theories that help us understand how to design educational research projects for learners who live in Indigenous and colonized spaces (Smith, Tuck & Yang, 2018). A major problem within Indigenous communities is that youth have limited access to resources in the formal education system that allows them to merge their ethnic identity with the content that is being taught (Kovach, 2010). Learners from Indigenous cultures construct concepts taught in the classroom in parallel with Indigenous concepts, with very little interference and interaction between the two (Jegde, 1995). It is important to note that many learners from Tribal communities desire to break the cycle of assimilation and associated loss of culture (Nelson, Adger, &

Brown, 2007). The project described in this paper is the first step to understand how to create a sense of belonging for learners from the Banjara community in western India.

Research design

We collected data using qualitative ethnographic methods in June 2022. We conducted 34 interviews with 7 parents, 17 educators, and 11 students. We also conducted approximately 35 hours of observations in educational spaces and tandas.

Analysis and findings

Most school materials and instruction is in Marathi, with some textbooks and lessons in Hindi and English as well. Banjara students note a stark transition in terms of language when they begin school. It is usually in school where they learn Marathi, but not necessarily from lessons or teachers. In narratives of assimilation to educational and societal norms and expectations for success, students describe a slow and often painful process lacking in scaffolding or resources to aid in the linguistic transition. Pratiksha, among other quotes on a poster, discusses how informal assistance to learn Marathi came from her peers.

> "In the first grade I couldn't speak any Marathi, and in second grade I could speak a little bit, and then in third grade I could speak just a little more. I just didn't know how to speak and I couldn't understand. [...] The teacher used only Marathi and my friends would say, "Why don't you raise your hand in class, is that because you can't speak Marathi?" "Yes, that's why." So, my friends used to write things down for me and I would remember them and repeat them. I couldn't read and I couldn't even speak. And everyone used to put their hands up (when the teacher asked questions). And I couldn't, but slowly Marathi came."

Language assimilation is a gradual process that generations of Banjara-speakers experience where students from Banjara communities must adapt to speaking, reading, and writing Marathi. A mother from one of the most disadvantaged Banjara tandas, said, "If we speak Marathi at home, [children] will also speak Marathi." When a schoolteacher asked her to speak Marathi at home, her response was, "If the teacher asks, we have to obey." Parents motivate younger generations to assimilate to the linguistic norms needed for jobs that offer more economic advancement. There is a recognition of values assigned to languages that brings into focus how the Banjara language is of limited use in broader society. Banjara-speaking students concurrently articulate both an ambivalence towards and an awareness of dynamic intersections of power with impacts of overlapping caste and class categories in socially and linguistically stratified settings. Balaji Dada, a Banjara educator, said, "Our language will just keep us in our group." Remaining in a tanda and using Banjara means that one remains limited in jobs.

Discussion

Implications of this study demonstrate that a production of identities for Banjara youth includes negotiating their social statuses within a structure of linguistic hegemony for social advancement through assimilation to the majority language group. To be educated in the Banjara community in the Osmanabad District in Maharashtra carries an expectation of suffering through a difficult transition of learning Marathi independent of others and independent of assistance from authority figures such as teachers. Banjara-speaking students concurrently articulate both an ambivalence and an awareness towards dynamic intersections of power with impacts of overlapping identity categories where language is mapped onto identity and belonging in socially and linguistically stratified settings (Bucholtz & Hall 2005). We have explored Banjara student's perceptions of identities and orientations to education in this phase of research. In next phases, we plan to explore classroom discourse directly and develop interventions for educators.

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Supporting K-12 Computer Science Formative Assessment Evaluation & Teacher Assessment Literacy

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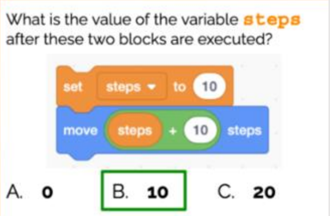
Abstract: As K-12 computer science (CS) education expands, there is a growing recognition of the need for formative classroom assessment practices. Grover's recently developed formative assessment framework for K-12 CS provides guidance, however tools for *evaluating* formative assessment remain a gap—as evidenced in feedback to our formative assessment literacy PD efforts. This paper examines the suitability of Pellegrino et al.'s validity framework for instructionally relevant assessment for use in K-12 CS classrooms and teacher PD.

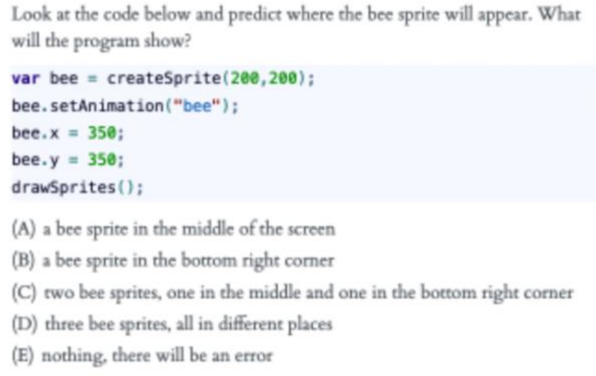
Background & motivation

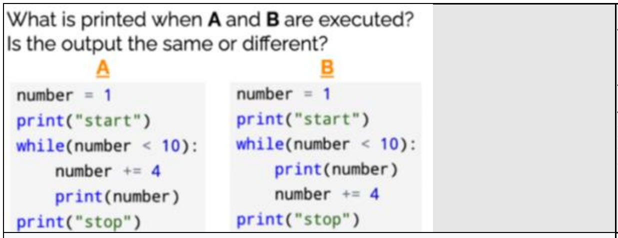
Teachers across the US are now teaching coding and computer science (CS) as part of a rapidly growing "CS for All" movement aimed at teaching CS to all K-12 learners. There is healthy progress on many aspects of this endeavor, including the creation of tools, curricula, teacher professional development (PD) programs, and research on CS teaching and learning (for students and teachers) and implementation. However, gaps remain in teacher preparation, key among which is the ability to measure student learning in the classroom for the purpose of improving learning outcomes for all students (Vivian et al., 2020).

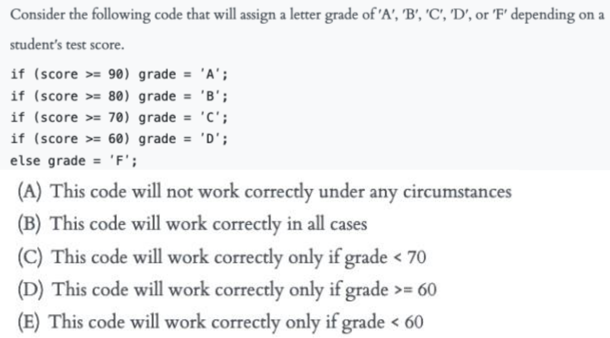
Formative assessment is assessment ***for*** learning, or measurement that helps monitor student learning and inform subsequent teaching moves. There is compelling evidence that attention to classroom formative assessment can produce greater gains in student achievement than any other change in what teachers do (Wiliam & Leahy, 2012). Professional learning of classroom assessment practices is *formative assessment literacy*. Teachers new to a content area and/or teaching practice face many challenges when it comes to engaging in appropriate assessment practices in their instruction (deLuca & Klinger, 2010). In order to address this need, we drew on a formative assessment framework for K-12 CS (Grover, 2021) to design and pilot a CS assessment literacy PD module, Formative Classroom Assessment for Teachers (FCAT), that is now publicly available as a "PD-in-a-Box" and in active use by various CSTA chapters in the US. Feedback on our three-session FCAT pilot and a CSTA conference workshop (total N=~500 teachers) was overwhelmingly positive, suggesting that FCAT succeeded in meeting its goals in helping teachers develop a foundational understanding of formative assessment (Grover & Twarek, 2023). However, several teachers requested tools to evaluate formative assessments.

Table 1
Evaluating K-12 CS classroom assessments on cognitive, instructional & inferential validity

Example Assessment	Evaluation/Analysis
 What is the value of the variable **steps** after these two blocks are executed? set steps to 10 move (steps + 10) steps A. 0 B. 10 C. 20	Cognitive: This is a good assessment as it clearly targets when/how variable values change/are updated. Instructional: Variables are a key concept. Inferential: Excellent diagnostic question and points to what must be done if students do not get this right. (For example, step through code and inspect variables, demonstrate the use of a 'set' and 'change' block).

 Look at the code below and predict where the bee sprite will appear. What will the program show?
`var bee = createSprite(200,200);`
`bee.setAnimation("bee");`
`bee.x = 350;`
`bee.y = 350;`
`drawSprites();`
(A) a bee sprite in the middle of the screen
(B) a bee sprite in the bottom right corner
(C) two bee sprites, one in the middle and one in the bottom right corner
(D) three bee sprites, all in different places
(E) nothing, there will be an error
	Cognitive: This assessment targets knowledge of the coordinate system for the Code.org programming environment "stage" as well as basic Javascript animation functions; neither is a generic domain skill for programming (same for Scratch stage-related Qs)
	Instructional: Presumably this content is covered when introducing learners to the programming environment
	Inferential: Weak. Since this assessment involves an understanding of basic Javascript functions to create and animate a sprite, as well as the x/y coordinate system of the stage, an incorrect answer could point to a lack of understanding of either of those.


What is printed when **A** and **B** are executed?
Is the output the same or different?
A
`number = 1`
`print("start")`
`while(number < 10):`
`    number += 4`
`    print(number)`
`print("stop")`
B
`number = 1`
`print("start")`
`while(number < 10):`
`    print(number)`
`    number += 4`
`print("stop")`
	<u>Cognitive</u>: This assessment targets how: while loops work, expressions control loops, and update of variables.
	<u>Instructional</u>: Loops are a key concept in programming
	<u>Inferential</u>: Even though 2 concepts are targeted, the responses provide a clear indication of where a student is lacking understanding. It targets a common misconception students have about 'while' loops


Consider the following code that will assign a letter grade of 'A', 'B', 'C', 'D', or 'F' depending on a student's test score.
`if (score >= 90) grade = 'A';`
`if (score >= 80) grade = 'B';`
`if (score >= 70) grade = 'C';`
`if (score >= 60) grade = 'D';`
`else grade = 'F';`
(A) This code will not work correctly under any circumstances
(B) This code will work correctly in all cases
(C) This code will work correctly only if grade < 70
(D) This code will work correctly only if grade >= 60
(E) This code will work correctly only if grade < 60
	<u>Cognitive</u>: This is a good assessment as it targets if statements and flow-of-control. *However*, there is a possible confound with understanding of the mathematical relational operator (>=) which many K-8 students finding confusing.
	<u>Instructional</u>: Conditional logic is a key part of teaching intro programming and it scores high on this feature.
	<u>Inferential</u>: If words like 'greater than or equal to' were used instead, it would be an excellent diagnostic question with clear follow-up feedback if students do not get this right. (code-tracing with various values of score including edge cases).

A framework for evaluating formative assessments for K-12 CS classrooms

Pellegrino, DiBello, and Goldman (2016) draw on contemporary thinking on validity of assessments to propose a framework for conceptualizing and evaluating the validity of classroom *assessment that is intended to function close to instruction*. It includes 3 validity components/dimensions: **Cognitive**: how well does assessment align to a domain knowledge/skill in ways that are not confounded with other aspects of cognition such as language or working memory load?; **Instructional:** how well is an assessment aligned with curriculum and instruction, including students' opportunities to learn?**;** **Inferential**: how well does the assessment accurately provide information & feedback about student performance for diagnostic purposes and follow-up action? Table 1 shares analyses of sample assessments relative to the three validity dimensions described. The contrasting cases of good assessments (grey) versus those needing improvement serve to highlight variations in assessment quality.

Based on our evaluation effort, we found the 3 validity categories useful & straightforward to use. However, we also concluded that (1) some assessments, especially those pertaining to the syntax and specifics of a programming language, are necessary for formative feedback but are not aligned to a CS domain skill or K-12 CS standard. It would be helpful for CS teachers to draw this distinction as they evaluate items; (2) evaluation on **instructional** is contextual (*was this topic taught in this particular classroom?*) when done in the abstract (as we have) but it would be easy for a teacher to evaluate an assessment on this component. We believe that this evaluation framework should be a part of K-12 CS teacher assessment literacy PD such as FCAT and any K-12 CS formative assessment framework would also be more robust with the inclusion of these evaluative elements.

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Engagement With an Online Syllabus: Preferences for Design and Interactivity

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Abstract: We examined the impact of design and interactivity on undergraduates' engagement with an online syllabus. We found that appealing design and interactivity elements, such as embedded videos and tabs, influenced student engagement. Age, race, gender, and disability accommodations did not affect engagement. A course overview video is recommended.

Introduction

Traditionally, a syllabus provided a schedule and policies but now has taken various forms: "a contract between the instructor and the student," (Parkes & Harris, 2002, p. 55) or a welcoming document for fostering belonging and enthusiasm (Gin et al., 2021). But it is common that students do not read syllabi, as they are often lengthy and boring (Ludy et al., 2016). Attempts at engaging syllabi vary from newspaper-style handouts (Dobersek et al., 2019) to *liquid*, online syllabi featuring design, video messages, and supportive language (Pacansky-Brock et al., 2020). The use of videos is recommended (Johnson, 2022), particularly a warm introduction from the instructor demonstrating an interest in students' learning. In this study, six formats of a single online syllabus were used, with consistent information, language, and tone, but varying in design and interactivity. We examined students' perceptions and interest in the syllabus and their engagement with the different versions. The conceptual framework was based on syllabus studies related to design (e.g., Ludy et al., 2016) and interactivity (e.g., Kim & Ekachai, 2020). We considered images, color, and static charts as design elements, and accordion and tab structures, interactive charts, and embedded videos as interactive elements. We asked, *How do syllabus design and interactivity influence students' engagement with an online syllabus?*

Method

The study was conducted in an asynchronous online geology course at a public university. 515 students participated in six sections. Drupal, Rise, and Canvas were used (see Table 1 and Figure 1). Participants completed pre- and a post-surveys. Impression (Ludy et al., 2016), interest (Keller, 2010), and engagement (Schaufeli et al., 2002) scales were adapted. Dependent samples t-test, one-way ANOVA, and multiple regression analyses were conducted. Qualitative data was analyzed using a coding scheme based on our conceptual framework.

Table 1
Syllabus Information for Different Sections

	Syllabus design	Syllabus interactivity	Course content is in	The syllabus is in
Section 1 (n = 90)	text only/no design	no interactivity	Canvas	Rise
Section 2 (n = 76)	text only/no design	with interactivity	Canvas	Rise
Section 3 (n = 105)	design included	no interactivity	Canvas	Rise
Section 4 (n = 101)	design included	with interactivity	Canvas	Rise
Section 5 (n = 89)	text only/no design	with interactivity	Canvas	Canvas
Section 6 (n =54)	text only/no design	no interactivity	Canvas	Drupal

Quantitative results

Only Section 5 had a significant improvement in students' perception of the syllabus being easy to navigate and comprehensive. The overall impression score significantly improved only in Section 5. Section 6 had the lowest means on all impression subscales, while Section 5 had the highest means on the subscales of easy-to-navigate and comprehensiveness. Before the study, there were no significant differences in impressions between sections. However, after using the assigned syllabi, Section 4 found their syllabus to be significantly more visually appealing than Section 6 found theirs. Age, gender, disability accommodation, and race did not significantly affect student engagement with the syllabus. Referring to the syllabus, preference for design and interactivity, the impression of and interest in the syllabus, and the text/video format of the course overview and instructor introduction significantly affected engagement.

Qualitative findings

We examined qualitative data from three sections (Sections 1, 4, and 5) based on the quantitative results. 16 participants' post-survey responses per section were included. Participants in only Section 4 were shown videos. Including videos in a syllabus resulted in positive perceptions and a preference for the inclusion of videos in a syllabus. Sample quote: "I think making a syllabus more interactive [with videos] is a great way to get students involved in reading it [the syllabus]" (Section 4). Participants who did not experience course overview videos in this study expressed concerns about the use of video in the syllabus. Sample quote: "When I refer back to the syllabus, I want to find a certain section to read quickly, not comb through a 5-minute video" (Section 1). Participants in all the three sections praised the inclusion of design in their syllabi, citing increased visual appeal, ability to skim quickly, engagement, and interest. Participants in Section 4 were particularly positive about the efficacy of design in their syllabus. Sample quote: "All of the words [text-only] can seem overwhelming at times, so it might be beneficial to include more images" (Section1). Participants from sections 4 and 5 found their syllabi more interesting and enjoyable than those from Section 1, possibly due to the interactivity included in Sections 4 and 5. Sample quote: "It [a syllabus with short videos, images, and colorful infographics] is more interesting and visually appealing than a wall of text that makes everything seem of equal importance" (Section 1).

Figure 1

Design and Interactivity Samples from the Online Syllabi of Sections 1, 4, and 5

Section 1 Section 4 Section 5

Conclusion and recommendations

Design and interactivity in an online syllabus significantly affect students' engagement with the syllabus. We recommend including colors, images, videos, accordions, and tabs. We found that age, gender, race, and disability accommodations did not have a significant effect on student engagement with the syllabus. We suggest that further research is needed, given the diverse student population in higher education. Our study suggests that students prefer instructor introductions that are presented via text. We recommend including a short course overview video.

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The Marketization of Education: A Microanalytic Analysis

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Abstract: The neoliberal turn inspired processes of marketization, meaning that Discourses originating in the business sector are applied to educational contexts to construe education as a competitive market selling products and services to consumers. But *how* does marketization occur? In this poster we use linguistic-ethnographic methods to explore how the marketization of educational discourse played out in the context of a learning community comprising educational practitioners who were exploring the notion of teacher inquiry and who were led by an organizational consultant who encouraged them to adopt a business Discourse. Our findings revealed an initial resistance to this Discourse, an incompatibility between business and educational Discourses, and the means by which the business Discourse ultimately took hold.

Theoretical background

A figured world is "a picture of a simplified world that captures what is to be taken for typical" (Gee, 2011, p. 71) that is construed by individuals and communities to make sense of their social surroundings and their positions within them. The education system is one example of a figured world that can be construed in various ways. Big-D Discourses are "ways of combining and integrating language, actions, interactions, ways of thinking [etc.] … to enact a particular sort of socially recognizable identity" (Gee, 2011, p. 201). Discourses are reflexively linked to figured worlds, meaning that they are co-constitutive (Gee, 2011). Individuals draw on the resources that are available to them through their social identities and discursive repertoires to construe figured worlds. Concurrently, the way in which figured worlds are construed foregrounds certain Discourses that are taken as normal. Figured worlds and Discourses are fundamental elements of learning, when it is viewed as a situated activity that is defined in terms of identity and community (e.g., Lave & Wenger, 1991).

Fairclough (1993) argued that the adoption of a neoliberal Discourse can fuel a process whereby the figured world of education is construed as a free market driven by profit and competition. In Israel, where we conducted our study, the high-tech sector is especially influential. Several scholars have therefore focused on the ways in which Discourses imported from high-tech have shaped Israeli education. For example, Ramiel (2019, p. 11) argued that redefining Israeli learners as *users* "universalizes the teacher, student and schools, […] tends towards 'global uniformity' or a 'one size fits all' approach [and] unifies all students under an uncritical technological solutionism" (see also Tamir & Davidson, 2020). In this poster, we explore some micro-processes underlying one attempt to introduce a business Discourse imported from high-tech in order to marketize education. Specifically, in this case study we investigated one community's learning trajectory, asking how a business Discourse came into play, what figured worlds interlocutors construed in response to it, the challenges that they encountered, and how, ultimately, the business Discourse shaped the learning process in consequential ways.

Methods

Context

The data for this poster were collected as part of a Research-Practice Partnership between our University and the INBAR Institute (we use pseudonyms throughout), a "national intercollegiate center for the research and development of curricula and programs in teacher education" (INBAR website). Recently, the Institute's leadership was dissatisfied with intra-organizational coordination and knowledge management. To improve them, INBAR established a learning community comprising nine professionals representing six different units who met bi-weekly, to explore the notion of *teacher inquiry*. In addition to the shared bi-weekly meetings, the team also met for a series of three two-day seminars, which marked the beginning, middle, and end of their yearlong collaboration. These seminars were led by Eric, an experienced organizational consultant who used to work as a software developer. In the sessions he led at the seminars, Eric imported discursive tools from high-tech that were business-oriented to improve the group's work and outcomes. We identified these sessions as a unique opportunity to analyze the marketization of education.

Analysis

We drew on linguistic ethnography, which combines the rigor of linguistics with the situatedness of ethnography (Rampton et al., 2015). This involved a review of our entire corpus of field notes, selection of a sequence of interactions that was especially *telling* (Tabak & Baumgartner, 2004), detailed transcription, and discourse analysis methods to investigate the emergence of interactive meaning in the sequential unfolding of the interactions. Our turn-by-turn analysis of the sequences drew on Gee's (2014) approach to discourse analysis, and particularly on the view that in addition to conveying ideas, language also functions as means of engaging in socially recognizable activities and identifying as certain types of people. Hence, we asked about each turn at talk: (1) What ideas the interlocutors were conveying; (2) what socially recognizable activities they were engaged in (or were encouraging others to engage in); and (3) what socially recognizable identities they assumed.

Data sources

As participant-observer, Etan attended all team meetings, documenting them through video recordings and field notes, and conducted 16 semi-structured interviews with the team members. Our analysis focuses on a sequence of three interactions that was purposefully selected because it was especially telling vis-à-vis our research questions. We also note that our interpretations embodied a broader ethnographic analysis and reflected our understandings of the entire data set and Etan's experience as participant-observer.

Findings

In this section, we analyze a sequence of three brief interactions that occurred during the second 2-day seminar in February 2022, which portrays a shift in the learning community's Discourse. Prior to the seminar, the Discourses employed by the community and the identities assumed by its members were primarily academic: they spoke in terms of theories, data, and research methods; and conducted literature reviews and interviews to advance their goals. Yet Eric, the group moderator, encouraged them to forgo their academic Discourse, and adopt elements drawn from a business Discourse that he associated with high-tech culture, instead. The first interaction in this sequence of three shows that when these efforts were abstract and overt, the group resisted them. The second interaction reveals some tensions and obstacles that emerged when there were multiple and incompatible Discourses at play. And finally, the third interaction shows how the use of a cognitive tool ultimately mediated a process of marketization, as the team adopted a business Discourse to engage in their educational pursuits.

Discussion and conclusion

In this poster, we focus on the marketization of education, and singled out one process by which the figured world of education came to be reconstrued as a business. While far from exhaustive, our microanalytic account showed how one learning community grappled with an attempt to shift its knowledge building activity away from an academic Discourse, and towards a business one that was imported from the high-tech sector. Despite initially resisting the effort to marketize their discourse, the community ultimately succumbed, begging the question: Why?

Our data suggests that one possible reason for this outcome may be that the community resisted the business metaphor only so long as it was advanced overtly and in the abstract (interaction 1). However, adoption of the Business Model Canvas to advance the team's knowledge was a far more subtle proposal, and thus less contentious. Although it initially generated some confusion (as outlined in interaction 2), it was seen as a productive way to move forward nonetheless (interaction 3), which significantly impacted the team's work.

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Exploring the AI Experiences of Rural Students and Teachers: A Sociocultural Perspective

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Abstract: Artificial intelligence (AI) education is especially needed for young rural students who have limited access to high-quality learning opportunities. We are developing an AI-centered learning environment that introduces rural middle grades students to AI concepts through digital game design activities. We interviewed students and teachers on their understanding of and background with AI. The results will guide the design of our professional development for teachers and game design activities for students.

Introduction and theoretical framework

Artificial intelligence (AI) education is increasingly seen as a critical endeavor for students to be successful in the world and workplace of the future where AI will be ubiquitous (Touretzky et al., 2019). It is essential to expand efforts to increase students' interest in AI and provide youth with early AI learning experiences, especially middle grades students who are developing their perceptions and dispositions toward STEM (English, 2017). Rural schools, which represent approximately 80% of North Carolina schools, are smaller and more isolated than their urban and suburban counterparts and face challenges with attracting and retaining high-quality teachers and student access to advanced coursework in STEM (Assouline et al., 2017). Game design holds potential for cultivating student interest and knowledge in computing (Comber et al., 2019), and game-based learning shows potential for teaching AI concepts to K-12 students (Lee et al., 2021). Our AI-centered learning environment, called AI PLAY, introduces AI concepts to middle grades students (ages 11-14) and teachers through camps and school-based programs in rural North Carolina. In this work, we present our initial findings from student and teacher interviews on their understanding and use of AI.

Sociocultural theories posit that all learning must consider social and cultural dimensions of human interaction and that these dimensions become internalized as children learn and mature (Vygotsky & Cole, 1978), indicating that childrens' surroundings—be they human or environmental—shape their knowledge and experiences. Our context, computer science (CS) in general and AI in particular, is not broadly accessible to all students. Rural students often have restricted access to innovative educational opportunities and their families and teachers are more likely to not have had these experiences either. As such, a goal of our work is to augment rural students' social capital by fostering their skills to learn and use CS and AI now and in the future.

Methods

We conducted interviews and focus groups with rural participants: nine students and two teachers. All interviews were conducted and recorded via Zoom video conferencing. We utilized a semi-structured protocol that queried participants on their background knowledge of AI, experiences with coding, and gaming interests. Two members of the research team individually open-coded the transcripts and met to discuss the codes. A third team member facilitated collapsing codes into themes, which we report below.

Findings

Teachers

Our teacher participants taught at rural, low-income schools and their courses focused on prescribed curricular materials that did not specifically target goals for in-depth CS or programming concepts. Both teachers acknowledged providing some time for their students to experiment with coding using physical computing with drones or robots, with one describing these experiences as an "incentive." Both teachers had either limited or dated prior training with CS and programming. When asked about their knowledge of AI, both teachers candidly expressed that they knew very little; however, they were receptive to professional development (PD). One teacher noted "[AI is] obviously kind of trending in that direction in the future, so I think it's important for students to learn about it." Both teachers felt that students would be motivated by an engaging game design-based learning experience to learn about AI.

Students

When asked to share what AI is, students' responses included the following, under the theme of *programming and general computer usage*: "stuff that's online," "computers [are] robots," and "a coffee machine." Under the theme of *AI awareness and understanding*, students' responses ranged from superficial awareness (i.e., "smart computers") to more pronounced understandings of AI (i.e., "the doorbell camera… will pop on" and "drones can water plants"). When asked to share their background with programming and gaming, most students knew of Scratch and many had coded a game using Roblox. Students mentioned learning about programming from a parent, YouTube, or simply from playing online, and not in school. All students indicated they played digital games and when asked their interest for learning about AI through digital game design, students expressed a high degree by saying "if you know how to code you could essentially get a job that involves coding" and "it'd make the game more funner (sic) to play."

Discussion, conclusions, and future directions

We approached understanding what rural middle grades learners and educators know about AI by interviewing students and teachers. Despite having a limited number of participants, we surmise that their experiences are common across rural areas of our state. Sociocultural perspectives help us understand the role of a person's immediate environment—people and devices—in what they know. We know that rural schools and families often lack access to the internet, suitable devices, and diverse learning opportunities. The students in this initial study have more of an understanding of AI, albeit often superficially, than their teachers, which has prompted us to consider the accuracy of what students know about AI and CS. North Carolina does not certify middle grades teachers as CS teachers; as such, middle grades students tend not to have teachers with specific training in CS and programming. One of our goals is to augment the training middle grades teachers receive in service of exposing more students to advanced technologies, programming, and AI. Additionally, teachers' awareness of what students could learn about AI was limited and therefore, any professional development must explicitly teach these concepts to teachers. Students had high enthusiasm for playing and designing digital games; therefore, teaching advanced technologies through game design holds great potential for their learning and potentially their career trajectories. These initial findings are essential as we design a set of prototype activities on core AI concepts for students and PD activities and resources for teachers.

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Analyzing Collective Imagination: A Complex Systems Approach

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Abstract: Typical approaches for investigating collaborative learning and problem-solving neglect how individual interactions give rise to emergent group-level behaviors. In this study, I adopted a complex systems approach to analyze collective imagination during a collaborative fiction writing activity in a high school classroom. I qualitatively coded discourse data at two levels of analysis: individual talk turns and collective imagination episodes. I employed nonlinear computational analysis techniques to examine the multilevel time series data.

Introduction

Imagination is a complex form of mental activity where consciousness transcends the here-and-now of proximal experience to mentally represent objects, ideas, images, and world states not currently present (Vygotsky, 1980). It is both an individual cognitive process as well as a situated and distributed social process (Kolovou et al., 2021). Movement towards a shared imaginary space has been suggested to coincide with collaborative emergence: a flow of ideas among individuals who are directed toward the same imagined object (Kolovou et al., 2021).

Typical approaches for investigating collaborative learning and problem-solving neglect the dynamics of how individual interactions give rise to emergent group-level behaviors, which generally exhibit nonlinearity where patterns at the macro-level have different properties from the constituent parts (Hilpert & Marchand, 2018; Jacobson et al., 2019). Quantitative linear cause-effect models are only apt for contexts where a linear relationship among components exists (Hilpert & Marchand, 2018). Qualitative methods are better suited for examining nonlinearity and emergence, but the vast amount of data and reliance on textual description can obscure dynamic patterns (Jacobson et al., 2019). There is growing recognition of the importance of using a complex systems approach for investigating learning and collaboration (Jacobson et al., 2019; Hilpert & Marchand, 2018).

In this study, I adopted a computational complex systems approach to analyze a collaborative fiction writing activity in a high school classroom. Specifically, I sought to investigate the following hypotheses:

H1: Group interaction processes will exhibit characteristics of a complex dynamical system.

H2: The emergence of collective imagination will be associated with a flow of ideas among participants.

Methodology

Participants and context

The participants were students in an environmental science class at a public high school in Northern California. They were taking part in a learning experience that integrated engineering and fiction writing to develop stories depicting sustainable climate futures. There was a total of 48 students split into 12 groups of 3 to 5 students each. Participants self-reported demographic information (gender: 65% female, 35% male; age: M = 17, SD = 0.8; race/ethnicity: 71% White, 12.5% Hispanic/Latinx, 12.5% Asian, 2% Native American, 14.5% did not respond). I focus on a single group of four students during a collaborative writing activity to demonstrate the methodology.

Data collection

Dynamic behavior of group interactions can be observed in microgenetic time series data where many measures of the same variable are taken in close proximity over time (Hilpert & Marchand, 2018). Since group-level behaviors emerge from and influence individual-level interactions, one should examine multiple levels of analysis (Hilpert & Marchand, 2018). I considered both individual-level talk turns and group-level collective imagination episodes. To capture this time series data, I audio recorded and transcribed all group utterances.

Data analysis

I used qualitative methods to code the collaborative discourse data and computational nonlinear analysis techniques to examine the coded discourse. Utterances were coded at two levels of analysis (see Table 1). At the level of an individual talk turn, I coded utterances using a collaborative problem-solving scheme. At the level of a discursive episode, I used a binary code for whether two or more members were in a state of collective imagination. Every talk turn received an individual discourse code and a group-level collective imagination code. Two researchers independently coded the entire transcript (~350 utterances) and achieved a pooled Cohen's Kappa of 0.91, indicating excellent inter-rater reliability.

Table 1

Codes for individual-level discourse and group-level collective imagination

Code	Description
1. Team Process (TP)	Utterances that regulate how members organize themselves to get work done.
2. Information Sharing (IS)	Utterances that request or provide simple information about the task itself.
3. Knowledge Sharing (KS)	Utterances that request or provide knowledge beyond simple information.
4. Idea Request (IR)	Utterances that request ideas for addressing the task.
5. Idea Proposal (IP)	Utterances that propose ideas for addressing the task.
6. Idea Elaboration (IE)	Utterances that elaborate on a previously stated idea.
7. Idea Analysis (IA)	Utterances that seek to clarify, evaluate, or (not) support an idea.
8. Acknowledgment / Agreement (AA)	Utterances that recognize receipt of information or that express (dis)agreement.
9. Tangent / Off-task (TOT)	Non-task related utterances.
10. Exclamation / Incomplete (EI)	Exclamations emphatically express emotion.
Collective Imagination (CI)	Two or more members have disengaged consciousness from the proximal experience and are directed toward the same imagined intentional entity.

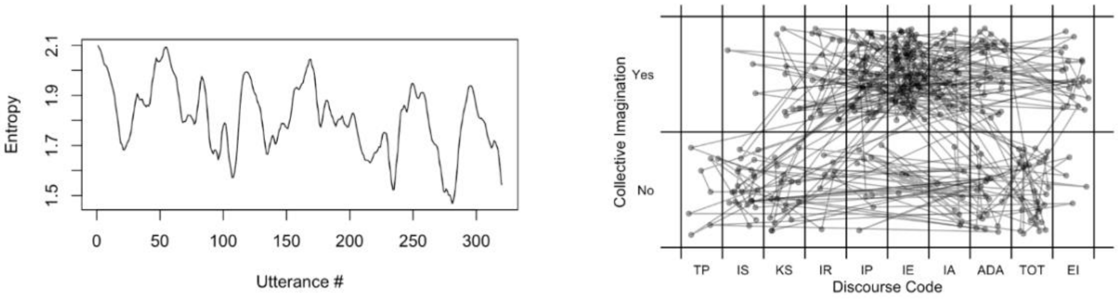
Regarding H1, one characteristic of a complex system is chaotic dynamics—that is, a balance of randomness and order in system behavior (Hilpert & Marchand, 2018)—which I evaluated using Shannon information entropy, a widely used indicator of disorder (David et al., 2022). To examine H2, I employed two techniques: state-space grids and lag sequential analysis (David et al., 2022). State-space grids are a graphical representation of a system's trajectory as it moves through the range of possible system states defined by the relationship between two categorical variables that are synchronized in time. Lag sequential analysis (LSA) can be used to identify sequential patterns of behaviors. One indicator of the degree of association between two time series in LSA is Yule's *Q*, which yields values between +1 (complete positive association) and -1 (complete negative association).

Results and discussion

Entropy values of the discourse code time series (Figure 1, left) range between 1.5 and 2.1, indicating neither random nor deterministic behavior (David et al., 2020). Thus, H1 is supported: the group interaction exhibits characteristics of a complex system. The state-space grid trajectory (Figure 1, right) shows that collective imagination was most highly associated with idea proposal (IP), idea elaboration (IE), and idea analysis (IA). Significant positive Yule's *Q* values were also found for IP ($Q = 0.49$), IE ($Q = 0.92$), and IA ($Q = 0.36$). Thus, H2 is supported: collective imagination is associated with a flow of ideas. While this study focused solely on a single group interaction, the results demonstrate the utility and novelty of the approach.

Figure 1

Time series plots of discourse code entropy values (left) and state-space grid trajectory (right)



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Student Motivation in Unplugged Computational Thinking Activities in Upper Secondary Science Education

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Abstract: In this case study, we investigate the use of unplugged Computational Thinking activities to learn topics within biology and chemistry. The tasks involved constructing decision trees, and thus algorithmic thinking. The students found the activities interesting but also difficult. At the same time, there are signs of utility value because the constructed decision trees could be used for solving exam tasks. Even though the construction of decision trees seems to be a promising way to include CT in science teaching, it may be difficult to do so in every science subject.

‘Unplugged’ computational thinking in upper secondary science education

Computational thinking (CT) is a set of computer science concepts and practices that can be applied to many different disciplines for problem solving and understanding (Grover & Pea, 2013). Incorporating CT into science education may help foster students to learn science content and practices (Wilensky & Reisman, 2006). A large strand within the literature emphasizes that CT can be performed ‘unplugged’, that is, without the step of coding the designed algorithm into a computer program (Caeli & Yadav, 2020). The claimed pedagogical advantage is that students become familiar with the steps of the problem-solving method without the additional complexity of having to learn a code language. This is particularly relevant when CT is utilized to learn other disciplines than computer science. However, there are only a few studies of unplugged CT activities in upper secondary science education, and the few that are published focus on students’ understanding of for instance conceptions of natural selection (Peel et al., 2019). So far there has been very little focus on students’ motivation in relation to unplugged activities. Accordingly, we know very little about the extent to which students want to deal with unplugged CT in science education. In this case study, we therefore investigate students’ motivation in two unplugged CT-activities at the upper secondary level. The study is part of a larger, four-year multiple-case study on embodied CT.

Methodology

This study involves one teacher and his Year 11 biotechnology class, which he taught both in biology and chemistry. The class size was 26 students. The teacher developed two unplugged activities on constructing decision trees, which involves algorithmic thinking, a central element of CT (Grover & Pea, 2013). Tasks were solved in small groups of students. In biology, the task was to construct a decision tree algorithm to be able to distinguish between 7 different inheritance paths in genetics: 1) autosomal dominant, 2) mitochondrial inheritance, 3) dominant X-linked, 4) Y-linked dominant, 5) recessive X-linked, 6) co-dominant, and 7) autosomal recessive. The students had to construct relevant questions for a given inheritance, which could be answered with yes/no, for example: Do all children with trait X also have at least one parent with trait X? Does a father with trait X always have daughters with trait X? The decision tree then had to be tested on several family trees that had been used in previous exam tasks. In chemistry, students were tasked with constructing a decision tree for identifying chemical substances. Classical chemical analysis relies on chemical reactions between the material being analyzed (the analyte) and a reagent that is added to the analyte that is easily detected. For example, the product could be colored or could be a solid that sediments from a solution. The task was to design a decision tree to identify an unknown positive or negative ion from a scheme of precipitation reactions where certain mixtures of readily soluble salts resulted in the formation of a precipitate and eventual color. The next step was to test the algorithm on 10 unknown solutions in the laboratory and count how many reactions they minimally had to make to ensure correct identification. Finally, students calculated goodness-of-fit of their proposed algorithmic model.

The two sessions each lasted 90 minutes. To evaluate students’ motivation, we used self-report with open questions supplemented by classroom observations and informal interviews. In the self-report, produced in a pen-and-paper format, students were asked to describe their positive and negative experiences with the activity and to comment on whether the activity made the content easier to understand. Thus, we did not directly prompt for expressions of motivation so as not to provoke biased responses from the students (e.g., to give answers that they believe the researchers want). Observations, conducted by the first author, were focused on situations in which students were engaged but also on situations where students appeared confused, frustrated, or demotivated. Students who appeared to display particularly high or low motivation were interviewed on how they experienced a given situation, and why it was or was not motivating. The interviews were short, lasting 1–2 minutes.

The analysis was data-driven, as we searched for signs of how involvement impacted students' self-reported understanding of the science content and of motivation. In our search for signs of motivation, we did not limit ourselves to one theory but were open to statements being interpreted inductively in different directions, especially interest (Hidi & Renninger, 2006), self-efficacy (Bandura, 2001), and utility value (Eccles & Wigfield, 2020). The following exemplifies our analysis: In the statement "The activity was fun, especially at the beginning when you had to make the system", we interpret 'fun' as a sign of enjoyment, which is proxy for interest and intrinsic motivation. In the statement "I personally think it was boring" we interpret 'boring' as an epistemic emotion and sign of absence of interest. "It is something we can use in the future" indicates experienced utility value.

Results

The tasks were challenging to most students and required them to engage in a "detective task" (their wording). In biology, the students found it difficult to come up with enough relevant questions regarding inheritance for their decision trees. Several groups initially used trial-and-error. By the end of the lesson, half of the students had a decision tree that worked for all seven types of inheritances, while a third succeeded in making parts of an overall algorithm. When an algorithm worked on a random inheritance path, there was great cheering in class. In chemistry, several groups sat for a long time and discussed while other groups started right on with chemical analysis in the laboratory. As soon as the students had constructed an algorithm that they were convinced was correct, they showed great commitment in the laboratory. However, some students were also frustrated by lack of reaction (nitrate does not react with the tested positive ions, but the students had not realized this and tried adding nitrate).

The results suggest that students find CT-activities with decision trees fun and interesting, allowing them to address curricular content in new ways. Many praised the logical thinking behind the tasks. Wordings like "new", "alternative", and "different" are proxies of interest and intrinsic motivation (Palmer, 2009). At the same time, many students also reported that the CT-activities were challenging and confusing and thus frustrating, indicating attributional thinking on task difficulty with possible consequences for competence beliefs (self-efficacy). According to students' expressions, it required a deep understanding of the biology/chemistry concepts involved to be able to create a meaningful algorithm. Finally, there are signs of experienced utility value (c.f.: Eccles & Wigfield, 2020) because the constructed decision trees were evaluated as useful for solving exam tasks.

Although the two learning tasks required algorithmic thinking, it is uncertain to what extent such decision tree tasks can be implemented in every science topic, which may be a limitation as regards the general aim of introducing algorithmic thinking into upper secondary science education.

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Sustaining Participation in an Elementary Science PD Community

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Abstract: We consider how a teacher-designed unit, *Rainbows*, became a longitudinal tool within an elementary science teacher PD community. *Rainbows* allowed teachers to enact roles of teacher, designer, facilitator, and PD designer. *Rainbows* also oriented new teachers joining the community and served as a trace of the community's practice over time.

Background and conceptual framing

Professional development (PD) fosters learning when teachers navigate the complexities of their work. Research demonstrates that one element of effective PD is its sustainability over time (Darling-Hammond et al., 2017). However, longitudinal PD communities inherently change, necessitating support for integrating new members and developing all members' practice over time. Drawing on the lens of communities of practice (CoP; Lave & Wenger, 1991), we frame learning as participating in community practices that are mediated by "novel cultural tools that trans[form] the action" over time (Wertsch, 1998, p. 42). This analysis considers how a teacher-designed unit known as *Rainbows* became a multimodal cultural tool that transformed the practices of a CoP of elementary science teachers. *Rainbows* was a phenomenon-first based science unit focused on light and color. As *Rainbows* evolved over time, it reflected new shared understandings of what it means to teach science. It also created opportunities for members to take up new roles and for new members to join the community. As teachers engaged with *Rainbows*, they enacted roles of teacher, designer, facilitator, and PD designer. We ask how *Rainbows* became a trace of learning and shared practice within our PD community.

Study context and analysis

Data came from a multi-year, design-based research study of an elementary science PD community focused on using representations and modeling to support student thinking. Year 1 included 9 teachers (Cohort 1 or C1) who participated in an initial summer workshop, academic year science lesson enactments, and 4 video club meetings (Sherin & Van Es, 2009). Year 2 was impacted by COVID-19; no new members joined. In Year 3, 7 of the C1 teachers returned and took on leadership roles. Six new teachers (Cohort 2 or C2) joined the community. All 13 teachers participated in Year 3 summer workshops and academic-year science lesson enactments and video clubs. We focused on moments where *Rainbows* was an explicit part of PD activities. Using content and thematic analysis (Morse, 2012), we analyzed how *Rainbows* evolved to transform community practices and participation.

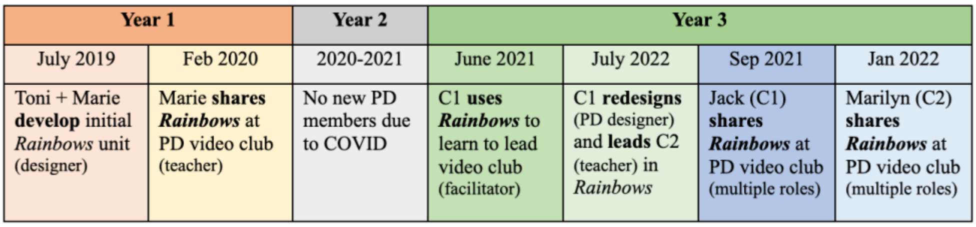
Findings

Figure 1 traces how *Rainbows* supported teachers' participation over time. The initial development of *Rainbows* (Year 1) helped 4th grade teachers Toni and Marie M. (self-chosen pseudonyms) enact roles as designers and teachers to take up new pedagogical practices. In summer Year 3, C1 took up new roles as facilitators and PD designers by engaging with the *Rainbows* unit in new ways. *Rainbows* also apprenticed C2 members into the community. During academic Year 3, *Rainbows* supported longitudinal learning for community members as reflective practitioners.

Year 1: Tool development and teacher learning

During Year 1 summer PD (July 2019), Toni and Marie took on the role of designer as they planned a unit for 4th grade standards on light and color. While they initially struggled to apply phenomenon-first approaches, their collaboration culminated in the original *Rainbows* unit, which both teachers implemented during the 2019-2020 school year. Marie reflected on students' learning in *Rainbows* during a PD video club, noting that practices such as modeling helped students "construct some type of meaning" about science phenomena. *Rainbows* served as a tool during Year 1 to introduce teachers to pedagogical approaches as they enacted roles of designers and teachers.

Figure 1
The Rainbows Unit Over Time



Year 1		Year 2	Year 3			
July 2019	Feb 2020	2020-2021	June 2021	July 2022	Sep 2021	Jan 2022
Toni + Marie **develop** initial *Rainbows* unit (designer)	Marie **shares** ***Rainbows*** at PD video club (teacher)	No new PD members due to COVID	C1 **uses** ***Rainbows*** to learn to lead video club (facilitator)	C1 **redesigns** (PD designer) and **leads** C2 (teacher) in *Rainbows*	Jack (C1) **shares** ***Rainbows*** at PD video club (multiple roles)	Marilyn (C2) **shares** ***Rainbows*** at PD video club (multiple roles)

Summer year 3: New roles and new members

In June 2021, C1 teachers prepared to take on a new role of facilitator for incoming C2 members. A video clip of Marie teaching *Rainbows* became a tool that C1 teachers used to learn how to facilitate the familiar community activity of video club. C1 teachers also took on a new role of PD designers as they collectively re-designed *Rainbows* to integrate their learning from the PD community. They enacted their role as facilitators as they implemented their adapted *Rainbows* unit and led video club activities with new C2 teachers in July 2021. These experiences allowed incoming C2 teachers to become oriented to pedagogical practices valued by the PD community (e.g., modeling, phenomenon-based approaches). During summer 2021, *Rainbows* became the bridge between C1 in their roles as PD designers and facilitators and C2 in their roles as teachers and designers.

Academic year 3: Longitudinal learning and practice

Rainbows supported teachers in developing their practice over time. Both Toni and Marie continued to revise *Rainbows* and enacted the unit yearly with their students. Other C1 teachers also adapted and implemented *Rainbows*, as did C2 teachers in Year 3. Teachers from both cohorts brought implementations of *Rainbows* to video clubs, where classroom video and student work supported the whole community's learning about how representations and modeling support students' science thinking.

Discussion and implications

Analysis demonstrates how *Rainbows* was taken up by our PD community as a cultural tool that shaped practice and participation. As it was adapted for different purposes, the unit supported access to shared and developing understandings of practice and to roles of learner, teacher, designer, facilitator, and PD designer. It also challenged traditional power roles by redistributing power across researchers and teachers. We argue that *Rainbows* was significant in part because it was created by C1 teachers, rather than researchers. In further analyses, we hope to extend explanations for how and why tools like *Rainbows* support teacher learning in longitudinal PD communities.

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Professional Learning Communities in Higher Education: Investigating a Possible Introduction Among University Faculty

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Abstract: This study explores the introduction of faculty Professional Learning Communities (PLCs) in order to enhance instructors' teaching competencies in higher education. The study identified faculty PLCs structures that encourage evidence-based reform in faculty members' teaching practice. Data were collected from 127 faculty using an online questionnaire. Analysis identified factors relating to the willingness to engage in faculty PLCs and sources of information for shaping teaching reform. We discuss the implications of possible new directions of supporting faculty in their efforts to enhance their teaching competencies. Policy implications point to a novel approach to supporting faculty for enhancing their teaching competencies.

Theoretical framework

Professional Learning Communities (PLCs) refer to small teams of instructors with shared interests and visions that meet regularly, exchange expertise, and work collaboratively with the goal of improving their teaching practice (e.g., Margalef & Roblin, 2016). PLCs are viewed as continuously collaborating groups of like-minded colleagues, sharing and engaging together in the practice of learning for improvement in daily business, connected by similar values, opening up to one another trustfully about routines and obstacles, discussing openly and thus contributing to each colleague's concern (e.g., Stoll et al., 2006). In the context of PLCs, professional learning takes the form of an ongoing, sustained, intensive and collaborative approach to improving teachers'/instructors' effectiveness in raising student achievement and enhancing student learning experiences.

Although a recently growing number of studies have investigated the use and function of PLCs at primary and secondary education levels, there is to date relatively little evidence whether changes occurred within PLCs in higher education can be sustainable beyond the faculty participation in PLCs (Tinnell, Ralston, Tretter & Mills, 2019). Faculty PLCs are playing an increasingly important role in higher education, connecting faculty with their students and colleagues (Cox, 2001), and placing an emphasis on evidence-based changes in teaching (Ralston, Tretter, & Kendall-Brown, 2017).

Purpose and research questions

This study explores the potential introduction of faculty PLCs ay to enhance instructors' teaching competencies. The current study focuses on a "young," small, private university in Cyprus. Our purpose in this paper focuses on identifying faculty PLCs' structures that encourage long-term sustainability of evidence-based teaching reform in faculty members' teaching practice. Data collected aimed to investigate the characteristics of productive and sustainable faculty PLCs. Toward this end, the study seeks to answer the following two research questions: (1) Which factors are related to the faculty's willingness to engage in PLCs? (2) Which sources of information are considered important in shaping their teaching?

Methods

Data were collected from 127 faculty at the end of the Spring semester of 2022 through an online questionnaire (https://qr.page/g/4vSda0UjlIh). Working from the literature on PLCs and faculty PLCs, we identified several main themes related to the ways that are supportive of the productive work of PLCs, as well as aspects that may encourage or discourage faculty to participate in long-term changes in their teaching competencies. The questionnaire examined the current state of faculty PLCs at the University in order to identify good practices and needs for supporting and sustaining faculty PLCs as tools for professional learning, growth, and development.

Results

Analysis of the data indicated factors that relate to the faculty members' willingness to engage in PLCs as well as sources of information that participants in the survey highlighted as important in shaping their teaching. Factors included: (i) sharing teaching experiences with colleagues, (ii) gaining valuable information from hearing about colleagues' experiences, (iii) sharing experiences about student results, (iv) experimentation with new ideas, (v) meetings with colleagues, (vi) reflecting with colleagues about common teaching issues, (vii) working in a small group of colleagues on improving teaching, (viii) reflecting on own teaching. Factor analysis indicated that 8 items included in the questionnaire loaded in one factor and with a good Cronbach's alpha score (α =0.85).

Further, a series of exploratory bivariate analyses were performed using gender, mode of employment (full-time or part-time faculty), rank, and the academic school that the participants belong to. The analysis showed that the demographic variables did not distinguish different modes of willingness. In effect, this possibly suggests that there was a uniform approach and positive willingness to engage in faculty PLCs. Interestingly, this willingness to engage in faculty PLCs did not relate to the workload of the teaching staff. Willingness to engage in PLCs was positively related to the perceived importance of teaching among other academic activities.

An important finding related to the sources of information that participants highlighted as important in shaping their teaching. These related to both informal and formal feedback instructors get from their students, student learning results from exams and/or assignments, discussion of feedback from students with the program coordinator or the department chair and other colleagues, and participation in workshops and/or seminars. Finally, the participants suggested several thematic areas for faculty PLCs that would be of interest in the future. These were (i) pedagogical principles & methods of teaching (including inclusive learning & differentiation), (ii) digital tools & emerging new technologies for teaching & learning (including in-class activities for enhancing student engagement during lectures), (iii) evaluation and assessment strategies and approaches, and (iv) interactivity between the students, the instructor & the course materials.

Discussion

Overall, the study revealed participating instructors' very positive inclination to engage in PLCs. Factors connected to that willingness were in line with the literature about important characteristics for productive instructors PLCs, related to e.g., having shared values and vision, adopting a collective responsibility for student learning, and actively and regularly engaging in individual and group professional learning (Bolam et al., 2005; Hord, 1997; Stoll & Earl, 2003; Vescio, Ross & Adams, 2008). Of course, it needs to be acknowledged that the lack of differentiation identified in the ways faculty responded to the questionnaire could be influenced by a self-selection bias of the people who have opted to participate in the study in the end.

An additional important finding relates to the ranking of the items identified by participants in the study as sources of information that shape their perceptions of teaching. Participating instructors seem to feel that collaborative pedagogical reflection is valuable for their teaching duties, although prior research has suggested that the notion of community-wide collaboration is usually absent from higher education meetings, curricular planning, and pedagogical discussions (e.g., Massy, Wilger, & Colbeck, 1994).

Taken all these together, the findings point towards new directions in faculty professional development, away from traditional approaches of lectures or seminars, focusing more on peer interaction and support, and student data focusing on learning outcomes aligned with the increasing research interest in the field. At the same time, findings point to a direction for further, more detailed investigations about the impact of faculty PLCs on higher education (Richlin & Cox, 2004; Tinnell et al., 2019).

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"Let's Go; We're Writing a Song": Co-Creating Auditory and Placial Space in an Afterschool Music Program

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Abstract: Auditory space, an underrecognized dimension of placial space, is key to understanding and designing unique learning environments. In this single case study, we analyze an interview with two afterschool music program teachers. We found that as students learn music, co-created auditory space progresses from merely consuming music or making individual sounds, to listening to and playing with one another, and finally collaboratively composing songs. Implications for attending to sound when designing learning environments.

Introduction

Sounds, like birds in nature or traffic on the street outside your home, play a particular role in situating our understanding of physical space and place (Lochhead, 2019). Likewise, music plays an important role in setting cultural space and place (Low, 2014), the rhythms and melodies of a neighborhood market, a holiday festival, the radio on a car ride with your mom. Music researcher Judy Lochhead (2019) describes music as *placial*, emphasizing its role in our lived relationship with the physical space where "aural dimensions are often unarticulated" (p. 696). Like Lochhead, we use the anthropological term *placial space* to indicate the complex combination of physical and relational space in learning environments. In classrooms, physical attributes like desks and other learning tools unite with interpersonal interactions to create new spaces and sites for learning (Massey, 2005). While sharing physical markers with in-school contexts, afterschool spaces often offer more relational flexibility through casual relationships with teachers and less stringent structures and rules for behavior.

From a theoretical standpoint, we consider placial space to be something in the process of becoming, interactionally constituted, and both physically and socioculturally formed (Massey, 2005). The arts, particularly music, set placial space in unique ways through playing, composing, and movement practices. Arts learning is both individual and social, a representational process described as an expression of collective meaning-making or emergent student voice (e.g, Peppler et al., 2022). Like other sites for learning, arts and music-making spaces can be described as co-created (e.g., Dahn et al., 2023) and "made meaningful through peoples' engagement with them" (Taylor & Phillips, 2017, p. 596). While there are unique sounds that overlay our sense of physical space in a learning environment, little is known about the ways educators describe and interact with sound in a classroom or afterschool setting, or how they use music production as a tool for demonstrating or externalizing learning. In this poster, we consider the ways music overlays a learning setting by asking the following questions: *How do teaching artists describe auditory space in relation to placial space in an afterschool music program? How do auditory space and music learning interact throughout the duration of the music program?*

Methods

Our poster is part of a larger study based on semi-structured interviews conducted with pairs of teaching artists and classroom teacher collaborators. For this single case study (Cresswell & Poth, 2018), we focused on a teaching artist duo, Nick and Michelle, who taught a high school music afterschool program in the 2021-22 school year. Interview questions included thinking about designing for space in their classroom environments, and the role of student agency in co-creating space. We analyzed the interview by coding for mentions of physical space, relational space, music, and other sounds. We then created a qualitative timeline identifying cooccurrences of descriptions of music and sound with placial space. Finally, we analyzed the timeline for the trajectory of change in participation and musical representation from the beginning, middle, and end of the music program.

Findings: Changes in music learning and auditory space

Teaching artists described auditory space in relation to placial space in a few key ways. At the start of the program, students entered the physical space of the music room with one wall lined with keyboards, guitars, and drum sets, and another wall set with rows of chairs with music stands. The center of the room was set for a teacher to act as conductor and accompanist, with a laptop and pickups for amplified sound output. The teaching artists encouraged students to tinker with the instruments and explore the sounds they make explaining, "the approach to space is really open ended and experimental, experiential, and then students gradually [decide] this is where I want to organize my space." The placement, physical feel, and sound of the instrument affected a student's choice of what to play and where to play it in the music classroom. Michelle emphasized the affordances of the afterschool space in responding to student needs, "[we] get input from students of what they want, what is a space for them where they feel comfortable doing what they want to do." That co-creation of auditory space, driven by listening to student interests, also played out in repertoire selection, where students brought in song requests, learned covers, and eventually wrote and recorded their own song.

As the program progressed, the students went from recognizing and experimenting with sound, to understanding the ways sound interacts in auditory space, Nick described the placial space shifting as the program progressed based on sound production and the students' need to hear one another as they learned to play together. "It has to do with the bands and being able to hear the drums when you're playing, or like being able to hear the bass." Musically, drums and bass set beat, rhythm, and tempo, driving students nearer to one another so they can follow along together. Nick then explained, "It was also about individual students feeling comfortable, scooting closer to each other gradually." While the students engaged in the physical and auditory creation of space, their relationships to one another within the space led to an added sense of belonging.

Toward the end of the program, the physical space shifted as the group left the music room to record their original song in a second space at the school, an intimate recording studio filled with professional recording equipment like a soundboard and microphones. "This professional setup felt like an escalation for everybody." One student sat in the lead engineer's chair and directed the other musicians. Nick explained to the students, "'you're pressing record. You're gonna let them know when to start playing the piece.' So there was an interplay in that space and ownership too." Musically, playing and singing their own original song connected the auditory to their roles, directing the collaboration or playing the music, in the physical space.

Nick described working in the recording studio as a powerful turning point in their music learning and song playing, "when we came back to the music room, it was like there was a whole new set of confidence that the students exhibited. We put together twice as many songs in three weeks after the studio than we did in the six months before the studio. I think that shifting space was really powerful." Michelle explains that relationships also grew, "after the recording was done there was this different camaraderie and they were all closer than they had been before. There was an ease with the way that they spoke and moved around the room that was different." Student learning was entrenched in the combination of sound and placial space.

Conclusion

Teaching artist descriptions situate co-created auditory space as key to the placial learning environment. In the context of collaborative songwriting, students' arts learning is evidenced through a shift in participation and investigative process—a progression from music and sound consumption to an external representation of their understanding of how music works as they learn to write melody and lyrics, produce and record, and finally, put the pieces together to create cohesive, collaborative, original songs. Considerations of aural aspects of placial space have implications for other learning spaces, layering sound into designs for future learning environments and considering possibilities for sound in mediating learning processes.

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Critical Race Theory and the Use of Media

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Abstract: Politics worldwide have become increasingly polarized, limiting education policies, particularly discourse on race and gender. This theoretical essay examines the relationship between Critical Race Theory (CRT) and current education policies as acts of white fragility and suggests that using media to talk about race at an early age can support the ability to think about and discuss race. Based on tenets of CRT, the author presents two illustrative analyses of media objects for use in K-8 classrooms.

Introduction

In recent decades, politics worldwide has become increasingly more polarized with the upsurge of Far-Right Movements in countries such as the US, UK, Brazil, India, and more. These extremist politics have led to policies that limit education freedom worldwide. Particularly in the US, Republican party members are using critical race theory (CRT) as a scapegoat to push the dominant narrative of a post-racial society. Several states have proposed or passed policies restricting CRT or gender studies. As learning sciences and other related fields continue to advance theories and methods to be more inclusive of the experiences and knowledge of historically marginalized communities, these policies threaten the equitable educational experience for all youth by limiting racial and gender discussions. Discussions about race and gender are essential for children and youth socialization, and media is a tool that can be used to supplement these discussions. *Media* here is defined as a societal tool used to express information or entertainment using various mediums, such as TV shows, newspapers, magazines, books, and social media. As educational freedom continues to be attacked by policy makers, what does the research on CRT, white fragility, and media tell us about how to foster children and youth's understanding of race and gender in critical and responsive ways? To explore this question, I present two illustrative analyses of how media can be used in the classroom to facilitate critical discussion about race and other forms of oppression using the tenets of CRT.

Critical race theory

CRT was introduced into education in the '90s to intentionally examine education through a racial lens, focusing on how race is a significant determinator of educational difference (Howard & Navarro, 2016). Five main core tenets of CRT are commonly referenced (Carlton Parsons, 2017): (1) Racism is seen as systemic, not as an individual act, (2) Challenges the dominant ideology of race-evasive society, (3) Examines the historical and contextual of systems, (4) Highlights the lived experiences and experiential knowledge of minority communities, and (5) Seeks the elimination of racism and other forms of oppression. CRT is not taught in pre-college classrooms to the extent that far-right policy makers lead the media to believe. Instead, tenets of CRT are used to support the teaching and learning process by highlighting minority lived experiences, allowing students to reflect on their political identities and teachers to reflect on how their own experiences impact their classroom environment (Blaisdell, 2021; Carlton Parsons, 2017; Vakil, 2020).

Race-evasiveness does not make race go away

A key theme of CRT is that racism is a systemic societal issue. In a racial-evasive society, race is theoretically not acknowledged as a factor of one's ability and opportunity, but failing to acknowledge these factors leads to inequality. This system then reinforces the dominant narrative without taking action to deconstruct it. In failing to recognize and uphold differences, the race-evasive reaction to criticism is victimization. This reaction is ingrained within white fragility in that it denies other races and gender and fails to examine the intersectionality of their privileges and oppression. *White fragility*, initially coined by DiAngelo (2018), is the defensive reaction of white people toward discomfort when discussing race that challenges their dominant worldview (Applebaum, 2017). Racial-evasiveness and white fragility are concepts that limit societal transformation as they support the existing power structure of racism. White fragility and discomfort are products of a race-evasive society that ignores the issues of race and gender until late adolescence or early adulthood - much too late. However, such fragility and discomfort can be seen as performative acts, thereby rendering them changeable. Educators can thus provide opportunities for students to address the issue of race and racism (Applebaum, 2017) to counteract these reactions and promote healthy racial and gender socialization.

Methods

I contend that media can be used to alleviate the feeling of discomfort when talking about issues of race and gender. Using media to analyze social norms and supplement racial discourse can benefit youth socialization (Stout et al., 2020). In the next section, I propose two pedagogical examples of how media can support critical race pedagogies to facilitate the discussion of race and systemic oppression. Media examples were chosen for their fictional narrative worlds that mirrored issues of race and gender in modern society.

Illustrative analysis 1: Race in manga

I present an illustrative analysis of a middle school grade-level manga, *As a Reincarnated Aristocrat, I'll Use My Appraisal Skill to Rise in the World* by Natsumi Inoue, and how tenets of CRT are presented in the text. The story is set in another world that has a government monarchy. The main character, Ars Louvent, is reborn into aristocracy and quickly finds that he needs to find capable people to serve him as he prepares for a war in the future. As the main character brings capable people to his side, he deconstructs the dominant norms of his society by recruiting a darker-skinned character and other characters of oppressed backgrounds. Some of the core tenets of CRT are evidenced in the text. For example, the text highlights the first tenet, "Racism is Ordinary," by creating a society where one race is inherently better. People in the south are seen as dumb and are to be enslaved. This idea is embedded in every part of Inoue's fictitious society; thus, they are not treated with the same rights. If they are not enslaved, they normally live in poverty as they cannot get jobs like average citizens. Practitioners can use this example to relate to the history of oppressed peoples throughout the world and history. By first relating these topics to a fictional narrative, students may find it easier to identify and discuss these social norms without participating in white fragility.

Illustrative analysis 2: Gender norms in children's media

Here I present an illustrative analysis of gender roles in children's media, examining how these roles are presented through the tenets of CRT and other critical pedagogies. Children's media marketed to elementary-age students are often used to reflect moral stories that help children understand the norms of society. As societal attitudes change, the media begins to reflect those attitudes. This can be reflected by the recent increase in media that deconstruct traditional gender norms. For example, the book *Pink is for Boys*, by Robb Pearlman, deconstructs gender norms in a simple way to visualize matter by equating colors to both genders. This book highlights two essential tenets of CRT: challenging the dominant ideology and eliminating all forms of oppression, as it dismantles traditional gender stereotypes of genderism. Educators can use this book to help children reflect and counteract the dominant gender norms at an age-appropriate level without going into complex details of oppression.

Conclusion

As this new age of conservatism continues encroaching on our educational freedoms, enacting pedagogies that support children and youth's racial socialization becomes increasingly critical to prepare students. As practitioners continue to navigate these spaces, using media as a pedagogical tool to discuss race through the tenets of CRT can help encourage students to be better equipped to engage in productive conversation around race and to make more informed political decisions. Discussing race should not be discomforting, but it will always be discomforting if it is never discussed, and acts of white fragility will continue to run rampant.

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Assessing Scientific Reasoning: A Delphi-AHP Approach

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Abstract: The present study aims to develop a framework for assessing scientific reasoning using the Delphi-AHP methods. Twenty experts were surveyed for two rounds, during which they proposed assessment indices and ranked their importance. Based on pairwise comparison of expert ratings of the indices, we constructed a final framework which consisted of three Tier 1 indices, eight Tier 2 indices, and twenty Tier 3 indices. This work brings an innovative perspective into scientific reasoning assessment.

Objectives

Scientific reasoning ability entails a necessary set of skills in scientific endeavors (Fischer et al., 2014). It is an important cognitive element indispensable to classroom learning as well as daily life. As students' level of scientific reasoning is an important indicator of educational quality across the globe, how to effectively evaluate scientific reasoning has received great attention. Given that existing assessments usually focus on certain aspects of scientific reasoning (e.g., Luo et al., 2020), there is a great need of tools that can evaluate scientific reasoning in a systematic approach. The present study aims to develop an integrated framework for assessing scientific reasoning based on the AHP method, which can provide a more comprehensive evaluation of students' scientific reasoning competence.

Methods

To establish an assessment framework of scientific reasoning, we adopted the Delphi and analytical hierarchy process (AHP; Saaty, 1980) methods. The Delphi method is used to repeatedly obtain expert opinions until there is a comprehensive consensus (Delbecq, van de Ven, & Gustavson, 1975). AHP is a mathematical method which uses a pair-wise comparison approach to build a hierarchy, which provides a quantitatively justified criteria system for selecting the most qualified candidates as well as gathering information on students in educational circumstances (Thomas & Kirti, 2008).

The present study was carried out in four steps. First, content analysis was conducted on previous literature to analyze and synthesize existing definitions, theoretical frameworks, and models about scientific reasoning. Then, assessment criteria were developed based on the content analysis, recently released educational standards internationally, as well as the frameworks of international large-scale assessments (such as PISA and TIMSS). Next, a preliminary three-tier framework was proposed to categorize the essence of scientific reasoning, each of which included specific criteria with detailed descriptions. Given the domain-specific nature of scientific reasoning, we confined the current investigation to high school biology. To ensure the objectivity and feasibility of the framework, we used the Delphi method for two rounds, where we surveyed twenty experts to determine the evaluation criteria for scientific reasoning. All experts were either experienced scientific reasoning researchers or biology teachers with over 10 years of teaching experience. After the framework was constructed, the AHP method was applied to rank the ratings that experts provided for each criterion using pairwise comparison. Last, to evaluate the feasibility of this framework in real educational settings, a twenty-item questionnaire was developed based on the framework for high school students to report their perceived level of competence in each scientific reasoning element.

Results

Based on content analysis of extant literature, a preliminary model of scientific reasoning was constructed, with three Tier 1 indicators and nine Tier 2 indicators. Two rounds of Delphi consultation were conducted. During the first round, the reconciliation coefficient (which should fall into the range of 0 to 1) was 0.171. Experts reached an agreement on establishing the Tier 1 criteria, but not on Tier 2 criteria. In particular, the Tier 2 criterion of "scientific modeling" was suggested to be taken out as it overlapped with other criteria. During the second round, the reconciliation coefficient reached 0.573, indicating a relatively high degree of agreement among experts. Based on the ratings as well as suggestions from experts, we finally modified the preliminary model into a framework with three Tier 1 criteria, eight Tier 2 criteria, and twenty Tier 3 criteria.

The AHP method was used to rank the ratings from experts for each criterion. To ensure the reliability of ratings, we calculated the Consistency Ratio (CR), which reflects the level of experts' familiarity with the topic and their judgment. When CR is higher than 0.7, reliability is at a high level. In this study, CR was 0.915, which means the final rankings among the experts was very high. See details of the final rankings in Table 1.Last, we distributed the questionnaire that was developed based on this framework to 163 high school students (82 males and 81 females), and results showed that the Kaiser Meyer Olkin (KMO) value was 0.924, and the Bartlett Test of Sphericity $\chi2$ was 1618.634 (df = 190), p < 0.001. The questionnaire had a relatively high reliability and validity, indicating that the framework was applicable for classroom use.

Table 1
Weight Distribution of Indicators

Tier 1	Weights	Tier 2	Weights	Tier 3	Weights
Generating Hypotheses	0.222	Identify Problems	0.289	Be aware of problems	0.469
				Construct contextually relevant problem representations	0.531
		Ask Questions	0.399	Ask contextually relevant scientific questions	0.443
				Ask explorable scientific questions	0.557
		Make Assumptions	0.312	Formulate a scientific hypothesis related to the problem	0.500
				Develop testable scientific hypotheses	0.500
Experimentation	0.394	Design Experiments	0.635	Design scientifically sound experiment protocols	0.358
				Design a complete and feasible experiment plan	0.334
				Be aware of controlling variables	0.308
		Collect Evidence	0.365	Classify and organize experiment data	0.389
				Clarify the meaning of data representation	0.253
				Observe and analyze the experimented phenomena	0.358
Scientific Argumentation	0.384	Evaluate Evidence	0.419	Evaluate scientific arguments from different sources	0.267
				Analyze the limitations or deficiencies of experiments	0.232
				Evaluate and interpret the results of scientific investigations	0.501
		Draw Conclusions	0.356	Draw conclusions in response to scientific questions	0.273
				Conclude based on scientific evidence	0.243
				Summarize and apply scientific findings	0.484
		Exchange Evaluation	0.225	Communicate and share each other's scientific reasoning process	0.587
				Rationally evaluate others' scientific reasoning process	0.413

Discussion

Assessing students' scientific reasoning competence has been a crucial yet challenging task for educational researchers and practitioners. The present study introduced the Delphi and AHP methods into this line of research for the first time. The proposed framework transferred the reasoning processes into measurable indices, which can be directly applied in classroom settings.

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Perceived Helpfulness of Phatic Expressions in Online Help-Giving Interactions

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Abstract: In this survey study, we assessed how students rated the helpfulness of replies to online requests for help with and without *phatic expressions*, or comments serving a purely social purpose. We found that students perceived help-giving replies with neutral and self-oriented phatic comments to be less helpful than those discussing course content alone. In contrast, students perceived help-giving replies with greetings, salutations, and other-oriented comments to be equally helpful to those discussing course content alone.

Introduction

When struggling students seek academic help in online learning environments, it is important that they perceive the help they receive from others to be effective. In the online context, these perceptions of support have been found to be related to academic resilience (Permatasari et al., 2021), and students who have negative experiences with help-seeking are less likely to seek further help in the future (Mare & Sohbat, 2002).

In the present study, we contribute to literature on online collaborative learning by examining whether *phatic expressions*—comments that serve a social rather than informative purpose (Maíz-Arévalo, 2017)—contribute to or detract from the perceived helpfulness of replies to requests for help posted to an online college course discussion forum. Although existing work has shed light on behaviors that yield effective academic helping interactions in online courses (Nandi et al., 2012), little is known about the helpfulness of comments that serve a purely social function in these settings. On one hand, phatic expressions do not convey information about course content and thus do not directly address a help-seeker's academic problem. On the other hand, these expressions may help learners connect with others and thus increase their willingness to accept others' support.

Maíz-Arévalo (2017) previously identified four different types of phatic expressions that are used in online communicative settings: greeting/parting tokens, self-oriented comments, other-oriented comments, and neutral comments (see Table 1). Our investigation explores how the inclusion of each of these types of expressions predicts the perceived helpfulness of help-giving replies posted to an online discussion forum. Our research question is: *How do phatic expressions contribute to or detract from the perceived helpfulness of replies to requests for help posted to a college course discussion forum?*

Table 1
Types of Online Phatic Expressions (Maíz-Arévalo, 2017)

Type of phatic expression	Definition	Example
Greeting/parting token	Greetings and farewells to open/close messages	"Hi there"
Self-oriented comment	Comments that refer to the speaker	"I've had a busy week"
Other-oriented comment	Comments that refer to the addressee	"Thanks for your question"
Neutral comment	Comments on the "context shared by interlocutors" (Maíz-Arévalo, 2017, p. 440)	"Lots of posts on the forum today"

Methods

Participants and procedure

This study utilized a repeated measures survey design and was completed online during the Spring 2022 semester. Participants were undergraduate students enrolled in a large introductory statistics course at a public university in the midwestern United States. During the survey, participants rated the helpfulness of 16 replies to requests for help posted to an online statistics course discussion forum, on a scale from 1 = *Not helpful* to 5 = *Very helpful*. For each of the 16 replies, participants were randomly shown one of two possible versions of the same reply: (a) a version that only discussed course content (e.g., "For any z-score that is huge, to the point where it's off the chart, you can assume the p-value is going to be pretty much 0") or (b) an edited version that discussed the same course content and also included a phatic expression (e.g., "This is a very good question. Basically, for any z-score that is huge and off the chart, you can assume the p-value is pretty much 0"). The order in which the 16 replies were presented was randomized for each participant.

Of our 16 help-giving replies, 5 included greeting/parting tokens in the version of the reply with a phatic expression, 4 included self-oriented comments, 4 included other-oriented comments, and 3 included neutral comments. We dummy coded phatic expression type (i.e., the type of phatic expression associated with the version of each reply shown to each participant) into 4 variables ("greeting/parting token," "self-oriented comment," "other-oriented comment," and "neutral comment") at the individual rating level, with "no phatic expression" as the baseline group for comparison.

Originally, 345 participants completed the survey. We excluded 6 participants who demonstrated response bias by providing the same helpfulness rating for all 16 replies. Our final sample consisted of the remaining 339 participants. All participants were compensated with extra credit.

Data analysis

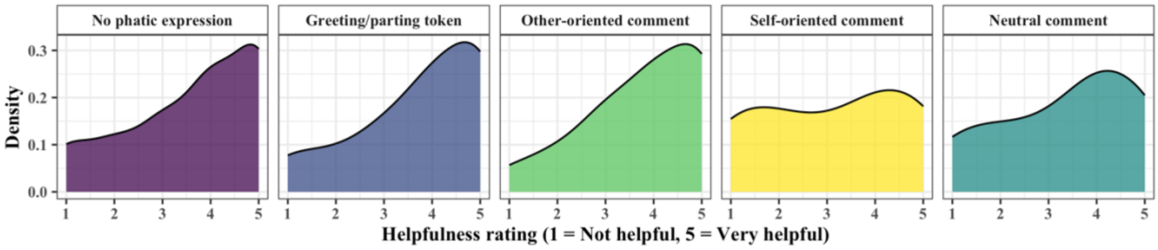
We analyzed the data with linear mixed model analysis because we could not consider multiple ratings from the same participant or for the same help-giving reply to be independent of one another. We included helpfulness rating as our dependent variable, participant ID and help-giving reply (post ID) as random effects, and the different types of phatic expressions as fixed effects. We centered and standardized helpfulness rating prior to analysis.

Results and discussion

Participants perceived help-giving replies with neutral (β = -0.16, *SE* = 0.05, *p* = .002) and self-oriented (β = -0.18, *SE* = 0.04, *p* < .001) comments to be significantly less helpful than replies discussing course content alone. In contrast, participants perceived replies with greetings/parting tokens (β = 0.03, *SE* = 0.04, *p* = .49) and other-oriented comments (β = 0.02, *SE* = 0.04, *p* = .96) to be equally helpful to replies discussing course content alone. Figure 1 is a density plot displaying the distribution of helpfulness ratings by the type of phatic expression used.

Figure 1

Distribution of Helpfulness Ratings by Type of Phatic Expression



Overall, our findings suggest that the ratings associated with help-giving replies were not improved by the inclusion of phatic expressions. In fact, self-oriented and neutral comments appeared to have a negative impact on perceived helpfulness. Participants may have perceived such expressions as adding little to the content of the help-giving reply and thus a potential waste of the help-seeker's time. However, our findings suggest that students can include other-oriented comments and greeting/parting tokens in their online help-giving replies without detracting from the message's overall perceived helpfulness. These expressions have the common characteristic of acknowledging the addressee's presence; it is possible participants saw them as worth including in help-giving posts because while they are not helpful in terms of conveying course material, they can provide social support by making students feel encouraged, appreciated, or seen by others. That being said, a limitation of our survey design is that it is possible our participants may have felt differently about the use of phatic expressions in more authentic contexts. Thus, future work should examine how online help-giving replies that include different phatic expressions are perceived by the students who receive them after seeking academic help.

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Predictors of Sense of Belonging to One's Course Community for Online and In-Person Learners

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Abstract: In this survey study, we examined the factors contributing to a sense of belonging to one's course community for college students enrolled in either the online or in-person version of the same introductory statistics course. We found no significant overall difference in online vs. in-person students' sense of belonging to their course community. However, online first-generation college students reported lower belonging to their course community than any other combination of course version and college-generation status.

Introduction

In educational settings, a sense of belonging refers to "the extent to which students feel personally accepted, respected, included, and supported by others in the school social environment" (Goodenow, 1993, p. 80). Research has shown that among college students, a sense of belonging to college settings is associated with important learning outcomes, including engagement, persistence, and well-being (Gopalan & Brady, 2020). Thus, it is paramount that researchers gain a full understanding of the factors that contribute to students' feelings of belonging in college, so that we are positioned to support student success.

Online students, specifically, may struggle to develop a sense of belonging to their course communities, due to the oftentimes lack of real-time, in-person interaction in such settings (Peacock et al., 2020). Nevertheless, few studies have investigated sense of belonging in the context of online learning. For this reason, the present study aims to expand our understanding of how online vs. in-person students of diverse backgrounds experience a sense of belonging to their course community. Our research questions (RQs) are as follows: (1) *Among college students, does course version (online vs. in person) predict sense of belonging to one's course community, holding course grade and demographic characteristics constant?*; and (2) *Among college students, are the associations between course grade and sense of belonging to one's course community, as well as demographic characteristics and sense of belonging to one's course community, moderated by course version?*

Method

Participants and procedure

We employed a cross-sectional survey design that was completed online during the Spring 2022 academic semester. Participants (N = 327) were students enrolled in either the in-person (n = 155) or online version of a large introductory statistics course taught at a public university in the midwestern United States. We collected data during the last month of the semester, so that participants would have had the chance to establish a sense of belonging to their course community. During the survey, participants completed a four-item measure assessing their sense of belonging to their course community (adapted from Goodenow, 1993; α = .73) and provided information on their course version (online vs. in-person), current course grade (out of 100), and demographic characteristics (race/ethnicity, gender, and college-generation status). Participants were compensated with extra credit in the course.

Data analysis

Participants could respond with "Prefer not to say" when providing their grade and demographic characteristics; we estimated missing values for these variables with multiple imputation, creating 50 imputed data sets in total. Next, we used multiple regression to address our RQs. In Model 1, we regressed sense of belonging to one's course community on course version, course grade, and demographic characteristics, thus addressing RQ1. In Model 2, we added interaction terms to examine whether the associations between (a) course grade and belonging and (b) demographic characteristics and belonging were moderated by course version, thus addressing RQ2.

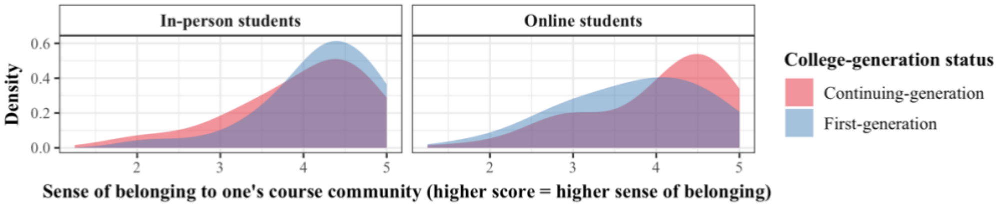
Results

Model 1 explained a significant pooled 13.34% of the variance in sense of belonging to one's course community (F[8, 318] = 6.12, p < .001). We found a non-significant difference in online and in-person students' reported degrees of belonging to their course community ($B = -0.13$, $SE = 0.09$, $p = .14$). Additionally, a higher course grade was associated with a significantly higher sense of belonging ($B = 0.02$, $SE = 0.004$, $p < .001$). Also, students identifying as men, on average, reported a significantly lower sense of belonging than students identifying as women or non-binary ($B = -0.20$, $SE = 0.10$, $p = .047$). Finally, students in the "Other race" category reported significantly higher degrees of belonging than students identifying as White ($B = 0.68$, $SE = 0.25$, $p = .01$). No other significant associations were observed in Model 1 ($ps > .05$).

The change in our pooled R^2 from adding the interaction terms in Model 2 was statistically significant, $\Delta R^2 = .04$, $F(7, 311) = 2.23$, $p = .03$. The association between college-generation status and sense of belonging to one's course community was moderated by course version ($B = -0.53$, $SE = 0.52$, $p = .01$). Specifically, online first-generation students experienced lower belonging to their course community than any other combination of college-generation status and course version. No other significant interactions were observed ($ps > .05$). Figure 1 shows the distribution of our sample's sense of belonging scores by college-generation status and course version.

Figure 1

Distribution of Sense of Belonging Scores by College-Generation Status and Course Version



Discussion

In this study, we found that online students do not necessarily experience a lower sense of belonging to their course community than their in-person counterparts. We believe our study's specific course context may have contributed to this finding; the large nature of the class, as well as its lecture-style format, may have limited the amount of in-person interaction available to students enrolled in the in-person version of the course. This lack of in-person interaction, in turn, could have limited in-person students' abilities to develop a sense of belonging above and beyond what was experienced by the online students.

Moreover, although online and in-person students reported similar overall degrees of belonging to their course community, we found that the disparity in feelings of belonging between continuing-generation and first-generation students was significantly larger for students enrolled in the online, compared to the in-person, version of the course. This finding aligns with previous research demonstrating that first-generation college students are often less likely than their continuing-generation counterparts to be socially integrated into their campus community (Stebleton et al., 2014); it is possible that the isolating nature of online learning compounded this sense of isolation for our online first-generation participants, which yielded a lower overall sense of belonging to the course community. This result points to the importance of supporting the academic and social integration of first-generation college students enrolled in online courses.

Overall, our findings suggest that a student's sense of belonging emerges out of multiple intertwined influences that span students' social identities, academic performance, and course context. Future research should continue to account for the ways in which associations between student characteristics and sense of belonging may depend on one's specific course context.

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All Rhodes Lead to Creativity

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Abstract: This paper took a look at the ways that individuals interacted with and conceptualized creativity. Utilizing authentic artifacts taken from senior level creativity students as well as articles centered around creativity written by experts from a broad range of expertise, two conceptualizations were found using network analysis, titled the Complex-Originality-Connections conceptualization and the Solutions-Tool-Freedom conceptualization. The two conceptualizations emphasized different perspectives, and no noticeable difference was found between student and expert level individuals.

Introduction and background

The study of creativity is a field composed of numerous and distinct groups of people from different backgrounds in the academic sphere. From psychologists and educators to businesses, engineers, and chemists there are a plethora of diverse perspectives (Sawyer, 2011), but a unifying framework–Rhodes' 4P–provides a lens by which creativity has often been viewed through the categories of person, product, process, press (Rhodes, 1961). Virtually every profession demands the ability to introduce novel and useful changes to our work and surroundings which is imperative for innovation, growth, and happiness. The questions of what creativity is, how to measure it, how it impacts people, what it arises from, and how to nurture it are more prevalent now than ever (Runco, 2017). Today's changing global climate, rapid technological advances, and increased globalization demands that learning scientists design and facilitate learning that will allow people to thrive in contexts that require heightened levels of creativity (Pierroux et al., 2022). Complex conceptual systems theory (Donaldson & Allen-Handy, 2020) argues that conceptualizations are complex systems, and that practices are emergent from these conceptualizations. Our study does not attempt to define creativity, but rather to gain a deeper understanding of how people conceptualize it as this is a necessary step for facilitating development of creative potential and practices.

Methods

Data in this study came from academic articles from creativity researchers as well as authentic artifacts produced by undergraduate university students in a senior-level creativity course. The artifacts were produced by teams and could take either of two distinct forms: games or assessments. Regardless of the medium, both represented original designs that were grounded in fundamental concepts from the creativity literature. We collected and analyzed the papers produced by each team in which they described their product and provided justification for their design choices. For the academic journal articles, we searched for papers that focused on discussing either creativity or subjects relating to creativity filtered by highest cited through the Web of Science database. The results were further filtered to exclude papers that featured the same authors or were published in the same journal, save for the *Creativity Research Journal* and *Thinking Skills and Creativity* to ensure representation of the broad diversity of perspectives used by creativity researchers ending with 50 articles. These papers were then coded using MAXQDA Analytics Pro to capture and categorize all uses of metaphors, non-metaphor characterizations, practices, and value statements. Once completed, Pearson correlations were calculated within each coding category and imported into the UCINET network analysis software. Girvan-Newman cluster analysis was used to identify clusters. Clusters of metaphors were interpreted as conceptual metaphors, clusters of non-metaphorical characterizations were interpreted as conceptual stories, and clusters of value statements were interpreted as worldviews. These clusters were named and collapsed in MAXQDA. New network maps of correlations between these elements were analyzed using Girvan-Newman cluster analysis to characterize the different complex conceptual systems representing unique conceptualizations of creativity.

Findings

When analyzing both student submissions and professional publications, we found two conceptualizations of creativity through network mapping of correlated conceptual elements at the $p<0.001$ level, each of which was aligned with particular clustered aspects of the creativity landscape framework: The Solutions-Tool-Freedom conceptualization and The Complex-Originality-Connections conceptualization. There were no differences in conceptualizations between the creativity experts (articles) and the creativity students (artifacts).

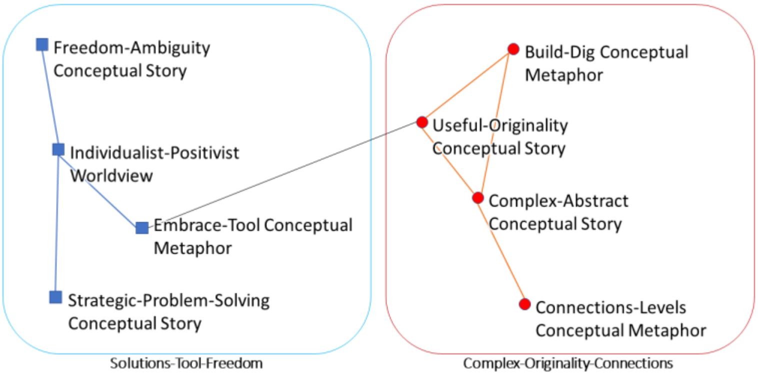
The Complex-Originality-Connections conceptualization (Figure 1, circle-nodes cluster) found that when people viewed creativity as all encompassing and difficult to define, they would use metaphors which had more physicality and spatial connotations, particularly when discussing creativity. Also contained within this conceptualization is the notion that creativity is a combination of divergent and convergent thinking in order to come to create a product or idea that is both relevant and useful, but also new and original.

The Solutions-Tool-Freedom conceptualization of creativity (Figure 1 - square-nodes cluster) found that when the concept of creativity was focused more on an individual characteristic, they would use metaphors that involved the personification of ideas. Additionally, this cluster more heavily emphasized the aspect of freedom and the ability to choose or, failing that, the importance of having a rebellious streak to go against the established norms. This is most heavily emphasized with the inclusion of an individual-focused worldview.

As mentioned above, the Individualist-Positivist worldview is part of the Solutions-Tool-Freedom conceptualization. In our study, we did find another worldview–the Collaborative-Interaction worldview–which did not cluster with any conceptualization of creativity. We interpreted this as suggesting that the Collaborative-Interaction worldview was ubiquitous.

Figure 1

Network map of elements in the two conceptualizations of creativity



Implications and discussion

The conceptualizations we found were aligned with important creativity theories and frameworks. Our finding of no difference in conceptualizations between the creativity experts and creativity students suggests that having students work in teams to design creativity games or assessments is a powerful means of structuring learning in creativity courses. Using the 4 Ps framework proposed by Rhodes (1961), we can observe that the two clusters emphasize different perspectives that are aligned with both the assignment itself and articulated tenets of creativity. The Solutions-Tool-Freedom conceptualization favored the person-centered and product-specific aspects of creativity. When it comes to designing new practices to improve and encourage learning, these individuals that have this conceptualization might approach the question by emphasizing the importance of individuals and evaluating based on the product produced, while underestimating the importance of supportive environments and collaboration. The Complex-Originality-Connections conceptualization emphasized the process and press aspect, while possibly overgeneralizing experiences and creating routine practices that may fit the requirements of most but allowing the few to fall through the cracks.

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Embodied Math Learning Through Design Friction: An Argument in Favor of Flawed Tools

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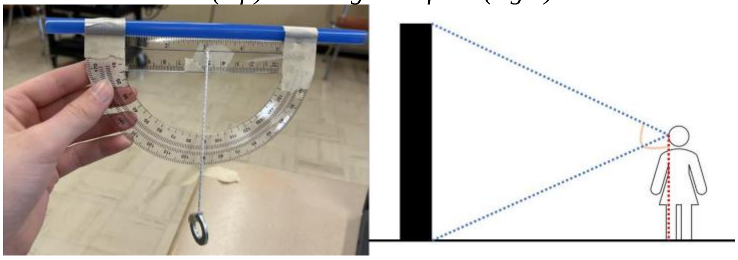
Abstract: This work explores the affordances of *design friction* – a term drawn from technology scholarship to denote embedded obstacles in tool use – in educational tools for mathematics learning. We present a case study analysis of a project-based learning geometry unit implemented in two classrooms. Analyses show that as students created a map of their local surroundings using a crude sextant rife with design frictions, they constructed powerful embodied understandings of mathematics.

Background

While most new technologies intentionally minimize design frictions, or "interactions that hinder people from painlessly achieving their goals when interacting with technology" (Mejtoft et al., 2019, p. 41), some scholars have argued that design frictions can interrupt mindless technology use, inspire reflective practices on the part of users, and produce clearer understandings of the technology's functions (Heeden, 2020; Sung, 2021). In turn, this body of research alludes to the learning potential of engaging design frictions, including those embedded within educational tools. We therefore use this poster to investigate how design frictions produce opportunities for embodied math learning. To do so, we draw on research that positions embodiment within human-tool interaction (Clark, 2008; Okita, 2015) and recognizes knowledge construction in mathematics education as an embodied process (Abrahamson & Sánchez-García, 2016; Ma & Kelton, 2018; Vogelstein et al., 2019). How design friction contributes to or detracts from embodied math learning, however, remains largely unexplored. To this end, we now turn to new empirical research to explore the intersection of design friction and embodied learning.

Figure 1
Crude sextant tool (left) and diagram of use (right)



Methods

Our findings come from case study research (Yin, 2019) into the initial implementation of a Project-Based Learning (PBL) unit in two geometry classes (with 20 students each) at a public US high school in a large, northeastern city. The unit aimed to develop trigonometry understandings by guiding students to create a map of their local surroundings without the aid of GPS or distance measuring tools (such as a tape measure), instead using a crude sextant (made out of a protractor, a drinking straw, a string and a weight) to measure various angles formed between themselves and external objects (see Figure 1). Because the sextant provided the angle formed between the object, the viewer's eye (acting as the vertex), and the ground (see Figure 1), students could use right angle trigonometry to determine distance. Due to numerous unintentional design frictions, the crude sextant students created proved difficult to use for multiple reasons: differences in posture produced inconsistent results, the string used to measure the angle would often swing back and forth, the protractors used by most students list two supplementary angles at every measure, and more. To collect data on this tool's use, we conducted 30-minute mid- and post-interviews with the teacher of both classes (Sam), two 30-minutes focus group interviews with seven students total, and collected/analyzed materials created by the students during the unit, thus ensuring reliability through triangulation (Denzin, 2012). To analyze the data, we employed a combination of descriptive and pattern coding techniques (Saldaña, 2015) to understand where participants encountered design frictions in the tool and how navigating those frictions created opportunities for learning mathematics.

Findings

Analyses revealed embodied mathematical understandings students developed when navigating design frictions in the sextant. One student, Laura, struggled to interpret the two vertically aligned supplementary angle measures displayed on the protractor: “It's hard to figure out which one’s the right one. If it's going up to 90, then I would be like, ‘OK, I am looking down.’ But if it was higher than 90, I was looking up.” By not readily providing users with an exact value, the sextant prompted students to consider the physical manifestations of contextualized angle measures and how they themselves embodied aspects of the problem (i.e. they represented one side of a right triangle). Similarly, Sam described the following issue that occurred when students tried to determine the distance to an object that was not on the ground: “when they were pointing their compass at the object, [they] had to take that into account how far above the ground that was. So I asked them ‘how could you work around it?’” In recognizing this problem, Sam locates a design friction with the tool (the sextant only gives limited information that may not be applicable in all instances) and identifies an embodied trigonometry problem (essentially, how to find the measurements of a trapezoid using trigonometry) that again positioned students within the problem.

Participants also discussed how design friction led to deep statistical thinking when developing techniques for increasing the sextant’s accuracy. As Laura described, “when [the string] was swinging back and forth, you couldn't really [record the angle measure] once. I did it a couple times to make sure that I was getting at least close numbers because it kept swinging.” In responding to the constant swinging of the string, Laura engages multiple mathematical thinking practices: checking one’s work by comparing that answer to contextual details (such as other recently recorded angle measurements), determining whether additional data is needed, and calculating averages to produce a more accurate solution. Sam engaged in a similar process when working with students: “I was having them [record measurements] a couple times and they would get different angles. I'd have them calculate the trig, see which one was farther away from the actual and say, ‘why do you think that was?’” In this example, Sam helped students better understand how to use the tool and check for accuracy. In doing so, he engaged them in statistical practices as they solved trigonometry problems.

Discussion and conclusion

Although the scope of this research does not translate into broad claims, our findings reveal one instance where design friction within an educational tool created opportunities for embodied mathematics learning. By not efficiently providing learners with the needed measurements, the crude sextant pushed students to situate themselves *within* trigonometry problems and use that embodiment to find solutions (such as by aligning specific values with “looking up” or “looking down” to work towards an answer). Drawing on these findings, we argue that education designers and researchers should further explore the use of design frictions in intentionally pushing students towards new and specific forms of mathematical thinking.

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Comparison of Self-Regulation Process Patterns Between High and Low Achievers in TPACK Development

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Abstract: The study explores teachers' self-regulated learning (SRL) process patterns in technological pedagogical content knowledge (TPACK) development. SRL processes were analyzed through think-aloud protocols. TPACK achievements were assessed by the quality of participants' lesson plans. Preliminary results showed high achievers performed a more recursive sequential regulatory pattern, while low achievers showed a more linear one. Teachers with a more successful SRL model could achieve better TPACK performances. These findings could contribute to detecting the relations between SRL and TPACK.

Introduction

Technological pedagogical content knowledge (TPACK) represents teachers' knowledge of integrating technology into different knowledge dimensions to scaffold students in constructing new knowledge (Mishra & Koehler, 2006). Recent research finds that developing TPACK should consider authentic instructional tasks and teachers' self-regulated learning abilities (Huang & Lajoie, 2021). Self-regulated learning (SRL) refers to the self-regulatory processes that enable learners to transform preexisting abilities into task-related behavior to attain goals, reflecting the degree to which learners are metacognitively, motivationally, and behaviorally active participants in learning processes (Zimmerman, 2000).

SRL supports TPACK development by engaging teachers in cognitive and metacognitive regulatory activities in a goal-oriented process (Poitras et al., 2017). Previous studies have found that learners with more SRL competence, especially metacognitive regulatory abilities, could achieve better TPACK performance (Huang & Lajoie, 2021). For example, the authors presented several self-regulatory process models SRL in response to different TPACK levels (Huang & Lajoie, 2021). One common feature of these significant studies is that SRL is measured through log data collected during learning. While log data are more objective, easy to be gathered, and informative of contexts where self-regulation occurs (such as time, sequences, etc.) (Azevedo & Gašević, 2019). Think-aloud protocols are another optimal option for capturing SRL processes accurately and dynamically, giving researchers access to learners' thought processes through their verbalizations in a learning task (Greene et al., 2010). Thus, the purpose of this study is to know how teacher performs self-regulation in TPACK learning. We collected and analyzed teachers' think-aloud protocols and created the SRL process patterns with a process mining algorithm. To gain the nuanced differences, we retrieved the SRL data from high achievers (5 participants had the best TPACK performances) and low achievers. This paper will present the preliminary results, given data analysis is still in progress. In this research, we aim to (1) identify SRL process patterns while teachers are involved in lesson design with TPACK, (2) compare patterns' differences between high and low achievers, and (3) better understand the role of SRL in TPACK.

Method, analysis, and results

Twenty-eight third-year student teachers from a normal university in China voluntarily participated in this study. They were asked to design a technology-integrated English lesson on nBrowser (c.f. Poitras et al., 2017), which is an open-ended learning environment that adaptively fosters SRL and TPACK development. Meanwhile, they needed to verbalize their thoughts during the whole process of recording their think-aloud data. Each of them met the experimenter and implemented the study individually.

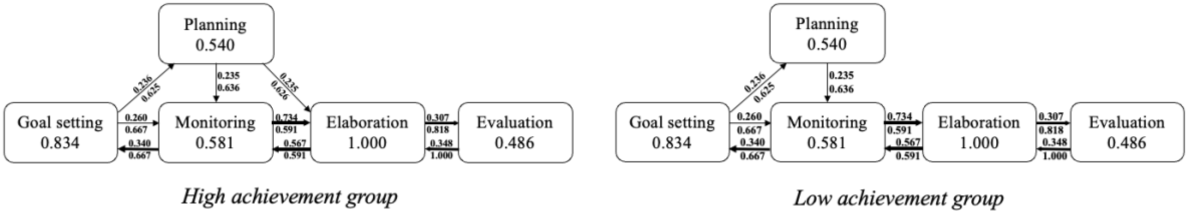
Pre-implementation began with the introduction of nBrowser and think-aloud training to familiarize participants with the platform and verbalization of thoughts. Then they had 45 minutes to design the lesson. Their lesson plans served as one indicator of TPACK achievements. The recorded think-aloud data were coded using an SRL coding scheme adapted from Azevedo et al.'s scheme (Azevedo & Gašević, 2019) and analyzed using Fuzzy Miner (Günther & van der Aalst, 2007), which is an algorithm to place the unstructured events into interpretable models. The alogorithm uses two fundamental metrics, *significance and correlation*, for computing a process model for the given data set. Thus, we could identify participants' SRL process patterns in TPACK development from unstructured think-aloud data. TPACK achievements were assessed by evaluating their lesson designs according to the criteria documented by Author et al.(2021).

We created a high-achiever sub-cluster (top 5 participants) and a low-achiever sub-cluster (last 5 participants) based on their TPACK achievements. The two preliminary process maps generated by Fuzzy Miner were described and presented in Figure 1. Even though both maps contained identical five events, their occurrence and relationships were quite different. In the high-achiever group, all SRL events were connected, forming an iterative and recursive sequential model. It showed that participants enacted the primary sequence of events: Goal-Setting-Planning-Elaboration-Evaluation. Regarding the event connections, Elaboration was strongly and significantly mutually connected with Monitoring. It is also connected with Evaluation with moderate strength and significance. The event of Monitoring was highly directed to Goal setting, but the magnitude of the connection from Goal setting to Monitoring was weak.

The process pattern in low achievers was more linear and straightforward. The primary common path of the pattern was a loop consisting of Goal setting, Monitoring, Elaboration, and Evaluation. There also existed a weak loop of Goal setting, Planning, and Monitoring. The connections between Elaboration and Monitoring/Evaluation had the highest significance in this pattern. But the lack of connections between Planning and Elaboration revealed that they less regulated their planned strategies, which was the main difference from higher achievers. It suggests that participants might finish their lesson design with fewer considerations of monitoring and evaluating specific plan strategies.

Figure 1

The SRL Process Patterns of the High (Left) and Low Achievers (Right)



High achievement group

Low achievement group

Discussion and conclusions

This study identified two distinct SRL process patterns of high and low achievers in TPACK learning. The results showed that high achievers' SRL pattern was more goal-oriented and recursive. Participants designed their lesson starting with constructing instructional goals, monitored and evaluated comprehension and modified learning. This aligns with previous evidence that teachers' SRL promotes TPACK (Huang & Lajoie, 2021). However, since it is a preliminary analysis based on partial data, we need more data to confirm such findings and to gain a holistic understanding of the relations between teachers' SRL and TPACK development. Despite so, the findings add solid evidence to the literature and provide implications for teachers, educators and school administrators regarding the importance of self-regulation in teachers' learning and professional development.

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Thinking About Values and Ethics of Transdisciplinary Science Activities: A Case of Palestinian Arab Young Learners

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Abstract: Learners' values and ethics systems shape how they engage with learning activities. We explore how ten young Arab Palestinian learners think about ethics and values when they talk about transdisciplinary science activities and roles. We argue that meaning-making related to values and ethics presents opportunities for young learners to draw upon their existing cultural resources as they engage in transdisciplinary activities and think of values and ethics.

Introduction and background

Many existing frameworks of science ethics center on ideas and perspectives around practices that exist within Western Science practices (Kimmerer, 2013; Medin & Bang, 2014). Conceptions of ethics through Western epistemologies often ignore the perspectives and ethical systems of nondominant communities (Bang et al., 2016) and may be in tension with the values of nondominant learners, thereby interfering with their engagement in science. Here, we report findings from interviews with ten Palestinian Arab learners, analyzing how they perceive and describe values and ethics. We build on Bang et al.'s (2016) work to conceptualize our findings as *axiological ways of thinking, doing, and being,* where axiologies are defined as "values, ethics, and aesthetics—that is, what is good, right, true, and beautiful—that shape current and possible meaning, meaning-making, positioning, and relations in cultural ecologies" (Bang et al., 2016, p. 1-2). We chose an axiological framing (Bang et al., 2016; Tolbert & Bazzul, 2020) because we identified that learners think in expansive, complex, and value-laden ways about ethics, aesthetics, and relations with humans and others when describing their experiences. Here, we ask: What values emerge when learners articulate their beliefs and perceptions about their science-related activities?

Methods

Context

Ten learners (5th and 6th grades) participated in four days of activities (~8 hours total) led by two educators from Al-Rowad for Science and Technology, an organization that supports Arab learners' participation in science and technology in Israel. Each day, learners completed a hands-on activity associated with a scientific phenomenon. The activities were transdisciplinary, combining science with art, engineering, and math through features like colors, shapes, and measurement. Following the four days of instruction, the first author, Areej (a member of the local community who speaks the local language) conducted interviews to explore learners' perceptions of their engagement in activities. Interviews were conducted individually and mainly in spoken Palestinian Arabic, the local language of the youth participants.

Interviews and data analysis

We used interviews to explore learners' beliefs and perceptions of transdisciplinary science activities. As an instrument, the interviews afforded us a space to engage learners in meaning-making about their activities in the program, as well as everyday science-related activities. The interviews lasted 48.4 minutes on average (SD=8.9min). We recorded and then transcribed the interviews. The interview protocol addressed a variety of questions related to students' perceptions of the activities and roles of scientists, artists, engineers, and inventors. This paper focuses on questions and stances related to values and ethics, such as the notion of responsibility when doing a science activity and understanding learners' ethical thinking (e.g., Imagine your invention caused an issue in your house. Who would be responsible for that?).

The interview data was coded across two cycles, and then an interpretive approach was applied (Saldaña, 2015). The applied codes were in English and selected examples were translated for discussion among authors. The first coding cycle focused on identifying places where students talked about responsibility in doing science. During the two coding cycles, we noticed learners were thinking in more complex ways about ethics than we had initially anticipated; therefore, in the second cycle, we expanded the coding into a "values" category to capture instances when learners talked about responsibility, harm, ethics and morality, design aesthetics, and the utility of science.

Findings

Ethical thinking is evident in learners' meaning-making related to their beliefs and perceptions of their learning activities in the program and other related activities in their everyday. We describe our findings through five themes: ethics, responsibility, utility, aesthetics, and relations.

Learners conceptualized *ethics* in multiple ways when describing people's roles and actions. These include ethics as: a characteristic of a scientist, the recognition of the consequences of actions, causing no harm or damage, and undertaking good or bad actions. For example, one student, explicitly mentioned ethics when responding to the question, "What characteristics should you have to become a scientist?" saying, "intelligence/smart, ethics, and patience."

We derived the *responsibility* category from our interview question about who should take responsibility if a hands-on science artifact that learners built as part of the program, or an invention they created, were to cause damage or harm (e.g., to humans, more-than-human beings, or objects). We identified that learners' perceptions are often connected to their experiences in school. For example, learners focused on the figure of a responsible student and the ethical valence of listening to one's teachers and following rules of discipline. We acknowledge this question threatens to narrow thinking about ethics by tethering it to issues of responsibility and consequences, yet there is evidence in our findings for learners' expansive thinking about ethics beyond this framing.

Through learners' stances about *the perceived utility of science activities*, they articulated how they would use the artifacts created through those activities, in varied ways that include: displaying the artifact, using it for personal play or with other family members, drawing on it, engaging family members in conversation about it, and observing changes in it. These examples demonstrate that learners had their own unique perceptions of how to use the products of hands-on activities, beyond viewing them as scientific artifacts. Overall, we found that learners perceived the utility of the activities they completed by making connections to values they describe (e.g., relations with family members, using artifacts in a beneficial way, considering the artifact as an aesthetic object).

In the analysis, we found learners describing the ethical features of artifacts and materials they engaged with in terms of design. The category of *aesthetics and beauty* emerged from learners' descriptions of their process, how materials or design manifest visually, and the learning experience as a "beautiful" one.

Finally, it is evident in the findings that learners' engagement with transdisciplinary science activities is contextualized in *relation to others* as well. This was particularly clear when learners described everyday experiences with humans and more-than-human beings, as well as perceptions of their activities. *Relationality* is not always characterized in a positive light; it also included examples where learners wrestled with ideas (e.g., using animals in scientific research) or described inequitable and fraught interactions among people.

Discussion

The findings suggest that learners' axiologies are interconnected and interact with learners' cultural resources and everyday experiences. These resources and experiences are essential for how they engage with learning activities and the possibilities they can imagine for themselves. In some cases, we identified tensions between values inherent to learners' worldviews and values inherent in science practices. Such tensions reflect how learners could be wrestling with contradictions between their own thinking and dominant science practices or normative ideas. These tensions also suggest complexities within the dynamics of childhood-adulthood, nature-human, and cultural values-dominant values when it comes to what counts as science knowledge and practices (e.g., Kimmerer, 2013). We see the complexity of ethical thinking among young learners as an invitation to consider values of relations, care, and aesthetics as fundamental to their engagement in learning environments.

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“You tried one hundred thousand times”: A Learner’s Resisting Behavior(s) towards Self and Collective Rights to Participate Equitably

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Abstract: The context of this poster work is an out-of-school transdisciplinary science program for young Arab learners. Here, I focus on moments of resistance to norms during participation in learning activities that included discussions and hands-on tasks. I present two examples of an interaction analysis where resistance as a form of self-determination creates learning opportunities for the individual learning and their peers collectively to participate, resist, and express themselves.

Introduction

Out-of-school learning environments can provide learners with opportunities to engage in activities where they do hands-on activities, discuss with one another, and explore materials they are not used to at school. This poster explores a learner’s engagement in a transdisciplinary science program activity to examine how it supports (or not) their acts of self-determination as reflected through resistance to activity norms and expressions that have individual and collective ends. Although prior work in the Learning Sciences addressed dynamics and interactions in STEM environments, less work has been focused on the enactment of self-determination of nondominant learners and its collective outcomes for classroom learning (Davis et al., 2020). Focusing on an episode of resisting norms during activities, I present two examples about the behaviors a young 5th grade Arab Palestinian learner. Throughout the learners’ interaction dynamics, I consider relationality building with peers as an ethical process that have implications for learning collaboratively with others (e.g., Vossoughi et al., 2020). I argue, the learner’s resisting behaviors reflect his active role as an actor in addressing power dynamics towards shifting it.

Methodology: Activities, participants, and major procedures

This study is part of a larger project aims to better understand the engagement and participation of young Arab Palestinian learners within a community-based organization’s transdisciplinary science program in Israel (Mawasi, 2021). This poster draws on interaction analysis from the third day of the program, when learners built an Illuminating Board artifact. I chose to focus on the two hours activities during this day because it afforded various activity contexts (i.e., building, testing materials, drawing, discussions) and learners became more familiar with the space norms, educators, and their peers. Ten fifth- and sixth-grade learners (five girls, five boys) participated in the program (Winter break of December 2019). Two educators were present in the space. Through the analysis, the focus on Rami’s case (pseudonym) was by noticing his interaction with peers when offering help, participation in discussion, and a mixed usage of play talk and scientific vocabulary. This interactivity also extended to ways the learner was using materials in the space to build his artifact, including, building step-by-step, testing materials, expressing with materials, and inviting other peers to join him for such activities. Finally, the observation in videos for the learner behaviors included his interaction with educators as well.

For this poster, I draw on videos of the third day activity of the program: recordings of 14 videos with segments of 7.75 minutes on average (~2 hours). These videos focused on Rami’s behavior when doing the hands-on activities. At the same time, I supplemented these videos with notes and photographs that I took in the space, and other video-camera angles that recorded the whole classroom as a supplement. Throughout the interaction analysis I developed analytical memos and notes that were also supported by screenshots from videos.

Figure 1
Calling for equitable participation: Rami (red) pointing his hand towards Faris (red)

This study focuses on Rami’s interactions with peers, educators in the setting, and materials. The interaction analysis of videos considered talk (e.g., playful talk, science vocabulary), hands gestures (e.g., pointing towards others or materials, building artifact with carefully), and moving in the space (e.g., standing, moving from his chair to white board) in the space (Erickson 1986, 2006; Jordan & Henderson, 1995; Vossoughi et al., 2020). I started this study with a broad question on how learners engage and interact in this learning setting. I wrote memos and analytical notes to identify Rami's behaviors with peers, materials, and educators. Then, I used Davis et al. (2020) as a framework to identify and expand Rami's acts of self-determination. This included, moments of resistance, expressions, humor and play, and interaction with others and materials.

Findings: Resisting for self and collective right to participate equitably

While Rami contributed to discussion, in some cases, he resisted existing norms and inserted his own right to participate and other participants rights to participate as well. This particularly was during two moments where he argued for fairness in participation among learners: one with the teacher and one with another student in the classroom. In one example, the teacher did not give Rami as much time as another student, Faris (pseudonym), to draw on a big Illuminating Board, consequentially, Rami attempted to take materials from the teacher without permission and then by end of the day activities, Rami expressed his frustration by writing the word "#Tuz #طز" (an Arabic expression that reflects frustration) on his own board. In a second example, this frustration about fair participation, was enacted not for himself, rather, for supporting other peers. In a discussion about the spectrum of light, students raised their hands to answer teacher questions, as a common norm of this setting. Faris from the back interrupted while raising his hand and said "me, I want to say something." The teacher said, "Can we try to listen to Noura, let's have turns, I will listen to you, I will listen." Faris insisted, "teacher no, let me." Rami turned to the back and pointed at Faris, he said, "you tried one hundred thousand times." While Rami was exaggerating, he was referring to that Faris had the opportunity to answer and talk in discussions many times, while others did not, and now Faris should give other people the opportunity to answer (see Figure 1). Faris put his face down. Noura (pseudonym) began to talk; Rami moved his face to his left side to listen and looked towards Noura. Faris looked towards Noura too, at the same time he was still moving his body up for teacher attention. Here, Rami's act of self-determination was to suggest to Faris to be respectful to others, which created an opportunity for Noura to talk and join the discussion.

Conclusions

The findings demonstrated varieties in how self-determination was enacted in the two examples by Rami. In the discussion flow, Rami's acts of self-determination were reflected in asking for fairness in participation, wondering out loud with peers in discussions, and expressing his frustration on his own artifact. The findings suggest, in alignment with Davis et al. (2020), these moments enabled Rami to navigate his learning trajectories, help others, express himself, and participate in the learning space practices to explore new ways of learning beyond disciplining norms. These behaviors were made possible by asserting his (and other learners) right to participate equitably in discussion and activities while exchanging this political view with educator in the space. Finally, these activities are contextualized in the evolving history of the learning that was happening in the program among learners and with teachers. Future work may consider examining the impact of teacher specific instructional moves and pedagogy on creating opportunities for the learner to engage in resisting, expressions, and playfulness.

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International Society of
the Learning Sciences

Documenting Out-of-School Time Learning: Opportunities, Tensions, and a Prototype

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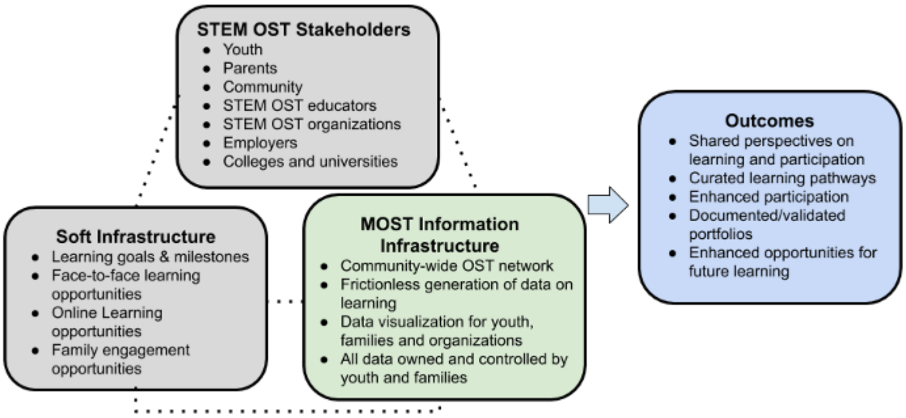
Abstract: This poster explores a method for documenting learning in out-of-school-time (OST) settings such that the values of youth and OST providers are preserved and highlighted. OST learning documentation can serve a variety of purposes, including as evidence of college readiness. The poster presents a prototype of a personal learning record for OST learning and discusses tensions and opportunities for such a record of learning and explores key tensions in creating such a representation.

Introduction

There are many reasons to document youth learning in out-of-school time (OST) or informal settings. These include helping guide youth to future learning opportunities, helping youth pursue work, or as part of pursuing future formal education such as college (Keune et al., 2022). Such documentation could also be valuable to OST organizations, both for program improvement and for obtaining funding. There are also a range of tensions that emerge from the process of attempting to document youth OST learning. What counts as learning? What kinds of knowledge are privileged? And how do we avoid damaging the motivations youth have for engaging in OST activities with the addition of formal assessment and documentation of learning (Torrance, 2012)?

This poster presents work-in-progress from an NSF-funded project exploring the documentation of learning in OST contexts as part of expanding college access. The poster contains a prototype record of learning intended to be used alongside traditional college application materials. It also describes the research on OST learning used to inform the prototype and invites discussion of pathways forward in this design space. A goal of the project is to center and elevate an OST STEM learning ecosystem (Pinkard, 2019) in which the views, values, and goals of different stakeholders are valued and represented (see Figure 1).

Figure 1
An OST STEM Learning Ecosystem

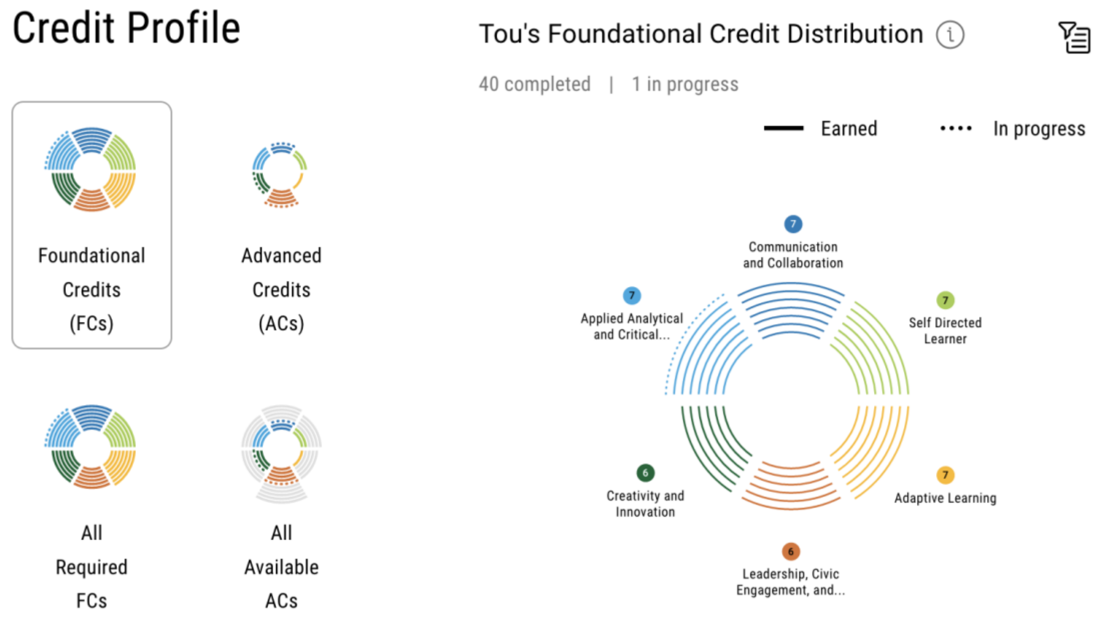


Design of the study

This project explores the learning experienced by youth in three different OST contexts, selected in part for their divergent goals and *modus operandi*. One is a community-based program in the U.S. Pacific Northwest for mixed income, refugee, and immigrant youth. Another is a middle-grades coding program in the U.S. Midwest designed to enhance learner self-concept around computing. And the third is a university-sponsored college preparatory program in the U.S. Midwest designed to enrich learning for high school students and prepare them for success in higher education. To investigate learning, we interviewed both youth and their caregivers and OST providers. We also interviewed college admissions personnel from a broad range of institutions to understand how they currently view OST learning and how different representations of OST learning might elevate its role in the college admissions process. Using inductive coding, we investigated each of these interviews to surface themes and patterns. We then shared these observations with OST youth, families, and providers to understand how they recognized their learning in our data, and with college admissions personnel to understand how they might view our data about learning in their work. From here, the project team worked with our partner the [redacted for review], an organization focused on the development of mastery-based transcripts for use in formal K-12 education, to extend their transcript concept into the OST space. This prototype (see Figure 2), which we refer to as a personal learning record instead of a transcript, was then shown to OST providers to see if they viewed it as useful and representative of their activities, with youth and families, to see if they viewed it as representative of their values and learning, and with college admissions personnel to see if they viewed it as useful in their holistic review processes. Detailed findings and a discussion of the tensions described above are presented in the poster.

Figure 2

A prototype personal learning record for OST learning



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Learning Analytics in the Context of Lifelong Guidance: User Expectations

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Abstract: Possibilities to support lifelong learners with learning analytics (LA) tools must be examined. We investigated what type of support user expect from LA guidance tool. Qualitative analysis identified five key themes important for users in the context of LA-supported lifelong guidance: Education and work information provision, diversification of understanding about available career paths, sense making, self-reflection, and transition support. The results highlight potential directions for developing LA guidance tools.

Introduction

The world of work is becoming increasingly unpredictable, leading to a growing number of occupational, industrial, and geographical transitions (Sullivan & Al Ariss, 2021). From the individuals' perspective this requires lifelong learning, building on past experiences, information about self and the world in order to make decisions and to find paths towards desired educational and occupational outcomes. Emerging technologies represent a major knowledge gap in this context as little is known how they can be utilized to support individuals through lifelong learning and work. Previous research has argued that LA holds potential to support humans through life transitions (Poquet et al., 2021). Through LA tools based on accumulated individual data it is possible to utilize individuals' previous learning information for lifelong guidance purposes. This process could be further optimized through individuals' needs and preferences. For instance, empirical research showed LA tools to be used for academic advising support within higher education institutions (Gutierrez et al., 2020). However, user needs and expectations in the context of lifelong guidance remains unexamined. In this research we investigate possible contributions of LA to lifelong guidance through the inquiry of users' expectations for and feedback about the LA lifelong guidance tool. We aim to better understand what type of support individuals expect to help them move through life transitions. This work contributes to better understanding future development directions of emerging technologies for guidance purposes.

Materials and methods

Participant group (N = 106) comprised of 42% men and 57% women; age mean 21.7 years. Basic education was completed by 72.6%, vocational education and training by 17% and higher education by 9.4% of the users. The users used a LA lifelong guidance tool, which suggested study programs and places based on user's interest, likes and dislikes in education. Users' expectations and feedback were gathered in a questionnaire and analysed inductively using qualitative content analysis to identify prominent themes in connection to the LA tool use.

Results and discussion

Results revealed five key themes important to users in the context of LA lifelong guidance (Figure 1), adding additional layer of understanding how LA could be used to benefit lifelong learners.

Quality career information on educational opportunities, and job market situation came out to be essential for the users. In agreement with previous research, provision of career information is a fundamental requirement of career guidance technology.

> Participant 1: *If you don't know about training/education, you get information and get acquainted with different levels of education or training, you get information on where to ask for more.*

Diversification of understanding of possible career paths was key expectation from the users' perspective. LA can respond to this need by helping users to re-evaluate their backgrounds and interests in different contexts. Results of this study provide promising direction for this possibility, which must be further researched. Developments in this direction could also facilitate career guidance objectives for social justice.

> Participant 2: *[The LA tool] provides a wide variety of educational opportunities that you may*

not have considered.

Sense making support was expected helping to understand and analyse provided information. Although traditionally this has been attributed to counsellor's work, availability of human support is often limited. Clear need has emerged not only to provide information but to support further analysis and interpretation for actionable career path insights.

Participant 3*: [I would use it] to compare study fields and different levels of education.*

Self-reflection support was expected to better understand career interest and options in the context of own life. Previously LA has been used to facilitate self-reflection in institutional learning context, however, it must be further explored in the lifelong guidance perspective. For instance, interest should be clearly reflected in the provided career recommendations.

> Participant 4: *[There should be] questions about career aspirations, life wishes and dreams (family, career, childlessness).*

Supporting transitions – the users note both technical LA tool support for transitions (e.g., applying to study programs) as well as psychological benefits (e.g., getting confidence needed to make decisions). Accordingly, LA could support users to set short- and long-term goals, progress into and out of education, into the world of work and between jobs. Although current maturity level of the LA guidance tool was limited, results present an interesting possibility. Thus, the category contains both kinds of answers.

Participant 5*: You get assurance of what to start doing.*

Figure 1
Identified types of support users expected from the LA tool

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AI-Integrated Virtual Students for Teacher Training: Comparing Simulation-Based Classroom Dialogue With the Real Thing

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Abstract: This paper reports on a study of AI-integrated virtual student agents designed for preservice teacher training. Eight preservice teachers engaged in a simulated science class where they conducted multiple lessons with the virtual students. Simulation lesson discourse was transcribed and compared to that of in-service teachers conducting lessons with real students. Results indicate that the virtual student authentically replicated declarative and interrogative patterns of discourse, but preservice teachers asked fewer questions than their in-service counterparts.

Introduction & theoretical background

Providing preservice teachers with authentic experience has been a focus for teacher educators. One way to accomplish this is through simulated teaching. Artificial intelligence (AI) can be used to render simulation-based virtual agents that reflect the cognitive-affective states of real students. However, AI-integrated virtual student agents need to be scrutinized for authenticity.

For agents to be perceived as authentic, cognitive-affective student models can be integrated into a language model (Dai & Ke, 2022) to generated discourse that is similar to that of real students. The difference between AI-generated discourse and that of human students remains an open question. This invites the use of discourse analysis as a tool for analyzing dialogue systems, which is a common tool for evaluating conversation agents to gain insight into the accuracy of the conversation agent's logic and the behavior of the human interlocutor (Hobert, 2019). A surface level inquiry into the function of statements made by the agents with preservice teachers on the one hand, and in-service teachers with real students on the other, can illuminate patterns of discourse that provide insight into both the agent's functionality and preservice teacher performance.

We therefore analyzed the classroom dialogue of preservice teachers and AI-integrated virtual students from a discourse perspective with the goal of comparing simulated and real classroom discourse, assessing both authenticity and efficacy for teacher training. The research question guiding this study is how do the mean frequencies and ratios of statement function (declarative, interrogative, imperative, and exclamatory) compare for teachers and students within and between actual and simulated classrooms?

Method

This split-plot study involved eight pre-service STEM teachers recruited from a teacher training program at a U.S. university. Participants underwent four-hour teaching practice sessions that included preparation, delivery, and reflection of teaching a STEM topic exemplified in Ambitious Science Teaching (Windschitl et al., 2018), a K-12 STEM teaching framework initiative. Lessons were delivered by the preservice teachers in *OpenSimulator*, a 3D virtual world, to AI-integrated virtual student agents. The agents were programmed with a generative, pre-trained transformer-based deep neural network model trained on authentic STEM classroom dialogue (see Bhowmik et al., 2022).

The text-based interactions between the preservice teachers and the AI-integrated virtual student agents resulted in a transcript of over 12,000 words for analysis across 12 separate teaching sessions. Additionally, 24,000 words were manually transcribed from actual teacher-student dialogue for comparison.

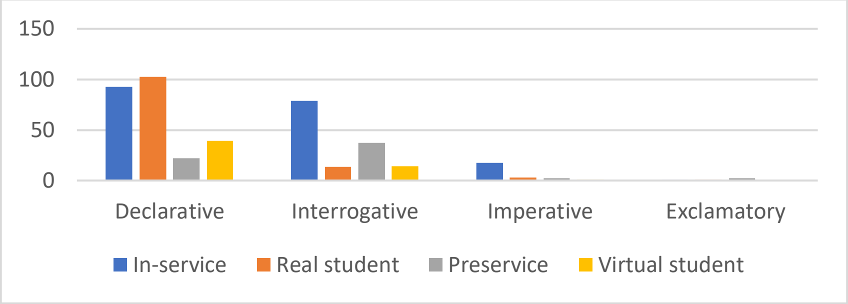
Data were analyzed by coding the transcripts by frequency of statement function based on the four typical function types: declarative, interrogative, imperative, and exclamatory. Frequencies were averaged per teaching session and ratios were calculated to allow comparisons between class contexts (actual and simulated). Select comparisons among these figures were made using an analysis of variance (ANOVA).

Results

Figure 1 depicts mean frequencies of statement type from the actual and simulated classroom sessions. In the simulated classroom, preservice teachers, on average, used significantly fewer declarative statements than the virtual student (F (1, 22) = 7.36, p = .013), but significantly more interrogatives (F (1, 22) = 8.22, p = .009). Imperative use was non-significant between preservice teachers and the virtual student (p = .181). For both simulated and real contexts, exclamatory statements were too infrequent to warrant comparisons. In-service teachers in an actual classroom context, on average, also used significantly more interrogative statements (F (1,

16) = 14.24, *p* = .002), and spoke more per turn at talk (*F* (1, 16) = 11.77, *p* = .003). However, unlike in the simulated classroom, in-service teachers did not have a significant difference in declarative statement use from real students (*F* (1, 16) = .185, *p* = .673), and used imperatives significantly more (*F* (1, 16) = 14.13, *p* = .002).

Figure 1
Mean frequencies of statement types in dialogues from simulated and actual classrooms.



Note. Actual classroom sessions tended to be almost twice as long as simulated sessions and therefore between-group comparisons in this figure should be avoided.

Table 1 shows the teacher-to-student mean ratios for statement functions for dialogues that took place in both the simulated and actual classrooms, allowing for between-group comparisons. For declarative statements, the mean teacher-to-student ratios were non-significant between simulated and actual contexts (*F* (1, 19) = 1.24, *p* = .280), as were the imperative ratios (*F* (1, 8) = .10, *p* = .765). Mean interrogative ratios, on the other hand, were significantly different between contexts (*F* (1, 19) = 9.95, *p* = .005).

Table 1
Teacher/student mean ratios for statement types from simulated and actual classrooms.

	Declarative	**Interrogative**	**Imperative**	**Exclamatory**
In-service teacher / Real student	0.93	16.89	1.02	-
Pre-service teacher / Virtual student	0.71	4.04	1.36	-

Conclusion

To summarize, within both contexts, students used more declarative statements than teachers, and teachers used more interrogatives than students. Between contexts, teacher-to-student interrogative ratios were much larger in real classrooms, with in-service teachers using them almost 17 times more than students, compared to preservice teachers' four-fold use. These findings can aid in better coaching of preservice teachers and in further developing the AI-integrated virtual student agent.

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Voices From the Field: Teachers' Perceptions of Who Teacher Leaders are and What They do

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Abstract: Teacher leadership is important for providing high-quality education. However, there is little consensus on what constitutes teacher leadership. We explored perceptions of eight teachers about teacher leadership. The following themes emerged to describe teacher leaders: being a model, lifetime learner, experienced teacher, listener, aware of everyone's needs, communicator, and collaborator as well as assisting teachers and improving students' learning. Those who participated in a teacher leadership program were engaged in professional development beyond school-level.

Introduction

Providing teacher leadership opportunities may be a potential solution to support building knowledge and sustaining a community of highly qualified teachers. To conduct rigorous research on the impacts of teacher leadership opportunities, many scholars attempted to describe teacher leadership and what teacher leaders do. However, many studies still failed to provide an encompassing definition of teacher leadership (Nguyen et al., 2019; Wenner & Campbell, 2017; York-Barr & Duke, 2004). The conceptualization of what constitutes teacher leadership is widely varied across literature (Neumerski, 2012; Nguyen et al., 2019). Broadly, some definitions of teacher leadership include going beyond classroom walls by "maintaining K-12 classroom-based teaching responsibilities, while also taking leadership responsibilities outside of classroom" (Wenner & Campbell, 2017, p. 140). However, these definitions mainly represent the perspectives of researchers that are external to the practice. Therefore, it is important to explore the teachers' perceptions regarding teacher leadership. Such exploration can advance the current teacher leadership frameworks and models (e.g., Teacher Leadership Exploratory Consortium, 2011) by bringing in the practice side of the coin and bridging research and practice. Handful of studies investigated how teachers' perceptions of teacher leadership (e.g., obtained through teacher leadership inventory survey; Angelle & Teague, 2014) relates to other factors such as self-efficacy, age, gender, educational qualifications, and teaching experience (Aliakbari & Sadeghi, 2014; Angelle & Teague, 2014) or the schools' culture and context (Bradley-Levine et al., 2014). These studies are limited by self-reported surveys of teacher perceptions and do not necessarily focus on defining teacher leadership. In this paper, through in-depth interviews, we aim to explore how master teacher fellows (MTFs) described the characteristics of teacher leaders and what teacher leaders do in comparison to non-MTFs. The following research questions framed our work: How do teachers perceive teacher leadership (characteristics and what do teacher leaders do)? Do perceptions of MTFs and non-MTFs differ in this regard?

Methods

We conducted one hour-long semi-structured Zoom interviews with eight mathematics teachers (three male, five female; six White, one biracial, one African American) with 10 to 25 years of teaching. In this paper, we focused on the following interview questions "What do you think the characteristics of a teacher leader are? What do you think teacher leaders do?" We used deductive, thematic data analysis (Saldaña, 2021) and drew from York-Barr and Duke's (2004) review summary.

Results

There were no noticeable differences between MTFs' and non-MTFs' descriptions of teacher leader characteristics. We found four common themes: being a (a) model, (b) lifetime learner, and experienced teacher, (c) listener and aware of everyone's needs, and (d) communicator and collaborator. Both non-MTFs and MTFs indicated that being a model for teachers and students is one of the teacher leaders' characteristics. For instance, a non-MTF, said, "A leader also sets the example by continuing to learn and change and to teach other people what to do." An MTF thought "they [teacher leaders] set an example for other teachers" and "model what they should be doing." To become a model for other teachers and students, teacher leaders need to also continue to learn and develop their knowledge of teaching and learning. Both MTFs and non-MTFs highlighted the importance of "continu[ing] to learn and change," "grow[ing] from what I was learning," and "learn[ing] from each other…grow[ing] together." An experienced and knowledgeable teacher can offer "suggestions on how to better fit into the faculty climate," provide "content-focused coaching," or "share ideas" about teaching and learning as well as understand and make use of students' assessment data. MTFs and non-MTFs described that teacher leaders need to listen and become aware of everyone's needs. It is only by being a good listener, a teacher leader can "understand what is needed and assist newer people in achieving certain levels." As a teacher leader, a non-MTF, said, "I need to listen to other people…to my students when they tell me things. I need to listen to other teachers when they tell me about the problems and the struggles that they are having." Being a good listener is one step toward being an effective communicator and collaborator. The communication skills and ability to collaborate were other characteristics of teacher leaders. For example, an MTF explained, "being able to communicate with a teacher without them feeling like they're inadequate, or they don't know what they do…always trying to be positive with them and just trying to build them up…"

The teachers describe the characteristics of a teacher leader in relation to their leadership responsibilities. These responsibilities illuminated what teacher leaders do or are expected to do, which were centered around different approaches to assisting teachers and improving students' learning. For example, an MTF said, "I think a teacher leader is someone who, you know, who assists teachers, works collaboratively with teachers to better craft their teaching, you know, through content-focused coaching." MTFs more often thought of these leadership responsibilities in a broader range and were more engaged in their school and district PD programs compared to non-MTFs. For example, an MTF took part in designing questions "for the high school level, national level."

Significance, contribution, implication

In this paper, we found four common themes highlighting the characteristics of teacher leaders: significant experience and extensive knowledge, lifelong learning, and communication and collaboration skills (in line with prior studies; e.g., Katzenmeyer & Moller, 2001; York-Barr & Duke, 2004). Further, teachers described what teacher leaders do by primarily focusing on what York-Barr and Duke (2004) referred to as the professional development of colleagues. However, in comparison with non-MTFs, the MTFs' engagement in leadership activities were beyond their schools. The implication of this study is particularly important for those who plan and support teacher leadership programs. The results of this paper contribute to the conceptualization of what constitutes teacher leadership from teachers' perspectives and provide practitioner insights into models and frameworks for teacher leadership.

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Science and Mathematics Teacher Retention: A Collective Analysis and Comparison Between Master Teachers and Other Teachers

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Abstract: Teacher retention has been a continuous challenge in the U.S. In this paper, we compared 84 Master Teaching Fellows (MTFs) and 83 non-MTFs in their self-efficacy, leadership skills, school-work environment, diversity dispositions, and professional network size. Using multinomial logistic regression, we also explored if these factors related to their retention. Results indicate that MTFs: (1) have higher levels of self-efficacy and diversity dispositions, and larger leadership networks; and (2) are more likely to shift to leadership positions. Findings provide insights for developing teacher leadership programs.

Introduction

Teacher turnover presents significant challenges for U.S. public schools for over decades, particularly for science and mathematics in high-need schools. Factors such as self-efficacy, leadership, autonomy, and social networks may help mitigate the adversities feeding into teacher turnover. In fact, because of the positive impacts of self-efficacy on instructional approaches and constructive learning, greater student motivation, and collaborating with other teachers (e.g., Boice, et al., 2021), many argue that higher self-efficacy can also yield other positive outcomes such as teacher retention (e.g., Polizzi et al., 2021). Related to leadership, mounting evidence suggests that K-12 school-based leadership can be one of the most successful forms of support to develop and sustain highly qualified teachers (e.g., Berg et al., 2014). Additionally, principal autonomy support and teacher-school fit have been associated with teachers' sense of belonging and job satisfaction (Youngs et al., 2015), which can, in turn, relate to teacher retention. Research indicates that teachers who have more connected networks are more likely to persist in teaching and develop leadership identities (Alemdar et. al., 2022). Professional social networks are important assets for teachers in several ways including informal professional development by learning from each other, supporting each other on non-teaching related factors such as cultural and administrative, and developing strong teacher identities (Polizzi et al., 2021). Moreover, research indicates that teachers who have more connected networks are more likely to persist in teaching and develop leadership identities (Alemdar et. al., 2022). The following research questions formally guided this study: (1) How do Master Teachers (MTFs) compare to non-MTFs in terms of their self-efficacy, leadership skills, diversity dispositions, school-work environment, network size, and retention? (2) To what extent do these factors relate to their retention? Is there a difference between MTFs and non-MTFs regarding this relation?

Methods

Data were collected from 84 MTFs and 83 non-MTFs across the nation (30% male and 70% female; 88% White and 12% from minoritized backgrounds). We define MTFs as science and mathematics teachers who participated in a five-year National Science Foundation Noyce Master Teaching Fellowship Program and taught in high-needs schools. Teachers completed self-reported comprehensive surveys comprising demographic and professional background questions; 4- or 5-point Likert-scale items about teaching self-efficacy (Klassen et al., 2009), leadership skills (Watt et al., 2010), person-organization (P-O) fit (Youngs et al., 2015), teacher autonomy (Baard et al., 2004), and diversity dispositions (Schulte et al., 2008); and social network (Polizzi et al., 2021). We used multinomial logistics regression analyses with retention as a four-level nominal outcome (stayer: continue teaching in the same school, mover: change schools, shifter: take a leadership position; and leaver). We explored the impact of independent variables on three retention levels compared to stayers.

Results

Findings indicated that MTFs' teaching self-efficacy (t (165) = 2.23, $p = .03$) and leadership network size (t (165) = 3.18, $p < .001$) are significantly greater than non-MTFs. Although not statistically significant, MTFs' availing diversity dispositions are slightly higher than non-MTFs (t (165) = 1.81, $p = .07$). There was no statistically significant difference between MTFs and non-MTFs on other factors. Regarding retention, there was no difference between MTFs and non-MTFs for being a mover or leavers. However, significant differences occurred between the two groups about staying (t (165) = -3.22, $p < .001$) and shifting (t (165) = 2.24, $p = .03$) to a leadership position. Interpreted collectively, we can infer that MTFs are more likely to assume a leadership role. Regarding the relation between retention and independent variables, results indicated that higher level of engagement in teacher leadership and lower degrees of P-O fit were associated with shifting to a leadership position (see Table 1). Leadership network size is positively associated with shifting to a leadership position. Lastly, leavers, compared to stayers, tend to have slightly higher levels of self-efficacy. The relationship between the independent variables and retention did not differ by MTF-ness.

Table 1
Multinomial Regression Results with Retention as the Outcome.

Variables	***Mover*[a]**			***Shifter*[a]**			***Leaver*[a]**		
	B	**S.E**	**Exp(B)**	**B**	**S.E**	**Exp(B)**	**B**	**S.E**	**Exp(B)**
Male	0.00	0.71	1.00	-0.29	0.56	0.75	-0.55	0.92	0.58
Teaching self-efficacy	0.48	0.65	1.62	0.32	0.54	1.38	*1.79*	*0.99*	*6.01^*
Leadership activities	-0.96	0.57	0.38	**1.76**	**0.54**	**5.81****	0.95	0.69	2.58
P-O fit	-0.26	0.45	0.77	**-0.80**	**0.37**	**0.45***	-0.34	0.51	0.71
Autonomy support	-0.19	0.36	0.83	0.29	0.30	1.33	-0.53	0.37	0.59
Diversity dispositions	-0.09	1.74	0.91	-1.21	1.43	0.30	-3.82	2.43	0.02
Leadership network size	-0.04	0.10	0.96	*0.14*	*0.07*	*1.15^*	0.14	0.11	1.15

[a] The reference category: Stayer. *$p < .05$. **$p < .01$. ^$p < .1$

Discussion and conclusions

Our study revealed that MTFs tend to have higher levels of self-efficacy and availing diversity dispositions and larger leadership networks. Another significant difference between MTFs and non-MTFs is the likelihood of shifting to a leadership position. One important area of discussion is whether a teacher's shift to a leadership position hurts the teacher retention. Perhaps, shifting results in impacting other teachers and contributing positively to teacher retention. Shifters indeed feel having more impact on other teachers and students when they assume a leadership role (Ekmekci et al., 2022). These findings favoring MTFs provide evidence for the impact of NSF Noyce programs on teachers. Additionally, teacher leadership activities had a significant impact on shifting and P-O fit had a negative impact on shifting. In brief, long-term professional development for developing teacher leaders seems to produce positive outcomes for teacher self-efficacy and leadership. Thus, school and district administrators should promote and encourage teachers to engage in leadership activities.

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Gatekeeping of Emerging Discipline-Based Education Researchers

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Abstract: Discipline-based education research (DBER) is a field which attracts many faculty who are not previously trained in education research. We conducted interviews with 27 emerging discipline-based education researchers to better understand their experiences and needs entering the field. Many of our participants have experienced gatekeeping during their journey into DBER. Using Barzilai-Nahon's Theory of Network Gatekeeping, we discuss some of the impacts of gatekeeping on emerging DBERers.

Introduction

Discipline-based education research (DBER) has become more formally established in recent years, gaining support and formal recognition from STEM disciplinary societies. DBER presents a unique challenge as research on tenure-stream DBER faculty shows that many do not follow the typical pathway into education research. Instead, faculty move into education-focused positions without significant prior background (e.g., science faculty with education specialties (SFES) discussed by Bush et al., 2017). Emerging DBER faculty often feel unprepared for research in education or find themselves lost and anxious as they try to engage with education research. We discovered that perceived gatekeeping–the process by which people with power in a community control or limit others' access to that community and its resources–significantly impacts new researchers. As new members of the education research community, these emerging DBERers find themselves daunted by the task of engaging with the education community. Many of them have experiences which negatively impact their engagement, however many of them also discuss experiences which have supported their move into education research. Here we discuss some of those experiences and call upon the education research community to consider how we might reach out to and include these new and emerging DBERers.

Theoretical framing

DBER has not focused on theoretical investigations of gatekeeping. Following Barzilai-Nahon's review in which they note the lack of consistent, broadly applicable theories of gatekeeping (Barzilai-Nahon, 2009), we use Barzilai-Nahon's (2008) Theory of Network Gatekeeping (TNG), which they produced as a synthesis of the fragmented literature, as a theoretical lens to analyze and discuss gatekeeping within DBER. Importantly, our approach to gatekeeping does not require that it be necessarily a bad thing (gatekeeping is an ordinary part of research communities, e.g. peer review), nor does it require gatekeeping to be malicious. In fact gatekeeping can be a healthy and normal feature of research communities.

Several important features of the TNG were utilized in this study (Barzilai-Nahon, 2008). The *gate* is a point of entry (physical or conceptual) through which a person or their ideas (the *gated*, emerging DBER faculty) must pass to join the DBER network (community). *Gatekeeping* is the process of controlling passage through the gate. *Gatekeepers* (members of the DBER community) are those who are responsible for deciding who or what can pass through the gate. The TNG also provides four attributes of the gated to explain the ways gatekeepers prioritize allowing entry of the gated (*gatekeeping salience*): power in relation to the gatekeeper, information production ability, relationship with the gatekeeper, and alternatives in the context of gatekeeping (for example, if you try to publish and get rejected, is there a publication alternative available to you). These attributes can occur in any combination, and any given instance of gatekeeping could involve some or all of them.

Methods

Authors 1 and 2 conducted semi-structured interviews, about one hour in length with 27 emerging DBERers. These interviews included 8 major questions, each with optional follow up questions. Our interviewees are 23 faculty (a mix of tenure and non-tenure track faculty), but also include 3 graduate students and post-doctoral researchers, as well as one high school teacher working on their master's degree. These interviews focused on the participants' experiences becoming involved in DBER, their career experiences, and their research goals and projects (in various stages of maturity) in DBER. We were particularly interested in the challenges participants faced and things that had supported them in overcoming those challenges, as well as their thoughts on their identity and place within or adjacent to DBER.

The first author conducted an initial analysis of the transcripts to find interviews where the interviewees had a clear discussion of their experiences navigating entry into the DBER community and gatekeeping (or lack thereof) that they had experienced. These gatekeeping experiences could include both direct events (e.g. someone actively blocking an individual's participation), indirect experiences (e.g. a lack of connections, or extensive use of jargon), or even imagined gatekeeping (e.g. concerns about stigma and expectations in the field). We found 12 interviews with strong discussions of gatekeeping for our thematic analysis (Clarke et al. 2015). The second author examined these themes, and agreement was reached between the two authors through discussion and refinement of themes. Poster presents the most prominent themes we have found for the community's consideration.

Themes of gatekeeping

We found three themes, each of which is grounded in the four attributes of the gated as defined in the TNG (Barzilai-Nahon, 2008): **qualification**, participants feel underqualified for DBER; **alienation**, educators feel out of place or excluded by established researchers in DBER; and **connections**, the importance of closer relationships with existing community members for becoming a part of the community. In an example of qualification, Cole (chair of a mathematics department) said: "here's [the interviewer] working on his PhD to be able to do this kind of research" and continues "I also think that research should be done by professional researchers, right?" These participants are capable of engaging in DBER scholarship (TNG, *information production ability*), however their perceived lack of qualification acts as a barrier to entry into the DBER discourse (TNG, *gatekeeping*). Alex highlights alienation (assistant professor of mathematics) when describing conversations with researchers at the Research in Undergraduate Mathematics Education (RUME) conference: "I have a lot of intuition that I feel comfortable talking about, and sometimes the RUME scholars are like, 'but this is the only thing that's been studied and because people have thought about this way in the past, this is sort of how the conversation has to go" (TNG, *power in relation to the gatekeeper*). In an example of connections Samuel (graduate student in Physics Education Research) said: "I've been in physics education research for probably about three years and we have a DBER group on campus that I'm in with other people, and I've found these to be enjoyable, effective places where I can learn about education research" (TNG, *relationship with the gatekeeper*).

This poster presents the themes to the audience, as well as excerpts from the data to explain our reasoning and ideas. We hope to highlight some of the negative experiences associated with gatekeeping in our field, the impacts they have on EDBERs, and talk about what we can do as a field to mitigate those negative impacts while sustaining the positive and necessary aspects of gatekeeping.

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Exploring the Relationship Between Flying Performance and the Dynamic Changes of Emotions in an Aviation Training Task

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Abstract: This study explored the relationship between dynamic changes of emotions and flying performance in a simulation. K-cluster analysis found a high (n=12) and a low-performing group (n=7) according to flying performance (precision and error). Groups experienced different sequences of emotions. Both groups had sequences among neutral-anger, and neutral-happy. High-performers had more sequences among disgust-fear, whereas low-performers had more sequences between disgust-anger. Aviation trainees experience dynamic changes in the emotions, which can impact performance outcomes.

Introduction

This study aims to understand the relationship between the dynamic changes of emotions and flying performance in a simulation. We aim to contribute to the literature by (1) using new approaches to account for multidimensional measures of performance, considering individual variability (i.e., precision) and accuracy approaching the target metric (i.e., error), and (2) understanding the emotional experience of aviation trainees, accounting for dynamic sequences of emotions with different performance levels.

Emotions and performance in aviation training

Research and education in aviation training aims to facilitate effective psychological processes that ensure proficient performance. Aviation training is increasingly interested in understanding the nuances of emotions in pilot trainees' performance, yet such research is still in its early stages (Murray & Martin, 2012). Additionally, flying performance was conventionally evaluated through instructor observations, however, recent approaches suggest using aircraft logfiles can increase consistency and decrease evaluation time (Li & Lajoie, 2021).

Theories of emotions in learning

Since emotions are short states that are triggered by specific events, such emotions can dynamically change throughout a learning activity. Therefore, recent research is exploring the interaction between dynamic emotional changes during learning on performance. Affective changes are expected to impact the cognitive processing of learners', facilitating, or blocking achievement of the learning goal (D'Mello & Graesser, 2012). When solving the problem in a functional way, learners are expected to have changes among confusion, frustration, and engagement (D'Mello & Graesser, 2012). If the learners are unable to solve impasses, they can stay in a sequence of frustration, resulting in boredom, disengaging from the task (D'Mello & Graesser, 2012).

Research question and methods

We pose the following research question: Do aviation trainees, grouped according to their performance, differ in the sequence of emotions they express during a flying task?

19 undergraduate and graduate students (M_{age}=24.36, σ=5.814) performed flying maneuvers in X-plane (Laminar Research, 2022), a flying simulation software designed to mirror real planes. Flying performance metrics (speed, altitude, heading) were obtained from logfiles and used to calculate precision and error: a larger number in precision (i.e., more variance) was interpreted as more movement, a larger error (calculated with root mean square error) would imply more distance to the objective set in the instructions.

Participants' facial expressions were video recorded and analyzed with specialized software (FaceReader 6.0, 90% accuracy rate, Noldus, 2015). Emotions (i.e., neutral, angry, sad, happy, disgust, surprise, and fear) are recorded in a sequential manner to assess the significant sequences of emotions. Interpreting results, we considered expression of happiness aligned with enjoyment and engagement/flow, anger with frustration, disgust with confusion, fear with anxiety, and sadness boredom (Harley et al., 2015).

Results

A 2 k-cluster analysis was conducted to group students according to performance scores, which required three iterations to create differentiated clusters. Z-scores were used to interpret each cluster. Cluster 1 (n=12) was labeled as high performance since trainees had low variance in precision (Z_{speed}=-0.57, $Z_{heading}$= -0.43, $Z_{altitude}$=-

0.58) and error (Z_{speed}=-0.51, $Z_{heading}$= 0.41, $Z_{altitude}$=-0.61). Cluster 2 (n=7) was labeled as low performance since trainees had a higher variance in precision (Z_{speed}=0.99, $Z_{heading}$=0.73, $Z_{altitude}$=0.99) and error (Z_{speed}=0.88, $Z_{heading}$=-0.70, $Z_{altitude}$=1.05).

A lag sequential analysis was performed to understand the difference in the sequence of emotions, using the Generalized Sequential Querier program (GESQ, Bakeman & Quera, 1995). Sequential transitions can be seen in table 1 for high-performers and table 2 for low-performers. Results show that 8 out of 42 potential sequences were statistically significant for high-performers, and 9 out of 42 sequences were significant for low-performers.

Table 1

The Sequential Transition Matrix of Emotions of High Performers

Z	Angry	Neutral	Surprise	Happy	Fear	Disgust	Sad
Angry	-8.24	9.47**	-0.59	-2.39	-1	0.82	-1.43
Neutral	9.23**	-16.64	3.07**	4.56**	-0.18	1.13	6.42
Surprise	-0.41	1.56	-2.09	-0.33	-0.53	1.98	-2.09
Happy	-1.4	5.6**	-1.6	-2.84	-0.6	-0.7	-2.35
Fear	-1.01	-0.19	-0.53	-0.59	-0.11	3.07**	-0.43
Disgust	0.95	0.98	0.75	1.18	3.05**	-3.45	-2.43
Sad	-2.6	6.5**	-1.55	-2.36	-0.44	-1.46	-1.72

Note. * p <.05; ** p < .01; *** p <.001

Table 2

The Sequential Transition Matrix of Emotions of Low Performers

Z	Angry	Neutral	Surprise	Happy	Fear	Disgust	Sad
Angry	-12.62	8.71**	3.9	-1.65	-3.76	5.04**	0
Neutral	11.65**	-16.86	-0.15	6.51**	3.89**	0.37	0
Surprise	1.94	3.13**	-3.66	-3.16	4.74**	-3.91	0
Happy	-4.23	7.59**	-2.41	-3.34	-2.08	1.33	0
Fear	-3.39	2.49	6.43	-2.08	-1.29	-2.31	0
Disgust	4.72**	1.23	-3.52	0.02	-2.3	-3.81	0
Sad	0	0	0	0	0	0	0

Note. *p < .05; ** p < .01; *** p <.001

Conclusion

The findings contribute to the literature by deepening the understanding of emotions in aviation training. Our findings confirm that trainees experience dynamic emotional changes during the flying task, and patterns vary according to performance. Trainees had significant bidirectional sequences between neutral and anger and neutral and happy. This finding aligns with the model of affect dynamics in which learners return to equilibrium after impasses (D'Mello & Graesser, 2012). Trainees who were more precise in their movements and were closer to the target metric (less error) had more sequences between disgust and fear. Conversely, trainees who were less precise and had more error experienced more loops between disgust and anger. High-performers were more likely successful in a high-concentration task after facing impasses (disgust/confusion) and expressing an activating emotion (fear/anxiety) that led them to solve the task. Low-performers experienced more frustration (anger) after facing impasses. These results emphasize the importance of understanding the relationship between emotions and performance in aviation training. We believe these results can be transferred to learners in high-stakes professions.

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Digital Clinical Simulations and Video Debriefs to Promote Equity Mindsets: Insights From a Mixed-Methods Staggered Randomized Experiment in an Online Course

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Abstract:. We developed a digital clinical simulation (DCS) and an asynchronous video-based simulation debrief (VD) and studied their effects within the first unit of an online professional development course (N = 767). Although we found no statistically significant differences in equity beliefs between participants in the two experimental conditions of the study (DCS-only and DCS + VD) and the control condition after the first unit, there were significant shifts overall by the end of the online course.

Introduction and background

Given the importance of DEI issues in education, finding a method for delivering high-impact, low-cost, scalable professional learning is an important goal. Digital clinical simulations (DCS) employ rich digital media to immerse participants in educational scenarios and prompt them to make improvisational decisions at key moments (Hillaire et al., 2021). These simulations afford opportunities for educators to practice how they would act in uncomfortable situations in low-stakes environments for students (McGarr, 2021). This study focuses on how a DCS and VD affected participants' views on educational equity within an online asynchronous professional learning course for teachers. We examined the "Jeremy's Journal" simulation which focuses on differentiating between equality, treating all students the same, and equity, modifying the learning environment based on student needs and sometimes providing more support and flexibility to some students (Milner, 2012). Participants played the role of a 7th grade ELA (English Language Arts) teacher of an outgoing but struggling student named Jeremy. Participants made decisions during the week on how to support Jeremy in his learning and, at the end, had to decide whether to accept his request to be excused from a weekly quiz (Figure 1). Participants then completed a six-minute video debrief depicting teachers debriefing the simulation during a live facilitated session. Interspersed within the segments were cutaway scenes of teachers reflecting on their experience in interviews (Figure 1).

Figure 1
Simulation Images and Video Debrief

Enact

Monday

A snapshot of Jeremy's journal is shown below:

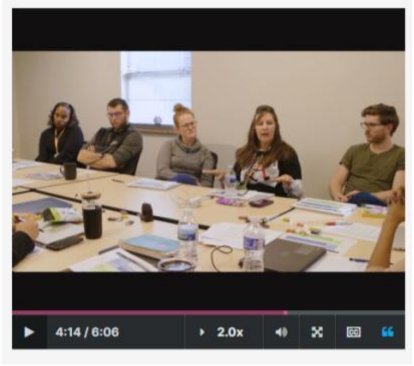
I never had a brain until Freak came along and let me borrow his for a while, and that's the truth, the whole truth.

-Freak the Mighty by Rodman Philbrick

Monday
Looks like a run-on. Thats it. All done
Scribble time.

Cause is subject and verbs
Hyperbole EXAGGERRRRAATTIOOON that
CANNOT POSSIBLY be true
His hands were as big as frying pans

Based on the class responses and Jeremy's journal entry, how do you want to respond?



"And no matter what looks like for that student they also have the same goals, but how do we help them get there. Building on talking to them, you start to see that maybe they need something different." *Debrief Participant*

Methods

Our data comes from the second run of a massive open online course (MOOC) for educators on a popular online learning platform (N = 787)—68% identified as female, 74% as White, and 84% identified as fluent English speakers. Most participants reported working in K-12 schools (54%). The demographics of participants in the analysis sample roughly reflected the demographics of educators and those in education-aligned industries. We used a staggered randomized multiple baseline design (Levin et al., 2018) to measure participant attitudes on an equality-equity survey measure (see Littenberg-Tobias et al., 2021 for survey items). The survey measure was randomized within the course structure (Figure 2). Although all participants eventually received the entire treatment through this design, we sought to estimate the immediate effects of both on participating in a DCS and combining a DCS with a video debrief. We also measured participant attitudes on the same measure after completing the course. Multilevel linear growth models were used for all analysis.

Figure 2
Study Design

	Time 1	Time 2	Time 3	Time 4	Time 5
Control	Survey	Intro videos	Survey	Jeremy's Journal	Video debrief
DCS	Survey	Intro videos	Jeremy's Journal	Survey	Video debrief
DCS + VD	Survey	Intro videos	Jeremy's Journal	Video debrief	Survey

Results

There were no statistically significant differences in participants' mindsets between the control group and those that had completed the digital clinical simulation (DCS) and those who had completed both the digital clinical simulation and the video debrief (DCS + VD). However, when we examined overall growth after completing the course, we did observe significant shifts toward equity beliefs ($\beta = 0.133$, t= 2.402, $p < 0.05$, ES= 0.25 SD)

Discussion

These findings raise important questions about when and how teachers change their beliefs about equity. As other studies have found shifts toward equity are not linear, and there may be diversions, half-learnings, and setbacks along the way (Self & Stengel, 2020). Changes in mindsets may not be therefore may not be immediately detectable on surveys even though participants may be beginning to shift in their beliefs. In future research, we intend to explore how different methods of feedback affect shifts in participants' equity attitudes to better understand how online instruction can be designed to best foster more equitable teaching practices.

Endnotes

(1) Course archived at https://openlearninglibrary.mit.edu/courses/course-v1:MITx+0.503x+T2020/course/

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Developing Pre-Service Teachers' Epistemic Cognition Through Learning Pedagogical Knowledge

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Abstract: We examined a course designed for pre-service teachers to develop their epistemic cognition on teaching practices through collaboratively learning pedagogical knowledge. Pre-service teachers' epistemic cognition was evaluated by asking them to interpret a teaching practice recorded in a video, before and after the course. Three patterns of epistemic cognition were identified using clustering analysis. Characteristics of each pattern were discussed for further refinement of the course design.

Background and research purpose

For educating students to develop their epistemic cognition, teachers must develop not only their own epistemic cognition on content knowledge, but also another type of epistemic cognition to improve their teaching practices (Mor-Hagani, & Barzilai, 2022). Recent studies have focused on how in- and pre-service teachers develop their epistemic cognition on teaching practices. Barnes et al. (2020), for instance, approached in-service teachers' epistemic cognition, by asking them how they evaluate students in their classroom. Referring to the "Aims, Ideals and Reliable Process (AIR)" model (Chinn et al., 2016), Barnes et al. (2020) found that teachers missed pedagogical knowledge to justify their teaching processes. In another study, Hartmann et al. (2021) designed an instruction based on an activity of multiple text integration, to elicit pre-service teachers' epistemic cognition on their teaching practices. They confirmed the effectiveness of the multiple text integration. Pre-service teachers who competently integrated multiple texts could appropriately demonstrate their epistemic cognition on teaching practices in their essays. Although studies have examined in- and pre-service teachers' epistemic cognition on their teaching practices as a unique nature of the profession, few studies have conducted design-based research to examine how acquisition of pedagogical knowledge facilitates teachers' epistemic cognition.

In this study, we, therefore, designed a course for pre-service teachers to learn pedagogical knowledge, based on the learning sciences. We examined how their learning facilitated their epistemic cognition on their teaching practices.

Method

Course description

Eighteen pre-service teachers took the course as part of their teacher certification program. They learned pedagogical knowledge based on the learning sciences through three modules: (1) knowledge-centered approach, (2) collaborative learning, and (3) self-regulated learning. In each module, we designed learning activities based on the framework of the preparation for future learning (Mylopoulos et al., 2016) and multiple text integration (Hartmann et al., 2021). Pre-service teachers were instructed to elicit their ideas related to the study topic in a module and collaboratively elaborate ideas based on their experiences. After listening to a lecture, they further engaged in multiple text integration through jigsaw activities (Miyake, & Kirschner, 2014). Each module took a day, and the course was conducted as an intensive summer course over three days. The course was co-designed by the three authors, who also taught the course.

Collected data and analysis

Pre-service teachers' epistemic cognition on teaching practices before and after taking the course

The same video recording was used to evaluate pre-service teachers' at the beginning and end of the course. The comparison between the pre- and post-test allowed us to examine the growth of their epistemic cognition consequent to taking the course. The video was an 11 minute-long summary of a science lesson on weather and air pressure. Eighth-grade students collaboratively engaged in problem-solving using their learned knowledge, coordinated by an experienced female teacher. At each test, pre-service teachers watched the video twice, and responded to the following questions in their worksheets: (1) what they noticed as instructional goals of the lesson, (2) what they noticed as effective processes to achieve the goals, and (3) what behaviors they noticed as students achieve the goals.

We developed a coding scheme to evaluate pre-service teachers' descriptions of the lesson's *Aims*, *Reliable Process*, and *Ideals*, based on the pedagogical knowledge that they could have learned through the three modules of the course. In terms of the lesson's aim, we assessed whether the overall goal of the lesson was described. For the processes and ideals, the descriptions were evaluated from the viewpoint of the three modules, with 1 point for each valid description, 0.5 points for partially accurate description by two independent raters (Cohen's k ranged from .5 to .7 for three components of AIR). The average scores were used as AIR model scores.

Data analysis

Pre-service teachers' epistemic cognition on teaching practices was coded as a sequence of *Aim*, *Ideals*, and *Reliable Process* scores. After standardizing the scores, we conducted an exploratory clustering analysis, to identify pre-service teachers' AIR model patterns of their teaching practices. Finally, we conducted an ANOVA on pedagogical scores, with AIR patterns as an independent variable, to examine how identified AIR patterns were related to the pedagogical knowledge scores in these three modules.

Results and discussion

In the clustering analysis of pre-service teachers' AIR model scores at the post-test, we found three clusters, each of which had unique score patterns. A 3 × 3 (Clusters × AIR components) ANOVA on the standardized scores revealed a significant main effect of Cluster, $F(2, 15) = 6.31$, $p < .05$, $h_p^2 = .4568$, and a significant interaction effect, $F(4, 30) = 17.09$, $p < .01$, $h_p^2 = .6949$. Multiple comparisons by HSD method showed that: (1) mean *Aim* score of Cluster 1 was significantly lower than those in other clusters, (2) mean *Ideals* score of Cluster 2 was significantly lower than those of the other two clusters, and (3) mean *Reliable Process* score of Cluster 2 was significantly higher than those of the other clusters. Based on the results, we named Clusters 1, 2, and 3 aIr, AiR, and AIr, where small characters represent significantly lower scores compared with other group(s), and capital characters represent significantly higher scores.

The aIr group of pre-service teachers had "Ideals" performance by students in the video, but did not specify *Aim* (i.e., why the performance is important to see from the perspective of learning deeply) and *Reliable Process* (i.e., how students should learn to attain the "Ideals" performance). We consider that the aIr pattern of teachers' epistemic cognition is typical for beginner teachers, and they are stuck with what is important at students' performance level but do not connect the performance with the theories behind it.

The differences in patterns of epistemic cognition should be further examined by conducting design conjectures (Sandoval, 2014) to analyze what mediating processes were facilitated by our design elements, so that we can further refine our instructional design.

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The Talk Move Patterns of Teacher-Student Interactions in K-12 Mathematics Lessons: An Analysis Based on the TalkMoves Dataset

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Abstract: The paper compared the talk move patterns of teacher-student interactions at the primary, middle, and high school levels. Specifically, this paper employed the sequential analysis method on 200 transcripts from a mathematics classroom discourse corpus *TalkMoves*. The preliminary results showed that although teachers from all three levels encouraged the whole class to participate, asked students questions, and required them to explain, students at different educational levels responded to teachers' talk moves differently. Students from primary and middle schools were more responsive than those in high schools.

Introduction

The academically productive talk (APT) advocates teachers adopting talk moves (i.e., specific dialog acts) to effectively elicit learners' participation in the discussion (Michaels et al., 2008; Resnick et al., 2010). To unravel key characteristics of talk moves supporting productive classroom discussions, researchers have made dedicated efforts to investigate teacher-student interaction patterns (e.g., Tytler & Aranda, 2015). Most studies, however, have focused on a single level of education. Few attempts were made to compare discourse patterns among different grade levels. The comparison of classroom discourse at different educational levels could not only inform researchers of generic patterns that advance knowledge acquisition but also assist teachers in mastering pedagogical approaches tailored to the needs of specific groups of students, especially for those teachers who straddle educational levels. Thus, this current research is intended to fill this gap by analyzing and comparing the talk move patterns of teacher-student interactions in mathematics lessons at the primary, middle, and high school levels.

Method

Data preparation

This paper employed the *TalkMoves* dataset as the data source for analysis and comparison. The *TalkMoves* dataset contains 567 transcripts from K-12 mathematics lessons (2022). Based on the APT framework, teacher utterances were labeled with *no talk moves* (T.N), *keeping everyone together* (T.K), *getting students to relate to another's ideas* (T.G), *restating* (T.RS), *revoicing* (T.RV), *pressing for accuracy* (T.PA), and *pressing for reasoning* (T.PR). Student utterances were labeled with *no talk moves* (S.N), *relating to another student* (S.R), *asking for more information* (S.A), *making a claim* (S.M), and *providing evidence* (S.P).

Before performing the analysis, data preprocessing measures were taken. Firstly, the data in the *TalkMoves* corpus were collected from 1990 to 2021. Considering instructional approaches three decades ago may be different from current pedagogies, this paper selected the latest transcripts recorded in 2019, 2020, and 2021. Secondly, each transcript in the corpus was either from an entire or partial mathematics lesson. Given that some partial sessions may have various durations, this paper uniformly chose transcripts from full mathematics lessons with a duration of around 55 minutes. After preprocessing, the paper finally obtained 122 transcripts from primary schools, 53 transcripts from middle schools, and 25 transcripts from high schools. The number of utterances was 72,237 for primary schools, 29,216 for middle schools, and 10,438 for high schools.

Data analysis

The lag sequential analysis (LSA) was mainly used to compute the probability of an action followed by another action and evaluate whether the probability is statistically significant (Bakeman & Gottman, 1997). Thus, this paper adopted this method to compare talk move patterns of classroom discourse among different grades and selected significant teacher-student talk move sequences to draw the sequential transition diagram (as shown in **Figure**). The values near the arrows and the arrow thickness represented the z-score and significance level, respectively. When the Z-score was equal to or above 1.96, the sequence of starting-following talk moves was statistically significant.

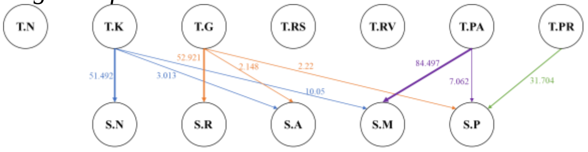
Preliminary findings

REF _Ref118971562 \h Figure 1 indicates how students at different educational levels responded to teachers in mathematics lessons. There were three teacher-student talk move sequences shared by the primary, middle, and high school levels, respectively, namely *keeping everyone together* → *relating to another student*, *pressing for accuracy* → *making a claim*, and *pressing for reasoning* → *providing evidence*. These three sequences implied that despite different grades, teachers all encouraged the whole class to participate, asked students questions, and required them to explain, demonstrating that teachers effectively used talk moves to contribute to learning communities, knowledge, and thinking.

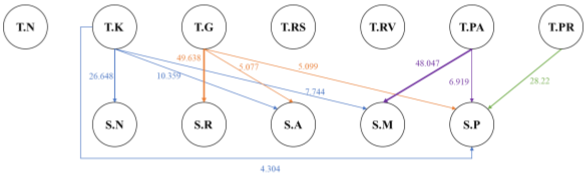
However, students at different educational levels responded differently to teachers' talk moves. Specifically, students from primary and middle schools were more responsive than those from high schools. For example, when teachers attempted to *get students to relate to another's ideas*, primary and middle school students replied by *relating to another student, asking for more information, and providing evidence*, while high school students only responded by *relating to another student.* A similar situation occurred when teachers tried to *keep every student together*.

Figure 1

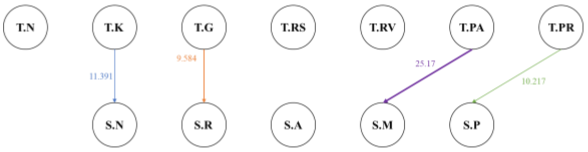
Transition diagram of teacher- student talk moves in K-12 mathematics lessons.



(a) Primary schools



(b) Middle schools



(c) High schools

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Automatically Assess Elementary Students' Hand-Drawn Scientific Models Using Deep Learning of Artificial Intelligence

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Abstract: Because of the complexity of scoring open-end tasks, machine learning (ML) has been utilized for automatically assessing students' constructed responses. However, most existing research focuses on grading text-based responses. No studies have investigated the automatic scoring of hand-drawn models created by elementary students. In this study, we applied ML to automatically score hand-drawn scientific models developed by elementary students for evaluating knowledge-in-use. We first developed algorithms using human-scored responses and then validated these algorithms with new data. We also implemented a data augmentation technique to enhance accuracy. Our findings demonstrate the potential of the developed algorithm to achieve high performance in automatically scoring hand-drawn models.

The Opportunities and Challenges of Scientific Modelling

Scientific modeling is a powerful approach for engaging students in science learning by enabling them to create multiple representations that explain or predict natural phenomena based on evidence (Li et al., 2021). However, the complexity and diversity of these models make their evaluation time-consuming and demanding (Zhai et al., 2022). Researchers have sought solutions by developing automatic scoring methods for students' written text-based constructed responses at the secondary or postsecondary levels (Mislevy et al., 2020). Yet, modeling still presents significant challenges for automatic assessment due to their tangible representations of intricate cognitive processes (Li et al., in press). This complexity is further amplified in hand-drawn scientific modeling tasks that measure complex constructs like knowledge-in-use. Students' hand-drawn models exhibit greater abstraction and within-class variation, reflecting their individualized interpretations of the same objects (Xu et al., 2021). Consequently, automatic scoring becomes more complex than other image classification tasks, as these drawings vary in style, skill, and detail compared to photographs (Lu & Tran, 2017). Because modeling is an essential scientific practice and scoring hand-drawn models is challenging and time-consuming, a need exists for automated assessment technology explicitly designed for students' hand-drawn models. This study explores: *How accurate is the neural network-based machine learning evaluation of hand-drawn scientific models developed by elementary students compared to human evaluators?*

Methods

This study utilized efficacy data from the ML-PBL project (Krajcik et al., 2023). Post-unit assessments were developed using a modified design process (Harris et al., 2019), employing 4-point holistic rubrics. Item validation was conducted using item response theory. We focus on three 3rd-grade modeling tasks. Task sq_v3, from the first unit, asks students to model the impact on squirrels if all trees were removed. Tasks ty_v4 and ty_v9, from the second unit, address "force and motion." Task ty_v4 requires students to create models explaining factors affecting toy car movements and collisions, while task ty_v9 involves designing a model to prevent car collisions. Students completed post-unit assessments, which were scanned and converted to PDFs for scoring. Six raters learned to score the items, and inter-rater reliability (IRR) checks were conducted to ensure consistency. A baseline 0.70 ICC coefficient was used to verify consensus between pairs of raters (0.68-0.87) (Koo & Li, 2016). Illustrating with task sq_v3, the dataset contains 2076 hand-drawn models by 2134 students across two years, distributed across 107 unique classes from four Michigan regions.

Machine Learning Algorithm Development and Validation

We developed Convolutional neural network (CNN)-based algorithms to score student hand-drawn models and compared the predicted scores to human expert scores (Krizhevsky & Hinton, 2012). A 10-fold cross-validation method validates the CNN-based scoring model. The 2076 student models were randomly divided into ten groups, with 10% for testing and 90% for training. The training set was further split into validation and actual training sets at a 1:4 ratio. As a result, we had 487 training samples, 382 validation samples, and 207 testing samples in each fold. We utilized the ResNet-18 architecture for feature extraction, implemented our model in Pytorch, and used an Adam optimizer with a learning rate of 1e-4 for both networks. The networks were trained for 200 epochs using an NVIDIA GeForce GTX 1080Ti graphics card, and data augmentation techniques were applied during the training process.

Findings

We calculated human-machine scoring agreement (HMA) accuracy for training and testing stages to determine the percentage of HMA. After each epoch, validation accuracy is computed, and network weights are saved. The highest validation accuracy weights are used to calculate test accuracy after training epochs (Lu & Tran, 2017). Average validation accuracies across folds were calculated during iterative training. In the testing stage, the validated CNN-based model assigned scores to a new testing group. A data augmentation model was compared to one without data augmentation. For task sq_v3, average training stage validation accuracies ranged between 38.31% and 64.12%. Table 1 presents the testing stage average test accuracies for task sq_v3, comparing data augmentation and non-data augmentation models, using data augmentation to reduce overfitting improved scoring performance, achieving a 62.32% +/-1.63% scoring accuracy. Task ty_v4 test accuracies were 73.25% ±1.47%, while task ty_v9 had a slightly lower accuracy of 53.29%±1.21%.

Table 1
Machine-human scoring agreement (test accuracies/ %) for tasks

Modeling tasks	With data augmentation techniques	Without data augmentation techniques
sq_v3	62.32±1.63	43.95±1.63
ty_v4	73.25±1.47	55.78±1.35
ty_v9	53.29±1.21	39.96±1.09

Discussion

This study explores ML for scoring hand-drawn models measuring knowledge-in-use, offering insights into factors affecting machine scoring. Automatically scoring hand-drawn models is challenging due to the variety of forms and artistic styles, the difficulty of machine classification using holistic rubrics (Nehmn & Haertig, 2012), and the complexities of automatic handwriting recognition with misspelled labels. The findings can help improve support for developing scientific models for deeper learning through timely assessment feedback.

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Teaching, Learning, and Mentoring for Racial Equity: A Multi-Dimensional Case Study

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Abstract: Scholars still have much to learn about how teachers learn about and teach for racial equity nested within multiple relations of power. Drawing on two illustrative moments within a qualitative case study, this study examines the co-construction of racial equity discourses and enactments within an equity-oriented induction mentoring program. I demonstrate how interpersonal dynamics coupled with organizational elements and the sociopolitical context constrained educators' engagement with liberatory equity discourses and enactments.

Introduction

As teacher-facing racial equity initiatives expand in some parts of the county and societal racial discourse shifts, scholars still have much to learn about how teachers *learn* about racial equity and *enact* their learning within racialized ecologies, organizations, and the larger sociopolitical environment (Nasir et al., 2016). This paper examines how teachers' racial equity learning and enactment are shaped by the social relations, organizations, and sociopolitical landscapes in which they work, and how their learning and enactment creates and/or forecloses opportunities for justice-oriented transformations. This study draws on recently reconceptualized sociopolitical theories of learning, which attend to learning ecologies as racialized, racializing, and situated within relations of power (Nasir et al., 2020). This multidimensional framework analyzes moment-to-moment micro interactions, and the dynamic macro sociopolitical environment and meso racialized organizations in which they occur, to explore the complex and constrained phenomenon of teacher learning within conditions that govern, constrain, and enable particular ideas, ideologies, identities, and interactions (Philip & Gupta, 2020; Ray, 2019).

Methods

This qualitative case study comes a larger Research-Practice-Partnership and focuses on a novice teacher-mentor pair within the New Educator Equity Mentoring Program, it draws from over 120 hours of observations and interviews. Reflective of district demographics, both the mentor (Evelyn) and teacher (Ashley) are white, and all the students are students of color (majority Latinx). Both educators expressed prior interested in racial equity and met each week to reflect and co-plan. Throughout data collection, I formalized transcripts, fieldnotes and content logs for all observations and interviews. I wrote analytic memos on themes while in the field and again at the end of data collection (Bogdan & Biklen, 2016). I used recursive inductive and deductive coding on MAXQDA, including index codes such as *discourses of equity, resources, social identities,* and *contestations*. I created additional analytic codes while reviewing data. After consolidating codes, I used critical discourse analysis with illustrative moments to investigate how racial (in)equity is noticed, given meaning, negotiated, and enacted (Fairclough, 2013; Hall, 1996).

Findings

Findings suggest that interpersonal dynamics coupled with organizational discourses and tools within larger neoliberal reforms constrained educators' engagement with transformative equity meanings. Even with various race-explicit discourses and different conversational processes (Horn et. al, 2017) power-avoidant discourses emerged as dominant.

Moment 1

In winter, Evelyn (mentor) raised the topic of "Black student engagement," as part of the district's initiatives for *Black Excellence.* Evelyn observed there was a "very subtle" lack of positive behavior narration with Josh, the one Black student present during an observation, and encouraged Ashely to do more. The mentor repeatedly qualified her observations and then rushed to the next topic. As the only observed discussion on antiblackness, this narrow focus failed to attend to interracial student tension in Ashley's class (including the frequent use of the n-word by non-Black students and the reliance on Black girls to correct it), nor the district's plans to close several majority Black schools and the subsequent grassroots resistance. This moment offered affective instruction for Ashley to expect emotional configurations that centered her comfort in interpersonal conversations about race (Vea, 2020) and foreclosed on an opportunity to build political and micropolitical racial literacy (Pham, 2022).

Moment 2

In spring, the teacher and mentor planned for table groups, starting with ideas of heterogeneity and collaborative learning. However, through interpersonal affective affinity, celebrating the others' ideas, student ability quickly emerged as the most important aspect for grouping, further facilitated by the easily available organizational tools of ranking students by standardized test scores. On the first day of table groups in the classroom, the teacher repeated neoliberal logics of ability and (un)desirability (Sengupta-Irving, 2021) to students directly as she justified the new seating arranged as based on "those with higher scores" and "those with lower scores," assuring students their "grade won't be affected by [their lower performing groupmates]." Students adopted related labels for themselves and other as students within their group, categorizing students who are "smart," "does their work," and "doesn't do their work."

Discussion

These moments illustrated the multiple discourses that teachers navigate in their learning and teaching and the interpersonal, organizational, and sociopolitical influences that shape how educators negotiate these discourses. Specifically, dominant ideas of equity embedded within mediational and discursive tools constrain transformative meaning making in interaction. Depoliticization of technical practices, hierarchies of learners, and dominant logics of ranking emerged through tool use in ways that went unquestioned and ultimately reproduced the status quo. These illustrative moments demonstrate how the (un)available organizational resources within the structural conditions and interactional arrangements may stymie more transformative learning and practice.

Scholarly significance & conclusion

Overall, this study expands understandings of teacher racial equity learning as critical and constrained actors. Specifically, by attending to the organizational tools that educators interactionally negotiated within their sociopolitical landscape, we gain a greater understanding of the complexity of teacher learning around racial equity. Rather than focusing on individuals or professed beliefs, this work demonstrates how dominant ideologies were reconstructed interactionally through engagement with seemingly "neutral" tools in ways that held implications for students' classroom opportunities. Mentoring and teacher learning communities offer integral teacher learning support. Yet, everyday tools and protocols ideologically structure the affordances and constraints of learning. Advancing this understanding supports the resistance of neoliberal deprofessionalizing reforms on teachers by underscoring the complex, situated, and dynamic process of learning and enactment within multilevel environments.

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Innovate to Mitigate: Teacher Role in a Student Competition

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Abstract: The Innovate to Mitigate (I2M) project poses challenges for secondary-school students to design feasible, innovative strategies that mitigate CO_2 emissions and thus global warming. Design is informed by research on problem-based learning, pedagogy for which poses demands on teachers. This paper presents preliminary evidence about how I2M teachers supported student teams to engage in science and engineering practices.

Introduction

The Innovate to Mitigate (I2M) project (https://terc.edu/innovatetomitigate) poses design challenges in climate change mitigation for middle- and high-school students. Student teams propose a mitigation strategy, describe how they consider it an innovation, and how feasible it might be to implement. The design of the challenge is informed by research on problem-based learning and on participatory pedagogy (Tucker-Raymond et al., 2021). Our initial research (Puttick et al., 2017; Drayton & Puttick, 2018) suggests that this open challenge can galvanize creativity and engagement among young people, and support "3-D learning" (NRC, 2012). In this paper, we present preliminary findings about the experience of four teachers as their students participated in the 2021-2022 I2M challenge. We ask: (i) How did teachers perceive their role in supporting student teams engaged in open-ended design challenges that mitigate global warming?

Building teacher capacity to support problem-based learning

In PBL contexts that drive towards pre-determined learning goals, the challenges that face teachers result from the tension between grounding student work in a general question that has multiple possible investigation methods and is not bounded by a curriculum, and this desired "end point." In the I2M challenges, unbounded by content learning goals, the science practices (NRC, 2012) themselves are the articulated learning goals. In this context, the teacher acts as facilitator, asking meta-cognitive questions to guide students. We expected that teachers would need assistance in supporting PBL and in helping students to understand science as an "evidence-based, model and theory building enterprise" (NRC, 2012).

Context and methods

Teachers support students through several phases: Submitting an abstract that outlines a mitigation strategy online for public discussion, revising based on these discussions and developing a prototype over the next 3 months, and finally submitting a short video and paper. At 3 transition points, teachers were oriented to (i) the purpose of participant crowdsourced conversations to improve designs, (ii) mentoring strategies and supporting distributed expertise, and (iii) supporting student epistemic agency using "science-as-practice" (Stroupe, 2014).

Participants

The four experienced teachers in the study signed up 10 student teams. Ms. Rotham, a mathematics teacher at a parochial high school, was recruited as mentor by a transfer student in 12th grade, who had participated in I2M previously. Ms. Schaaf, an environmental science teacher in a large urban school district, had 5 teams participating in independent study for an upper-level course. Ms. Staples, a language arts teacher at a private school, had two middle school teams in her special needs class. Ms. Hayter, a science teacher in a large urban school district, had two middle school teams participating in an after-school club.

Data sources and analysis

Data included transcripts of teacher post-interviews that focused on teacher role, challenges faced by students and teachers, perceptions of student learning, motivation, and school-related constraints on participation. Three researchers independently applied a concept-driven framework to code all data (Spencer et al. 2014). Codes were teacher role (general aspects of teachers' role in supporting students), PBL (affordances and challenges of PBL), science practices (NGSS science practices). Researchers iteratively discussed coded data. After coding was stable, a researcher wrote an interpretive research narrative pertaining to each code. The research team discussed narratives to test inferences, identify area requiring further analysis, and maximize the value of the data.

Findings

Across diverse learning contexts, all 4 teachers described how supporting student engagement in practices primarily centered on various aspects of working with data, and on constructing arguments. Not surprisingly, younger students needed support in how to take and record data. Ms. Hayter reported, "I kind of gave them a little template […] any time that they tested, we would take pictures and then we would write a little tidbit about what happened." Ms. Rotham's independent study students needed help identifying variables, "they were challenged as to what are the variables we're measuring, what's the independent variable." Both Ms. Hayter and Ms. Rotham reported that they also provided guidance about what to do with data once it was in hand. As Ms. Hayter put it, "there's a difference between data information, so you can have all these numbers, but actually putting meaning to it..." Furthermore, students needed to understand how to use data to build a persuasive scientific argument. For example, Ms. Rotham reported that she pushed her students to collect data from the prototype they were building, "you can't just build something and say it works," in other words, the claim needed substantiation.

For the senior independent study students, providing empirical rationales for their claims (Sandoval & Millwood, 2005) was a challenge. Ms. Schaaf observed, "[it was] a little bit of a learning curve for them, because I don't think they're used to defending their arguments." She reported that she pushed them on this, asking, "how can you support the claim that you're making…? Where is it coming from?"

Comments from three of the four teachers centered on the need to cede control (Puttick et al., 2015). Ms. Hayter's comment was representative, "So [I was] very much hands-off. So that was a bit of a change for me where it's not on giving them as many instructions," while Ms. Staples spoke about being challenged by the science, "I spent quite a bit of time studying so that I could help them understand the chemistry or the physics or whatever."

Discussion and significance

Working with the wide range of subject areas and possible technologies that were determined by student project choice, teacher moderation was focused on the practices. This mostly freed the teachers to cede authority (Puttick et al., 2015) and effectively support student directed PBL. The teachers made effective strategic use of targeted procedural questions, suggestions of resources, and project management strategies to support students' agency and capacity to conduct investigations. Within each context, McNeill et al. (2017) in a study focused on argumentation, found that teachers' decisions sometimes focused on surface features of argumentation rather than understanding it as an epistemic practice (Stroupe, 2014). Our preliminary data indicate that these teachers understood this deeper meaning of argumentation as a science practice. Teachers' guidance of argumentation practices will be one focus of future research.

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What Data is in K-12 Data Science? An Analytic Approach to Understanding the Data Used in K-12 Data Science Courses

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Abstract: To help students understand the role of data in their lives, it is important to introduce them to foundational data science. This paper presents an analysis of the data used in YouCubed's Explorations in Data Science curriculum. This work provides an analytic understanding of how data science is situated in students' lives and provides insights into ways curricula are preparing them for a data-rich world.

Introduction

As the role that data play in society grows, it is increasingly important to introduce foundational concepts and practices of data science to K-12 students (LaMar & Boaler, 2021). The last five years have seen the emergence of several year-long data science curricula (e.g., IDSSP Curriculum Team, 2019) that are playing an important role in defining what constitutes data science at the high school level. Given the ubiquity of data in the lived experiences of today's high school students, there is a tremendous opportunity to situate data science instruction in ways that draw on learners' interests, experiences, and cultures. Understanding the types of datasets being used in data science curricula and their alignment with the experiences of learners is an open question. In this work, we propose an approach for answering the overarching question: *What data is being used in K-12 data science curricula?* The proposed approach attends to what data is used, when it is from, its size, and how it relates to learners. To demonstrate this approach, we analyzed the YouCubed Explorations in Data Science curriculum (YouCubed, 2022), a year-long, freely available, and widely used data science curriculum. This work seeks to shed light on the nature of the datasets that are at the heart of a high school data science curriculum. In doing so, it contributes to our understanding of how best to introduce K-12 students to data science.

Analytic approach

To understand the data in K-12 data science curricula, we developed an analytic approach that attends to four interrelated measures (below). These measures were then applied to the 56 datasets identified in YouCubed.

- Topic - the ideas and topics represented, based on the Bootstrap:Data Science curriculum (Schanzer et al., 2022): *Sports, Politics, Media & Entertainment, Environment & Health, Education, Nutrition,* and *Other*.
- Recency - when the data is from, ranked by the following coding scheme: *Fresh* (just-created data), *Recent* (data from the last 3 years), *Past decade, Older than a decade,* and *Not relevant* (fictitious data/ no date).
- Size - the number of observations or entries in the dataset. We classified the datasets into five sizes: very small (<25), small (25-100), medium (100-1,000), large (1,000-10,000), and very large (>10,000).
- Proximity – how the datasets relate to learners, adopted from Lee and Delaney (2022). We used a slightly modified 5-point scale, ranging from 0-4, with 0 describing content-agnostic data, 1 describing fictional data, 2 describing data about a topic that might be familiar to some but not all students, 3 describing data on niche topics, and 4 capturing data that students collected about themselves and their peers.

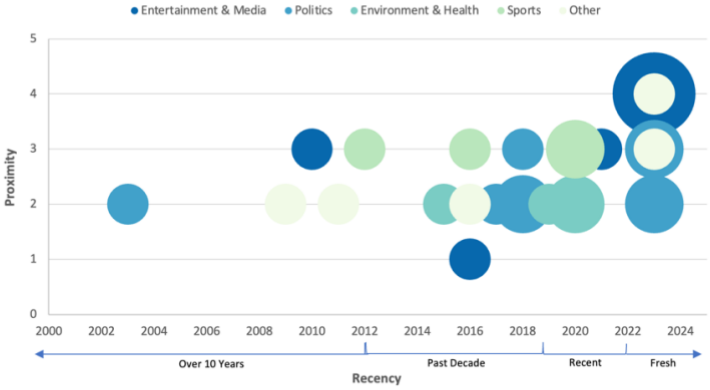
Findings

Our analysis revealed that the most common topic, comprising 16 of the 56 datasets, was Entertainment & Media. The next most common were Politics (12 datasets), with topics such as demographics and economics, followed by Environment & Health (9 datasets), and Sports (5 datasets). Regarding recency, the results show that most datasets are relatively recent, with 25 of 56 being from the last 3 years, with 13 of those datasets coded as *fresh,* meaning the data was/will be collected by the students. In analyzing datasets' sizes, we found that most of them were relatively small, with 13 Very Small datasets and 18 Small. In addition, the curriculum includes 10 Medium, 2 Large, and 4 Very Large datasets. Our analysis reveals that the curriculum includes datasets that fall across the full range of proximity levels, with a majoring of datasets rated as 2 or 3, meaning they are using real data. Specifically, 28 datasets are not related directly to the lives of students (level 2), and 18 datasets cover topics rated as more directly relating to students (level 3). In investigating the intersection of multiple categories, we found that datasets dealing with Entertainment & Media and Environment & Health tend to be relatively small. At the same time, topics related to Politics include very large datasets. In looking at the interaction of Proximity and

Topic, we can see that some topics like Politics and Environment & Health had a high level of datasets ranked as Level 2, which means they used real data but were not closely associated with the students' knowledge or interests. On the other hand, most Entertainment datasets were categorized as Levels 3 and 4 representing data that was either collected by the students or directly related to their personal lives. This analysis shows the types of topics that are close to students and identifies opportunities for potentially revising datasets within a curriculum to help make datasets and materials of greater interest to students. The final intersection we highlight is the relationship between Proximity and Recency, which sheds light on the question of whether more recent datasets are more *proximate* to students. Figure 1 illustrates that the answer to this question is generally yes. This can be seen in the trend where the higher the proximity level, the more recent the data is. This trend exists across all analyzed topics.

Figure 1

The Proximity of datasets in the YouCubed Explorations in Data Science curriculum, organized on a timeline. The bubble size represents the number of datasets with that Proximity/creation date.



Discussion and conclusion

This work presents a set of analytic lenses to deepen our understanding of the data used to introduce K-12 students to the field of data science. In attending to the topic, recency, size, and proximity of the data, we get a picture of what data are used in the YouCubed curriculum and see how it succeeds in incorporating datasets that are recent, *proximate*, and span various topics. At the same time, the analysis reveals opportunities for improvement, such as possibly revisiting the dataset coded as Politics to either make them more proximate to the learner, more recent, or replace them with datasets from other categories. This proposed analytic framework can be useful to curriculum developers to ensure that their materials incorporate various topics that are relevant to learners. Similarly, an educator could use this coding scheme to identify potentially problematic or less interesting datasets to make a more engaging curriculum. For researchers, this framework may be useful to understand the characteristics of a curriculum or as a way to compare different curricula. As the presence and importance of data in society continue to grow, it is important that all students develop a basic understanding of data science. A key aspect of this is developing effective, engaging, and equitable data science learning opportunities, which includes creating curricula with datasets that engage students. This paper builds on prior research to further develop an analytic framework that researchers, designers, and educators can use to ensure that K-12 data science curricula prepare students to be data-literate citizens.

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Online Family Jewish Learning: Cases of Non-traditional Partnerships

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Abstract: With the focus of online tools as a tool to connect people, most of whom are strangers, through the study of Jewish texts, this poster presents a phenomenon of family members practicing online *havruta* (paired couple) learning together. My research questions were: How does online family *havruta* learning function as a learning space? And, how do learners experience such learning? Generating data from six semi-structured interviews, these cases show how learners explore Jewish texts as they deepen their relationships. Their actual family relations reflected a broader definition of Jews as a single people constituting one albeit large, extended, historical, and global family. Thus, these cases can be viewed as metaphors for online communal learning, specifically, Jewish learning communities.

Introduction

Learning with a sibling or parent through the Jewish pedagogy of *havruta* (paired couple) surfaces new and interesting dimensions of the relationships involved in the learning process of text study. Six adult learners shared their personal stories with me about their experiences of *havruta* learning with family members. In these cases, the learners played different roles both as learners and teachers as they went back and forth between them. They experience online Jewish learning platforms to connect with a family member through Jewish text study as they take advantage of the tools available to do so. For family members, learning together seemed to be a safer space for them to disagree and switch between being a learner and a teacher at times. In these case studies, texts, learning, and argumentation are all central elements of what it means to participate in an ongoing discussion and negotiation of the Jewish textual meanings and the ways that can be applied today.

Theoretical framework

Textual interpretation in Jewish learning and teaching

The practice of interpretation is an essential part of Judaism. It was central to the Jewish canon formation and it is the heart of more modern Jewish learning traditions as well. Shulman (2008) argues that there are three signature pedagogies for Jewish education which embody the three dimensions of performance, setting, and interactions as they all emphasize the act of interpretation. One of these pedagogies is *havruta*. Havruta provides "a setting for mutual and reciprocal coaching, scaffolding, challenge, and debate" (p. 11). The negotiation and exchange of ideas is an essential part of the *havruta* learning practice which originates from traditional Jewish Torah studies called *beit Midrash* (literally "House of Learning"). There, the construction and reconstruction of the meaning of the text are integral parts of the learning process (Kent, 2010).

Jewish Education in the Age of Google

In their report, *The Future of Jewish Learning Is Here: How Digital Media Are Reshaping Jewish Education*, Kelman et al. (2019) find that as online learning becomes more accessible, Jewish learning opportunities and experiences are also shifting. These changes include the proliferation of more approachable learning materials, the creation of new social connections, and the engagement with Jewish content in new ways that reflect learning in the 21st century.

As transnational people, Jews have long used technology to distribute learning across great distances. Today, most distance learning is internet-based. Such new media also provide novel ways of reading ancient Jewish texts as well as new learning practices. Shifts in a set of paradigms are likely to change Jewish education in the 21st century, pushing it to become more learner-centered, relationship-infused, and life-relevant (Woocher, 2012). In the "age of Google" (Rubin Ross, 2017), there are also innovative shifts in the roles of learners, teachers, community, text, and social justice, parts of a broader change in Jewish education generally.

According to Woocher (2008), both "virtual" and "real" networks shift existing social ties, creating new connections and new types of communities that otherwise would not exist. Part of the transition to a digital age includes technological and cultural transformations, like "the transition from oral tradition to written text, and then from written to printed text" (Woocher, 2008, p. 190). Given the changing landscape of Jewish learning in the digital age, this study aims to deepen our understanding of contemporary online sacred text study, specifically with family members.

Methods

This qualitative study generated data from six semi-structured interviews with users of online Jewish learning platforms, investigating how they collaboratively interpret sacred texts with family members. To find and recruit participants, I posted a call for participation on social media platforms, such as *Facebook*. Some of the questions included questions about the reasons for learning with a family member, what this kind of learning partnership enabled and/or disabled, and how it is different from learning with a partner who is not a relative.

To analyze the data, I began open-coding, seeking themes related to the participants' learning experiences such as collaboration, interpretation, and digital learning. Second, I used *in vivo* coding, in which codes refer to phrasing from the language of the qualitative data record, the terms used by the participants themselves. Through this thematic analysis, I unearth how adult learners use online tools to learn and connect with family members through Jewish text study.

Discussion and Conclusions

The online space and digital tools enabled learners not only to stay connected on a personal level but to bypass the bickering that could punctuate their differences; the focus on the text allowed them to find common ground, and the online tools allowed them simultaneous access to the text. For example, Mary shared her learning experience with her sister who came from a different professional background as a teacher. This allowed them to maintain ‘learning mindsets’ or a ‘growth mindset’ (Dweck, 2007). They came into the *havruta* learning sessions being equal learners in this virtual space as they overcame the differences between them to learn Jewish texts together. Sometimes by being aware of these differences, they learned more about their sisters, about themselves, and the Jewish texts and their multiple meanings than simply participating in text study.

Others, like Jennifer, understand this learning practice as a way to unite with another person and become one with the text. For her, as a Jewish educator by profession, being a student in her *havruta* studies surfaced another identity. In her learning experience, Jennifer went back and forth between her identity as a teacher/expert/mother and a learner/novice/daughter. She enjoyed the unique learning moments in which she was the learner and was seeking additional opportunities to expand that experience with other learners. She also understood that it was “less critical *what* we're studying [than] *that* we're studying.” The digital tools available provided Jennifer and her family, like other learners, the power to study Jewish texts not only for personal growth, but also as a family value, ritual, and tradition that connected to the historical bases of Jewish communal learning.

Some participants also talked about moments of disagreement. For example, Alyssa understood that as an adult, she held different views than her father and *havruta* partner but debating and disagreeing regarding various topics was a powerful instrument for the Jewish people as a group and family members in particular. Meeting with her father virtually enabled Alyssa to experience such personal exploration through Jewish text study with a loved one. Like Alyssa, other learners were also able to collaboratively explore sensitive issues while also learning as equals through text study; thus, the hierarchical power relations involved in the father-daughter arrangement, for example, were somewhat equalized through *havruta*.

At present, this study is still underway, making it difficult to document its significance. However, this research already broadens the existing literature on Jewish learning practices by exploring how online environments shift the roles of participants learning with relatives and the possibilities for meaning-making as they take advantage of Jewish sacred textual interpretation that is more accessible and more engaging.

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Moving From the Spontaneous to the Intentional: More Evidence of How Children Use Visual Marginalia to Self-Regulate Their Learning

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Abstract: In this poster, we introduce the concept of Visual Marginalia (VM) and present our second study on this topic, carried out in Italian primary and secondary schools. Results give more evidence to our Visual Marginalia elaboration Model (VMeM) confirming how VM involve base and explicit intentionality and ongoing self-regulation processes that affect students' emotions, attention, motivation, memory, and knowledge integration and reorganization and revealing a new type of VM, Dynamic Visual Marginalia.

Introduction

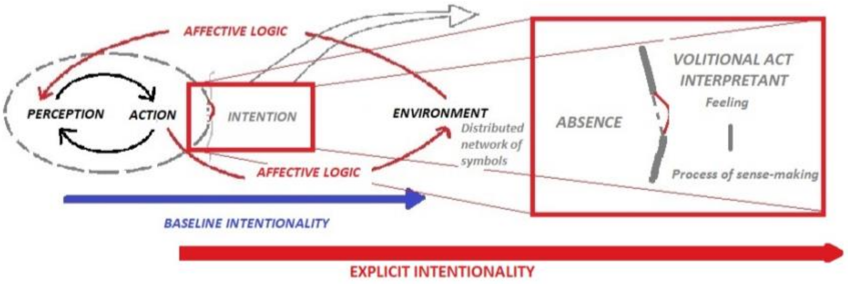
Humans leave traces of their existence over time, such as in cave paintings and graffiti. Marginalia refers to the graphical and textual elements produced by a reader in the margins of books. Great thinkers like Einstein and Bruner have produced Marginalia. Recently, we introduced the term Visual Marginalia to describe all visual self-expressions like para-writings, para-drawings, and creative modifications of book texts produced by students during the teaching-learning process (Dario, Lund, & Tateo, 2022; Dario & Tateo, 2022). According to our developmental approach, we study Visual Marginalia not as static but «in their making» (Valsiner, Chaudhary and Benetka, 2017). The second study, reported here, used a new methodology to capture VM elaboration in real classrooms (See Dario, Lund, & Tateo, 2022). Results showed more evidence for our Visual Marginalia elaboration Model (VMeM), which categorizes and confirms that VM connect intentionality and students' self-regulation. We also discovered a new type of VM, called Dynamic Visual Marginalia, which evolves from one type to another, illustrating the canalization of emotions and the maintenance of attention.

The relationship between intentionality and self-regulation

This poster demonstrates how students constantly move between different levels of intentionality deeply related to self-regulation (See Results and Interpretation). In Figure 1 we illustrate how baseline intentionality and explicit intentionality work.

Figure 1

Baseline and Explicit Intentionality



In particular, we argue that the VMeM model (Figure 2) shows spontaneous VM (e.g. scribbles and stylizations) which are governed by baseline intentionality and regulate emotional states, listening and memorization while deliberate VM (e.g. doodles and annotations) are controlled by explicit intentional actions and involve also comprehension and support self-initiated, self-planned, and self-sustained learning processes.

Study design

The study replicated the methodology used in Dario, Lund and Tateo (2022) that involved mixed methods to grasp the phenomenon of VM in its development during the teaching-learning process: we first organized kick-off meetings with principals and teachers, giving teachers a brief questionnaire. Then we video-recorded face-to-face lessons during the Covid-19 pandemic in 2022, collecting any VM that were produced by students, and conducting self-confrontation on-line interviews. We used the Big Blue Button Platform where we shared a screen with two windows: one with a wide-angle lens camera showing a recording of the lesson the students participated in; the other with an Interactive Whiteboard showing the VM where students moved a pointer to explain how they made it and what the production helped them deal with.

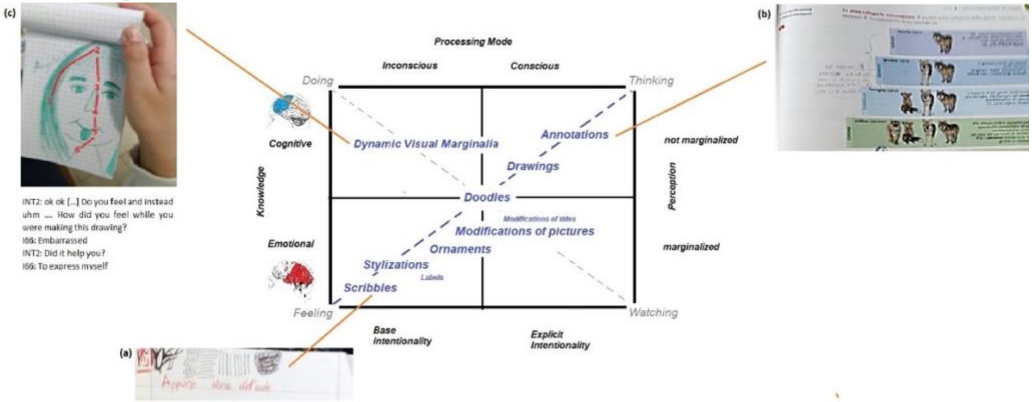
We had 67 students (ages 6-12) and 6 teachers, from primary and secondary schools in Northern Italy. All were native Italian speakers and did not have behavioral or learning difficulties. Each participant took part voluntarily, and parents provided authorizations.

Results and interpretation

Our poster will present VM forms (scribbles, stylizations, ornaments, modifications of titles and images, doodles, drawing realistic elements, annotations) however students often move from one kind to another, creating Dynamic Visual Marginalia. Here we report three examples of VM. The first is a scribble (Figure 2a), a combination of repetitive lines and scrawls, governed by a baseline intentionality, reflecting the student's sense of boredom and lack of interest during a pause in the art lesson.

Figure 2

VMeM and VM examples



INT2: ok ok [...] Do you feel and instead uhm .... How did you feel while you were making this drawing?
I66: Embarrassed
INT2: Did it help you?
I66: To express myself

In Figure 2b, while the teacher is explaining, the student seizes the initiative (explicit intentionality) to jot down an answer to a possible test question, taking into account the effect of her learning on the upcoming exam performance and her capacity for self-direction, self-planning, and knowledge retention.

In Figure 2c, a student produced a Dynamic Visual Marginalia dealing with her embarrassment during a sex education lesson. She drew a spontaneous scribble (hair) and transformed it into a girl, symbolizing her own sense of distaste. This VM helps the student to control her emotions (See text under Figure 2c) and promotes critical thinking. She thought the lesson was poorly done and the teacher was embarrassed. This knowledge produced in her a further sense of disgust.

Conclusion

This poster shows how VM are semiotic and self-regulatory tools with varying levels of intentionality that anchor learning to the context and help the learner to develop agency. Furthermore, we suggest that teachers accept VM as valuable tools and integrate them into the design of learning activities instead of discouraging their production.

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Supporting Teacher Reflection in Video-Coaching Settings

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Abstract: While video coaching has the potential to support teachers' learning, limited support is available for coaches who want to use video in their own schools. This study reports on one educational design research project (consisted of four sub-studies) that aimed (1) to conceptualize teacher reflection in video-coaching settings, (2) to articulate support to improve teacher reflection, and (3) to reify (make concrete) the articulated support. Findings related to the three research objectives are discussed.

Research background and objectives

Video coaching is a professional development approach in which teachers or coaches record teaching episodes and engage in video-based one-to-one or group-based discussions in a sustained manner (van der Linden & McKenney, 2020). While there is a need for more high-quality coaches, there is very limited insight into ways to support these coaches (Tekkumru-Kisa & Stein, 2017), especially in their own schools. A number of gaps in research can be observed in this regard. First, there are questions about the conceptualization of teacher reflection in video coaching settings, because comprehensive reviews on teacher video coaching are lacking. And despite the fact that productive teacher reflection is crucial for teacher professional learning (Darling-Hammond et al., 2017), it remains an ambiguous concept (Clarà, 2015). Second, while literature on coach moves (e.g. Borko et al., 2014) provides an extremely valuable basis for the enactment of coaching sessions, additional support for coaches to lead video-coaching initiatives within their own schools is lacking. Third, the literature currently lacks practical tools for coaches improve the quality of reflective conversations. Therefore, this study aimed to (1) conceptualize teacher coaching in video-coaching settings, (2) articulate support, and (3) reify the articulated support.

Method

This study reports a synthesis of findings from one educational design research (EDR) project. EDR was deemed as an appropriate approach because of its intention to simultaneously develop theoretical insights and practical outputs for real-world use (McKenney & Reeves, 2019), which matches the nature of the three aims. The study consisted of four sub-studies (A, B, C, D), each aligned with one of the main educational design-research processes (i.e. analysis, design, construction and evaluation, respectively), and contributed to one or more research aims, see Table 1. This study foregrounded qualitative methods due to its overall explorative approach, although mixed methods were also used. Participants consisted of teacher reflection experts from research and practice (C) and participants with insight into environments where coaching takes place (D). The results of two sub-studies have been published already (van der Linden & McKenney, 2020; van der Linden et al., 2022) and those of two others are currently under review. The proposed poster uniquely synthesizes findings across the four sub-studies, in light of the three overarching research objectives.

Table 1
Overview of the study

Aims	EDR-process	Study	Methods	Data sources	*n*
1	Analysis	A	Systematic review	Journal articles	59
1, 2	Design	B	Theoretical synthesis	Journal articles	n/a
1, 2, 3	Construction	C	Delphi-inspired	Surveys, interviews	27*
2, 3	Evaluation	D	Proof-of-concept	Surveys, interviews, use log, think-aloud	17*

Findings and discussion

Addressing the first research objective, a conceptual model representing teacher reflection in video-coaching settings has been developed, based on video coaching literature (A), reflection literature (B), and expert insights on what aspects should be included in a teacher reflection observation instrument (C). Three types of reflection were identified as central to teacher video-coaching, namely reflection on action as a retrospective process, reflection for action as an anticipatory process, (A, B), and reflection in action as knowing-in-action (B). In addition, the literature and expert insights emerging from sub-studies B and C yielded two perspectives on knowledge development, namely a deliberate perspective, which foregrounds collective knowledge on teaching as a frame of reference, and an aware perspective, which foregrounds knowledge development within practice and through interaction. Moreover, three phases of reflection were distinguished based on reflection literature (B), namely, (1) preparation, (2) image forming, and (3) conclusion drawing. Finally, the non-recurrent aspects of reflection include "attention" (i.e., focus) and "reasoning" processes (i.e., nature of talk, study A, B), and study B added "determining" as a concluding process, see Figure 1A.

Figure 1
Conceptual model (A), and the ReflAct Tool (B).

With regard to the second research objective, guidelines for supporting the improvement of teacher reflection in video-coaching contexts were articulated based on instructional design literature (B), teacher reflection expert insights (C), and the proof-of-concept (D). The four-components-instructional-design model (van Merriënboer & Kirschner, 2017) was selected to support the complex learning of united reflection in study B, and a blueprint for supporting reflective practices in video-coaching settings was put forward in this study. Experts deemed a formative assessment observation instrument as most needed (C), and this approach was described as a way to help coaches to get insight into the current situation, the desired situation, and ways to close this gap in study D.

Finally, an online tool, ReflAct (Figure 1B) reified the articulated support using the observation instrument from study C, which formed the basis for a computer-supported process that helps coaches to evaluate the current quality of reflection, gain insight into the desired state, and provides pre-programmed tailored advice how to improve the next conversation. Both studies C and D contributed to quality criteria for a viable tool to improve teacher reflection in video-coaching settings. Sub-study C did this through expert evaluations of the clarity of the developed indicators of the observation instrument, whereas sub-study D did so through a proof-of-concept study where experts used the prototype and commented on added value, compatibility, clarity, and tolerance. This study showed (amongst other things) that the prototype formative assessment tool for teacher reflection has the potential to provide added value in terms of effectiveness through coach development and calibration, through mirroring (i.e., insight into the current state) and advising (i.e., guidance on next steps).

The conceptual model could support teachers' attention problems of practice, by asking how core practices *have served* (united reflection-on-action), *will serve* (united reflection-for-action), *and are serving* (united reflection-in-action) the specific student population and the teacher. The support guidelines foreground approaches to develop this reflective ability that is needed to focus on problems of practice. The ReflAct tool provides initial directions for formative evaluation of video-rich reflective talk in ecologically valid ways. The conceptual model, support guidelines, the ReflAct tool and its underlying quality criteria will be illustrated on the proposed poster to guide a productive discussion with participants at the ISLS on the following additional topics: contextual variety and potential influence on the viability and institutionalization of video coaching interventions.

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Elaborateness of Explanations to Understand AI Recommendations

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Abstract: Successful human-AI collaboration requires an understanding of the AI system which can be achieved by human-interpretable explanations. In an experimental study ($N = 109$), we found more elaborated explanations to foster causability and trust, whereas adaptability of elaborateness provides no further benefit. Although cognitive load was not affected by explanations, its causal role requires further investigation. Future research should integrate learning sciences with explainable AI research to consider system and human aspects of understandable AI.

Introduction and research questions

Artificial Intelligence (AI) is increasingly used in the workplace. While the focus often lies on the optimization of work-related processes, there is an inherent link to learning. Especially within (but not limited to) the introductory phase of AI-workplace-integration, users not only have to understand complex content, but also need to learn about the AI system and its functioning in order to interact successfully with it. Research in explainable AI shows that transparency supports the understanding of AI systems as well as trust (Molina & Sundar, 2022). However, only because a system is explainable per se does not mean that the user actually understands it. We thus need to distinguish between the explainability of a system, actual explanations provided, and the users' processing of said explanations. Taking this one step further, we need to consider a system's ability to explain its functioning ("explainability", Adadi & Berrada, 2018) and the human perspective on the ability of these explanations to foster the users' understanding of the causal chain of system functioning (i.e., "causability", Holzinger et al., 2020). The latter depends on individual characteristics as different users may need or prefer differently elaborated explanations (e.g., Putnam & Conati, 2019). For example, novices may need more elaborate information than expert users, and the possibility to adjust the level of elaboration may provide even further benefits for learning processes. When designing human-computer interaction, there is always a trade-off between amount and complexity of information and the capacities of human information processing (e.g., Sweller, 2010). Thus, when designing explanations, human working memory capacities need to be taken into account to enable adequate resources for germane cognitive processes via balancing extraneous and intrinsic load. In sum, careful design is necessary to foster understanding of and trust in AI systems while considering individual learner characteristics, needs, and information processing, which can be achieved by using human-interpretable explanations. In our study, we thus investigate the effects of different types of instructional material (in terms of level and adaptability of elaborateness of explanations) on system causability (i.e., perceived appropriateness of explanations for understanding the system) and trust in the system. As additional information may strain cognitive resources but may also support learners during information processing, we exploratively investigate the role of cognitive load.

Experimental study

In a between-subjects online experiment, $N = 109$ participants (age: $M = 26.89$, $SD = 11.35$) were confronted with 12 scenarios and had to decide whether to play golf based on multifaceted weather data while guided by a bogus AI system. Participants were randomly assigned to one of three conditions: (1) high level or (2) low level of elaborateness of explanations or (3) the possibility to flexibly adapt the elaborateness by toggling between high and low. Afterwards, all participants conducted questionnaires regarding – amongst others – cognitive load (Klepsch et al., 2017), system causability (Holzinger et al., 2020), and trust (Jian et al., 2000).

While the level and adaptability of elaborateness of explanations did not affect trust in the system directly, mediation analysis showed that including causability as a mediator explained some of the variance of trust ($R^2 = .23$, $p < .001$) with the level of elaborateness (but not adaptability) affecting trust via changes in causability (CI[0.01; 0.43]). Direct effects on trust remained non-significant. This data indicates that explanations do not affect trust in AI directly but that the relationship between explanations and trust may rather be explained by causability. More elaborate explanations may increase their perceived appropriateness to help understand the system which, in turn, may increase trust in the overall system. The possibility to toggle between low and high elaborated explanations, however, did not provide further benefits regarding causability or trust. When examining how elaborateness of explanations, trust, and causability are related to cognitive load, we found negative correlations between cognitive load (i.e., extraneous and intrinsic load) and causability and also trust ($- .71 \leq r \leq$

-.42). This means that high load (induced by the content or presentation of the learning material) is associated with lower perceived appropriateness of explanations regarding system recommendations as well as lower trust.

Conclusion

Our study shows that while explanations may not affect trust per se, trust can be increased when learners perceive provided explanations as appropriate to understand the output of AI systems (causability). While the relationship between trust and the ability of explanations to foster actual understanding still needs to be considered, a learner's perspective seems to be an important part of the equation. Regarding the level of elaborateness of explanations, our findings are in line with research on transparency and traceability (e.g., Molina & Sundar, 2022) and also in line with the idea that (perceived) quality of explanations is a feature of trustworthy systems (Holzinger et al., 2020) that should be utilized to develop explainable AI. Regarding adaptability, however, research shows positive effects on understanding (Holzinger et al., 2020), while in our study, adaptability did not provide further benefits regarding understanding or trust. One reason may be that our scenario did not require such a feature. As adaptability is especially important when explanations may not only benefit but potentially also harm learning (for example by adding unnecessary load) its gain may increase with task complexity. Our results indicate that load is not affected by the explanations we provided, but cognitive load as well as the need for additional information may severely depend on learner characteristics like expertise (Putnam & Conati, 2019). Thus, adaptable explanations may have more merit when learners are confronted with a complex task and may gradually reduce their levels of support with developing expertise. Additionally, future research should examine which elements of an explanation need to be made adaptable (e.g., content features) to optimize effects. Thereby, cognitive load should be considered as it is connected to causability and trust in AI, although the causal relationships are yet unclear. Mistrust has previously been linked to cognitive load (Samson & Kostyszyn, 2015) and it may be worth exploring this relationship also in the context of human-AI collaboration. Understanding AI and using it in a responsible way is important in working and learning contexts (e.g., in vocational training), where end users are often no technology experts and may have varying knowledge regarding AI and its functioning. As AI algorithms are difficult to understand even for experts, it is thus crucial to gain insights on how to develop human-interpretable explanations and how to adapt them to learners' needs. Our study emphasizes considering both sides of the medal when analyzing understanding of AI: the system side and the human side.

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Digital Epistemic Scaffolds to Support Student Collaboration for the Integration of Evidence Across Multiple Documents

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Abstract: An important goal of 21st century education is preparing students to comprehend and integrate information from multiple documents to make informed judgments as lay people. This paper describes student use of a computer-supported collaborative learning (CSCL) system called EDDiE (Electronic Documents Disagreements Evaluation) that embeds epistemic scaffolds into a shared workspace designed to support students as they analyze, evaluate, interpret, and integrate evidence from multiple documents. In this study, the EDDiE system successfully promoted student discourse related to evidence analysis, evaluation, interpretation, and integration, and lay use of evidence. Findings indicate that students need further instruction and scaffolding to distinguish among the quality, amount, and strength of evidence and to support the development of epistemic criteria for evaluating the quality of document sources.

Introduction and theoretical framework

A crucial goal of education is to enable students to aptly comprehend and integrate information from a diverse range of oft-conflicting information sources (which we refer to as "documents") to make informed judgments (Barzilai et al., 2020). Because many issues faced by citizens hinge in large measure on evidence (such as evidence bearing on the efficacy of COVID-19 vaccines or on the reality of climate change), the competencies needed to reason well about evidence are of crucial importance. Prior research on efficacious digital tools to support student engagement with multiple documents include prompts to support students' metacognition (Stadtler & Bromme, 2007), as well as epistemic scripts or scaffolds which guide learners through the key activities of knowledge production (Weinberger et al., 2005). Digital epistemic tools have been effectively used to support students' engagement with and integration of information from multiple documents, such as through the use of document maps that enable the user to link sources and claims (Barzilai et al., 2020).

This paper reports on how students worked with a CSCL system designed to incorporate competencies for both experts and lay people to reason about evidence identified in the Grasp of Evidence (GoE) Framework (Duncan et al., 2018). The system, called EDDiE (Electronic Documents Disagreements Evaluation), is a browser-based application that provides a shared workspace for multiple students to read, discuss, and analyze a set of documents together (Mochizuki et al., 2022). EDDiE supports students as they engage in the five dimensions of reasoning about evidence specified by the GoE framework as they read and analyze the documents on EDDiE's collaborative graphic organizer, referred to as the *analysis tableau*. EDDiE incorporates epistemic scaffolds that encourage collaborating students to discuss evidence along each of the five dimensions and supports learners in using the results of evidential reasoning to resolve disagreements among documents to reach a sound conclusion.

Methods

Context, participants, and data collection procedures

This design-based research study was conducted in 2020 in the context of an online, Zoom-based undergraduate course on the design of learning environments at a private university in Japan. The participants were 7 male and 6 female undergraduate students majoring in informatics. Prior to data collection, participants watched a video demonstrating how to use each feature of EDDiE without providing substantive instruction on appraising evidence or resolving disagreements. Students also received a visual aid summarizing the features and functions of EDDiE.

The participants were divided into groups of three and assigned one or two trained student facilitators. The participants were provided with five Japanese documents (approximately 200-400 words in length when translated into English), that provided a variety of claims about different diets, described positive and negative effects of these diets, and provided evidence from relevant scientific studies and experts. Each document was presented as a digital media or blog post that included the source information and descriptions of one or more nutritional studies ranging in quality, strength, and number. The documents varied in the strength, quality, and number of expert sources referred to within each document. The students were given approximately 80 minutes to read and analyze the five documents together using EDDiE to reach a joint conclusion about the best diet(s) to follow based on the information provided across all five documents.

Data analysis

Three groups were selected for data analysis because they completed the task in full with minimal intervention by the facilitator. Data sources included English translations of the transcript of each group's discussion and the final version of the EDDiE tableau that the participants collaboratively created over the course of the discussion. Qualitative coding was conducted using NVivo. In the first phase, the first author conducted deductive coding to identify the presence or absence of the features of student discourse that EDDiE was intended to produce related to the analysis, evaluation, and integration of evidence as well as lay use of evidence. Inductive coding was also conducted to identify emerging patterns related to collaborative student discourse related to evidence or the features of EDDiE. The codebook was then reviewed and revised in collaboration with two additional researchers. In the second phase, the full dataset was recoded using the revised codebook. The coded data was then organized and analyzed in accordance with the five dimensions of the Grasp of Evidence framework with an additional category for portions of the discussion related to resolving disagreements among multiple conflicting documents.

Results

Analysis of student discourse demonstrates that the features of the EDDiE system that were most successful included the epistemic scaffolds for *evidence analysis* and *evidence evaluation* (e.g., the evidence circles feature), which functioned together to promote productive collaborative discussions about how various methodological features contribute to the overall quality of evidence, drew students' attention to methodological features they may not have otherwise examined, and encouraging collaborative judgments about which methodological features constitute a strong empirical study. However, although the epistemic scaffolds intended to support students' *lay use of evidence* (e.g., document author circles) produced extensive discussion about quality of document sources, students struggled to identify appropriate criteria to gauge which sources were more trustworthy than others. In addition, while the EDDiE graphic organizer was an effective scaffold for eliciting student discourse about reasons to explain disagreement, such as how differences in research methodology may explain conflicting evidence, students sometimes provided explanations that were ill-supported by the evidence across the five documents.

Discussion

While the epistemic scaffolds of the EDDiE system function to support students as they engage in the *analysis*, *evaluation*, *interpretation*, *integration*, and *lay use of evidence*, the findings identify specific areas where further scaffolding or other instructional supports are needed to further improve student comprehension and integration of information from multiple documents. Proposed revisions to the EDDiE system include: (1) opportunities to develop richer, more nuanced criteria for source credibility; (2) scaffolds to encourage the use of student-generated disagreement reasons as a springboard for thinking about how to resolve the disagreement between documents; and modifications to support students in distinguishing among the quality, amount, and strength of evidence. Classroom instruction that focuses on developing effective epistemic criteria for evaluating the quality and strength of evidence as well as the evaluation of the quality of document sources and expert judgments has the potential to support students' epistemic growth in conjunction with the use of the EDDiE system.

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Re-Envisioning Bibliometric Analysis as a Tool for Transforming the Field

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Abstract: New digital technologies can help create equitable educational outcomes. We used bibliometric methods, a powerful tool for analyzing large bibliographic datasets, with an open-source software to map the computer-supported collaborative learning literature. Applying a diversity, equity, and inclusion lens, we considered the strengths and weaknesses of this method and analyzed the resulting literature map. We offer recommendations to researchers using similar approaches and re-envision the transformational potential of bibliometric analysis.

Introduction

This conference theme, "Building knowledge and sustaining our community," calls for envisioning a new role of technology for building knowledge and community. We connect to the conference theme by focusing on bibliometric literature analysis and using this method as a tool that can point the way toward increasing diversity, equity, and inclusion (DEI) in a scholarly field and its community. Bibliometric analysis (BA)–a method for mapping and synthesizing scholarly fields–propagated in recent years with technological advances and the increasing accessibility of bibliographic databases (BDs) such as the Web of Science (WoS; Block & Fisch, 2020). We consider this method in the context of our literature synthesis. Due to space limitations, we provide high-level information about our work here and share additional details in the poster at the conference.

Our research project aims to map and synthesize literature on computer-supported collaborative learning (CSCL), identify topics relevant to K12 practitioners for translation from research to practice, and determine if new research is needed. The project has three phases; in this paper, we discuss Phase 1, literature mapping. In our work, we take a DEI lens and work to transcend the bounds of bibliometric analysis, re-evaluate it, and re-envision it as a tool for transforming the field. We focus on the following two questions: RQ1) what does a map of CSCL literature look like? and RQ2) what does the map reveal about DEI in this field?

Methods

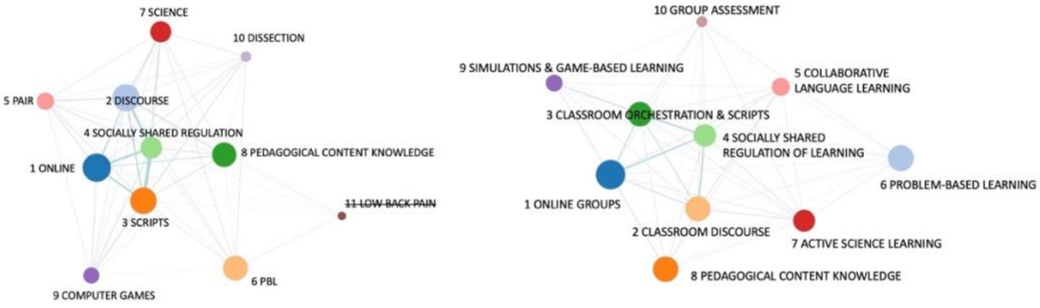
Bibliometric methods are quantitative methods used to analyze bibliographic datasets (e.g., author and journal names, article titles, abstracts, keywords, publication years) available through BDs (e.g., WoS). These methods identify topic clusters and links between them, impactful authors, articles, and publications, and reveal author networks; they have the potential to uncover academic silos and point to research gaps (Block & Fisch, 2020). WoS provided the relevant meta-data for our search on K12 STEM collaborative learning.

Our whole corpus included 16,470 publications. We analyzed this corpus using the existing open-source BiblioMaps tool (Grauwin, n.d.), utilizing the bibliographic coupling (BC) method. BC is based on the overlap between the references of each pair of publications. The resulting visual representation shows structures of nodes or topics in the literature. Our goal was to identify key research topics relevant for K12 practice, so we worked to refine the initial software-generated CSCL literature map (Figure 1, on the left). We determined the top 10% most relevant publications of our search was most appropriate (Figure 1, on the right). We independently reviewed publications in each node and excluded irrelevant nodes (i.e., low-back pain). Next, we evaluated node names and determined names that would be informative to researchers and teachers. To ensure that the map created through the BA reflected current knowledge, we compared the map topics to those in the recent "International handbook of computer-supported collaborative learning" (Cress et al., 2021). We noticed that two of the topics in the Handbook, DEI and argumentation, were not on our map. We decided to include these two topics in the project. Throughout the process of map curation, to ensure the map's trustworthiness, we engaged in peer-debriefing sessions with researchers not involved in this project to review the map and our curating decisions.

Results

In response to the RQ1, we found the initial whole corpus, software-generated literature map gathered publications into 21 topics and 151 subtopics based on the shared references. The initial map of the top 10% most relevant publications (11 topics, 40 subtopics) included some nodes with uninformative names and unrelated literature. Related to our RQ2, our analysis revealed a relatively small sub-node of works (27 publications) focused on equity, with the majority of publications originating from the U.S. The fact that DEI was not included at the node level in the map means that it did not share enough citations with the publications in other nodes.

Figure 1
The initial map (left) and the final map (right) of CSCL literature (top 10% most relevant publications)



Discussion

Our bibliometric research led us to concur with Gomez et al. (2021) that despite deep concerns with DEI within the CSCL field, the existing literature does not reflect a global effort to address DEI as a focal point of CSCL studies. Until a larger number of studies focus on DEI and become linked to the existing publications, bibliometric methods will not reflect changes in the literature structure. Researchers using the existing bibliometric tools should be aware of the following three caveats concerning DEI that became evident during our study: a) level of access to BDs, b) biases and lack of algorithmic transparency in the BDs and software tools, and c) accessibility of the research literature. First, as each bibliographic study starts with extracting data corpus from a BD, the level of institutional access to a BD might differ for researchers by the institution. Hence, researchers with different access levels would obtain different outputs from a BD for the same search terms. Second, there are proprietary search algorithms used by BDs to determine publications' rankings in search results. The criteria for the rankings are obscured, so it is not possible to identify biases that might influence the results. The third caveat is the ability to access the research literature. Researchers from under-resourced institutions may have less access to publications behind paywalls and may be unable to cite such works. Without these citations, their work will not be included in BC analyses because its references will not connect it to 'mainstream' research. Considering these caveats, we posit that the first step towards the transformative use of bibliometric analysis is the acknowledgment that software-generated literature maps reflect inequities, biases, and issues of power that are present and evident in the structure of scholarly fields and in the tools used in them. One recommendation to researchers who want to use bibliometric methods to do more than describe a field's structure is to center DEI in their work by reflecting on what is and is not present, whose voices are included or not, and what literature is yet to be created. Our list of caveats is not all-inclusive. Rather, it is meant to start a conversation about envisioning more equitable tools, approaches, and partnerships.

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Angry but Hopeful: Emotions About Climate Change on TikTok

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Abstract: Articulating emotions can help youth to contextualize seemingly distant issues such as climate change and invite dialogues. In this work, we examine how youth express emotions about climate change on social media. Our analyses of 171 TikTok videos with description tags related to climate change revealed multiple emotions, such as joy, optimism, anger, fear, sadness, and sarcasm. These findings help to frame climate science education to elevate individuals' emotions and experiences towards climate-minded actions.

Introduction

TikTok—one of the fastest growing social media platforms among youth aged 13-24 (Li et al., 2021)—provides a site for youth's self-expression. We focus on youth's emotional expression on TikTok in the context of climate change. The research illuminates how to frame climate education for youth, to motivate their uptake of sustainable actions. We focus on emotional expression as it can be conducive for learning (Curnow et al., 2020; Pekrun & Linnenbrink-Garcia, 2014). Students experience positive and negative emotions, from enjoyment and curiosity to anxiety and confusion in learning settings, and these emotions contribute to academic and personal growth (Pekrun & Linnenbrink-Garcia, 2014). Within climate science contexts, youth also articulate a range of emotions, from anxiety to optimism, to make sense of climate news and climate action (Ojala, 2012; Zummo et al., 2020). Emotional expression also helps to relate youth-created content to other social media users and facilitate learning and social movements (Kluttz & Walter, 2018). Prior work has examined climate change discussions without an explicit focus on categorizing emotions (e.g., Hautea et al., 2021). Our work examines (1) how emotions are displayed in climate change discussion, and (2) which emotion types might be associated with more user interactions. Generative interactions may indicate productive framing for climate change conversations.

Methodology

Data included 171 videos published between September 2020 and August 2022 on TikTok, a platform for creating and interacting with short-form videos. The sample was randomly drawn from a larger corpus of 500 videos, which we pulled from publicly available data under hashtags related to climate change, such as #climatechange, #climateaction, #sustainability, etc. In the current analysis, the videos showed varying number of interactions, likes (*M* = 149,057.60, *SD* = 608,408.18), shares (*M* = 4072.5; *SD* = 13,045.85), and comments (*M* = 2576.86; *SD* = 13,119.35). The large standard deviations suggest the sample's representativeness to not only include videos that are popular on the platform. Before data collection, we received confirmation from the university's IRB that the research did not involve human subjects, because the data were publicly available.

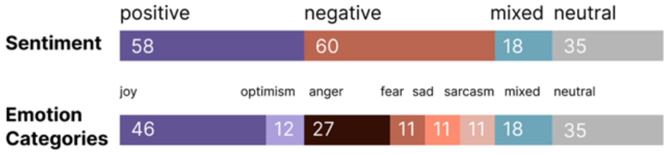
Our qualitative analysis of the videos focused on emotions, drawing from video creators' facial expressions and gestures, video captions, and on-screen text (Hautea et al., 2021; Li et al., 2021). We went through two coding stages. First, the first author watched 50 videos and developed first-level, low-inference codes of emotions (e.g., "hopeful", "happy", "angry"). Second, the authors collaboratively discussed the first-level codes to refine the coding scheme. We developed two layers of codes: sentiments (positive, negative, and neutral) and emotion categories that captured nuances in the sentiments. The categories drew from emotion frameworks to include joy, sadness, anger, and fear (Jack et al., 2014). We added codes for "sarcasm" and "optimism", as these emotions were identified as critical to climate change discourse (Curnow et al., 2020; Ojala, 2012). To establish inter-rater agreement, the two authors separately coded 69 videos each (40% of the corpus) and achieved 88.5% agreement on sentiments and 86.9% on emotion categories. The first author coded the rest of the data.

Results

For RQ1, we noted a range of sentiments in the videos: positive (*n* = 58; 34%), negative (*n* = 60; 35%), a mix of positive and negative sentiments (*n* = 18; 11%) and neutral (i.e., no sentiment; *n* = 36; 21%; Figure 1). Positive videos showcased *joy* (e.g., uplifting environmental news, appreciation of climate activists, and personal sustainability practices, among other themes; *n* = 46, 27% of total videos) and *optimism* for climate solutions (*n* = 12, 7%). For example, videos coded with optimism focused on concrete actions, such as using renewable energy sources, regenerative agricultural practices, and local produce. These videos emphasized climate optimism, or belief that human agents (e.g., youth, scientists, policy makers) have clear directions to address climate change.

Figure 1

Distribution of Sentiment and Emotion Categories



There were also videos with negative sentiments that expressed *anger* (*n* = 27; 16%), *fear* (*n* = 11; 6%), *sadness* (*n* = 11; 6%), and *sarcasm* (*n* = 11; 6%). In one video coded with anger, a creator combined footage of himself picking up plastic on the beach and images that showed the harmful impact of plastic waste on the marine ecosystem. The creator used strong language to express his emotion (e.g., "sea turtles, whales, dolphins are trapped in them, killing them."). Combining visuals also helped to show sarcasm. One video displayed footage of a creator reacting to statements from corporations (e.g., "we can achieve net zero by 2050") by raising his eyebrows and looking down. These expressions suggested sarcasm: Despite their statements, corporations had not taken meaningful action. Videos that showed fear were also related to the lack of climate action. Meanwhile, those that displayed sadness focused on climate-induced biodiversity loss and violence against climate activists.

We observed videos showing both positive and negative sentiments, most commonly a mix of fear and optimism. For example, one video displayed a creator's fear (the onscreen text read "feeling hopeless about the future"). Her expressions and body movements gradually changed, however. She started dancing and putting her hands up while the onscreen text stated: "seeing young people come together to take action and make change".

To answer RQ2 about effective emotional framing to generate interactions with other users, we ran analyses of variance (ANOVA) to examine the relation between videos' sentiments and the number of likes, comments, and shares. We did not find significant associations (likes: $F(3, 167) = .76$, $p = .52$; shares: $F(3, 167) = 2.41$, $p = .07$; comments: $F(3, 167) = 1.30$, $p = .28$). This suggests that the average interaction counts (as indicators of a video's popularity) did not significantly differ for videos with different sentiments.

Discussion and conclusion

We found that youth more often display emotions than no emotions, with similar amounts of positive and negative sentiments. Researchers have emphasized the role of negative emotions in inviting conversations about civic topics (Curnow et al. 2020). Youth also express hope to cope with climate anxiety (Ojala, 2012). Emotional expression may provide opportunities to connect with a broader audience and contextualize climate change discussion to facilitate sustainable practices. Our future work involves examining the videos' comments, to understand how audience relates to emotional display and engage in conversations that may enrich learning.

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Guidelines for Social Justice-Oriented Design

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Abstract: Social justice-oriented design has influenced design practice and research in various design fields. While the number of justice-oriented research and practices increases, it remains unclear how to incorporate justice-oriented design into the actual design process, particularly for projects that involve specific marginalized groups. This poster introduces social justice-oriented design guidelines with applied case examples.

Introduction

There is an increasing interest among learning scientists in contributing to social changes and promoting social justice (e.g., Reynante, 2021). Social justice-oriented design is to create an equitable social environment through design processes and products. To raise designers' awareness of social justice issues, several justice-oriented frameworks have been proposed. For instance, inclusive design and universal design encourage user experience designers to consider the full range of human diversity and increase the inclusiveness and accessibility of their design solutions. Other frameworks also emerged, such as culturally responsive and sustaining education framework (NYSED, 2018) focusing on creating curricula affirming students' linguistic and cultural identities. These frameworks highlight the essential components of social justice-oriented design and provide directions for designers to promote social justice. However, it is not necessarily clear how they can be applied to design for/with particular marginalized cultural groups. Designers need guidelines and methods to incorporate culture and values into their design products (Moalosi, Popovic, & Hicking-Hudson, 2010).

The purpose of this poster is to introduce justice-oriented design guidelines that we created and used and to demonstrate how they guided our design of a simulation for domestic violence victims on a US Department of Justice (DOJ) funded research project.

Conceptual framework

The conceptual framework used in the present work was built based on the literature on critical theory (e.g., Horkheimer, 2002) and social justice-oriented design studies (e.g., Bellini et al., 2022) as well as six dimensions of justice-oriented design (Dombrowski, Harmon, & Fox, 2016). *Critical Theory as a philosophical foundation*. Critical theory encourages people to reflect and critique the current power structures with considerations of historical, cultural, and ideological contexts. According to critical theory, inequality occurs when certain groups' interests or needs are less valued by others and thus have less access to resources such as education, healthcare, and food security. Designers can lead social change by recognizing inequality that exists and address inequalities with possible solutions. In our project, critical theory led the design team to focus on the lived experiences of Korean immigrants who suffer from domestic violence and to identify the resources they need to change unjust situations. Grounded in their cultural and linguistic uniqueness, they prefer to approach Korean church leaders (if they seek help), which led to the design of a simulation that engages Korean church leaders in the community's domestic violence prevention. *Social justice-oriented design*. Social justice-oriented design is rooted in critical theory with the purpose of promoting equity and fairness among people, regardless of the social groups to which they belong. It focuses on the injustice caused by social or cultural norms that may limit the agency of community groups. Many social justice-oriented design projects aim to reduce the harm caused by unjust practices influenced by those norms or traditions. In addition, justice-oriented design emphasizes increasing the cultural inclusiveness of the design products. Those studies explored the meaningful design collaboration or co-design process with people from diverse ethnic backgrounds (e.g., Chauhan et al., 2021) and investigated the cultural needs of user groups to include their values, cultural norms, and into the design products (e.g., Reynante, 2021). *Six dimensions of justice-oriented design*. The conceptual framework of Dombrowski, Harmon, and Fox (2016) highlights the six design dimensions of social justice-oriented design: transformation, recognition, reciprocity, enablement, distribution, and accountability.

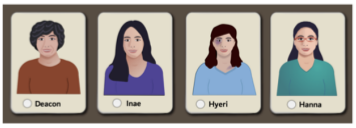
Design guidelines

Figure 1 illustrates the social justice-oriented design guidelines we created and used in our project for social justice among victims of intimate partner violence, along with two design examples. Our poster will showcase design cases that illustrate how each guideline informed the project design.

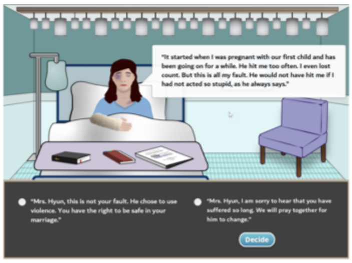
Figure 1

Simplified Presentation of Design Guidelines and Example Design

- *Guideline 1: Inequality Identification.* Designers focus on the larger contexts to identify the inequality issues that may marginalize or produce disadvantages for a certain group.
- *Guideline 2: Cultural Recognition*. Recognize the cultural norms, values, and assumptions that may cause the inequity. Particularly, the design team can conduct literature review or user analysis to identify cultural related factors that contribute to inequity.
- *Guideline 3: Ideation*. Based on the inequality and inequity identified, conceptualize the pathway to the ideal just situation that can be created by design. This may lead to the possible design solutions or interventions that improve the unjust situation.
- *Guideline 4: Culturally Responsive Design*. Incorporate cultural factors into the intervention design process that may lead to equitable engagements: a) create culturally responsive functions and features that lead to equitable engagements, b) incorporate cultural norms and values into the design of the content, c) create graphics that carry symbolic meanings resonating with the target users, and d) incorporate cultural attractors into the design of the interface elements that match expectations of a specific culture.
- *Guideline 5: Equitable Distribution.* Consider the equitable distribution of the design solution, including opportunities and access to related resources: a) collaborate with community partners to help distribute the design, b) provide alternative access to the related resources, c) consider the language needs of the user group.



Ideation: conceptualize four simulated virtual cases to change the unjust situation


"It started when I was pregnant with our first child and has been going on for a while. He hit me too often. I even lost count. But this is all my fault. He would not have hit me if I had not acted so stupid, as he always says."

● "Mrs. Hyun, this is not your fault. He chose to use violence. You have the right to be safe in your marriage."

● "Mrs. Hyun, I am sorry to hear that you have suffered so long. We will pray together for him to change."

Culturally Responsive Design – incorporate cultural norms and values into the design of narratives

Preliminary impact findings

We have implemented the simulation designed using those guidelines in collaboration with victim service organizations and church leaders. We found that religious leaders who participated in this program increased in their knowledge and self-efficacy in domestic violence prevention (Choi et al., 2022).

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Positive Education to Promote Flourishing: PERMA Framework Applied to College Students

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Abstract: This study aims to promote students’ autonomy and self-facilitation of well-being through positive education as an instructional approach. The participants were divided into an experimental group (*n* = 45) and a control group (*n* = 49). Data include online behavioral logs and a survey. The findings showed:1) Students practiced proactively positive psychology interventions (PPIs) and worked interactively with one another in an online platform. 2) PPIs were found significantly effective in increasing subjective well-being, and in reducing depressive symptoms.

Introduction

It has been estimated that there is between 12 and 46 percent of university students experiencing mental health problems (Harrer et al., 2019). Mental illness is associated with issues in academic contexts, including lower academic engagement, underachievement, and dropout (Ishii et al., 2018), as well as higher levels of academic dissatisfaction (Lipson & Eisenberg, 2018). School-based positive psychology interventions (PPIs) are a new curriculum for students to learn some coping skills with an aim of promoting their well-being（Shankland & Rosset, 2017). PPIs are aimed at increasing positive feelings, behaviors, and cognitions, while also using theoretically and empirically based pathways or strategies to increase well-being (Liau et al., 2016). The PERMA framework proposed by Seligman (2011) considers well-being to be broadly comprised of five elements: Positive emotions refer to hedonic feelings of happiness, such as feeling contentment and joy; engagement refers to feeling completely absorbed and engaged in life and connected to activities/organizations; positive relationships refer to feeling socially integrated, cared about and supported by others, and satisfied with authentically connected to others; meaning or purpose refers to believing that one’s life is valuable and feeling connected to something greater than oneself; and a sense of accomplishment includes making progress toward goals, feeling capable (Au et al., 2018).

This study employs Knowledge Forum (KF)–an educational software designed to help and support knowledge building communities. A main tool feature that KF uses is scaffolding (Scardamalia, 2004). In this study, the components of the PERMA model were directly employed as scaffolds in KF. This study is based on the PERMA model, designed and implemented school-based positive psychology interventions (PPIs) for 16 weeks, and employed an online Knowledge Forum learning environment for students to practice PPIs. Accordingly, the research questions are: (1) Can students practice proactively PPIs and work interactively with one another in an online KF? (2) Can the PERMA model activities (designed as KF scaffolds) improve college students' well-being?

Method

45 Taiwanese college students in an experimental group took a positive psychology course with PPIs treatment. In contrast, 49 Taiwanese college students in a control group took a psychology course with no PPIS treatment. The members of the experimental group, who practiced PPIs with the help of the PERMA framework, planned about good memories, character strengths, gratitude, and resilience and worked online in KF for note-creating, modifying, reading, and replying using the PERMA scaffolds during the 16-week course. Finally, the teaching assessment is to understand about student's learning engagement and process, as well as the effects of treatment for promoting students’ well-being and decreasing depressive symptoms. Regarding the data sources, the first pre-post survey items were taken from *Taiwan Subjective Well-Being Scale—Short Form (TSWBS-SF)* with 15 items (such as “I feel joyful all the time”) (Yu et al., 2017). *Taiwan Depression Scale (TDS)* with 22 items (such as “I am stressed”) (Yu et al., 2008). Second, online activity logs were concerning notes created, modified, read, and replied to by students in KF were also gathered.

Results

First, Table 1 shows how the students of the experimental group practiced proactively PPIs online in KF. Students were found to consistently work with ideas by creating, revising, and reading notes over four activities in a semester. Students spent most of the time on the activity of good memories. And one particular student was found to have a total of 21 notes-created and 17 notes-replied to others, showing that this student actively participated in KF activities and interacted intensively with others. The overall results show that students were able to progressively increase their interactive engagement as reflected in their built-on notes about practicing PPIs. The finding also suggests that students were able to work collaboratively as a community in this course. Students who created notes in KF used the PERMA model as scaffolds, such as “When you can face every day of life with gratitude, you will be happier” (positive emotions, P), “ Thanks to my family for their support and encouragement when I encounter setbacks (Relationships, R)”. Second, Table 2 shows the scores of subjective well-being（t（92） = 3.6，*p* = .001，*d* = .74）, and depression（t（92） = -2.83，*p* = .006，*d* = .58） were significantly different between the experimental group and the control group. The survey results indicated PPIs practiced in KF are related to improving mental health and decreasing depressive symptoms.

Table 1

Descriptive Analysis of the Experimental Group’s Activities in KF (N = 45)

KF Activities	Good Memories		Character Strengths		Gratitude		Resilience	
Activity Frequency	Total	Percentage	Total	Percentage	Total	Percentage	Total	Percentage
Creation	148	11%	105	18%	54	20%	66	17%
Modification	266	21%	192	32%	84	30%	112	28%
Reading	864	68%	295	50%	140	5%	216	55%

Table 2

Independent Samples t-test in the Experimental Group and the Control Group

Items	M(SD）		df	t-value	*p*	ES（*d*）
	Ne = 45	Nc = 49				
Subjective Well-being	46.87（ 7.98）	41.06（ 7.66）	92	3.60	.001	.74
Depression	13.18（11.53）	20.31（12.81）	92	-2.83	.006	.58

Discussion, summary and conclusion

With the help of positive education as an instructional framework, the participants wrote the PERMA plan and shared ideas online, while interacting with peers in the scaffolded KF environment. During the 16-week practice, they were constantly immersed in the PERMA activities. Finally, the survey results also showed statistically significant differences in the mental scales. It is shown that PPIs can effectively improve college students’ flourishing and reduce depressive symptoms. Positive education as an instructional approach can promote students’ autonomy and self-facilitation of well-being. However, during the practicing PPIs sessions, participants were encouraged to share their thoughts and experiences, and there was an associated risk that participants might disclose information about their health and mental health. The teacher who manages the PPIs had the responsibility to comfort students and help them avoid being negatively affected.

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Exploring Physicality in Out-of-School Time Learning

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Abstract: Bodily experience in learning has been an ongoing discussion in Learning Sciences. Informed by prior research on the value of embodiment, we explore bodily experience slightly differently by highlighting place-based physical attributes of youth in an out-of-school time (OST) context. Through interviewing students, parents, and OST providers, we discuss how such physicality imbued with interaction within space can capture and foster OST learning and engagement over time, supporting how parents and providers perceive OST STEM education.

Introduction and background

Learning is considered an embodied process where the body is key to acquiring knowledge and constructing shared meaning (Abrahamson & Lindgren, 2014). A vast literature on embodiment exists in Learning Sciences. For example, Lyons (2018) studied the use of technology in museums to help people make sense of exhibits and gain playful and collaborative experiences. Vossoughi and colleagues (2020) illuminated how children organized learning for the self and others using received embodied assistance in an OST tinkering program. There is another stream of inquiry where scholars probed how mobility affected learning. Marin and Bang (2018) investigated how learning occurred by observing children and parents walking in the forest. Informed by prior work, we explore bodily experience, including senses, by highlighting place-based physical attributes as physicality—how youth's bodily interactions with space may support their engagement in OST learning. This poster comes from a larger research project where we work with students, parents, OST providers, and college admission officers to discuss how OST STEM learning can be documented via personal learning records. Our goal is to show the potential of utilizing physicality as a way of knowing *how* youth engage in OST STEM activities.

Methods

This poster reports preliminary data from interviewing 24 youths, 10 OST providers, 10 OST alums, and 4 parents from one specific OST venue, *STEM Space*. STEM Space is an OST program affiliated with a public university in the Midwestern United States to offer free college preparation guidance and academic resources for middle and high schoolers living nearby. All our recent interviews were done remotely and audio recorded. We followed semi-structured protocols to request participants to share their experiences with OST STEM learning, participation, and programming. We analyzed the interview data using qualitative content analysis (Hsieh & Shannon, 2005). As the initial step, we transcribed audio recordings into verbatim transcripts and interpretable content logs. Codes were derived from the data inductively. Each document was coded by at least two researchers following the social moderation process (Frederiksen et al., 1998; Herrenkohl & Cornelius, 2013) to address discrepancies in coding. Although social moderation is time-consuming compared to other evaluation approaches, such as intercoder reliability, we select this strategy to ensure that all possible themes are captured and recorded. We also created memos to document thoughts during data analysis and assigned pseudonyms to each participant.

Findings and discussion

Among the 48 participants, the most frequent example of physicality occurred when students recalled their college campus trips. For example, when asked about what she found valuable when participating in STEM Space, Toni said that she was impressed by her trip to the university with which STEM Space was affiliated.

> I highly enjoyed the trips. I love going to other places and seeing the college. […] I love seeing the museums; I love seeing the areas; all those experiences are very nice to me. I have never been to a big campus […] Finding those spaces I could go to, like "this will be my space; that will be my space," just understanding what I am comfortable with is very good. (Toni)

This view is echoed by several other students, including Karla, Alicia, Veronica, Shelia, Lydia, Tanya, and Melanie. Apart from youth, several parents and OST providers shared the same positive perspective of these college and field trips and summer camps. One illustrative parent example is Beth, a mother whose two daughters have both taken part in the STEM Space program for years. When asked whether she thought her children learned something about STEM, Beth appreciated that the Earth Camp included "a lot of hands-on experimentation" and the learning supplies sent by STEM Space: "I thought it was well planned because the kids are just sick of Zoom. […] The teacher had set it up was very much hands-on […] that really, really worked." In a similar vein, we saw appreciation for physicality from OST providers. Jessica, an experienced OST provider in charge of earth and environmental sciences outreach programs for high schoolers, recalled how she employed physical activities to encourage problem-solving and peer cooperation in her program.

> The first thing we do is go to the adventure center on campus; there are high ropes course and the climbing wall. We tell them [youth] to focus on cooperation and problem-solving, and we've never had interpersonal conflicts with our groups. At night, we often sit by a bonfire on the beach […] where we will have our counselors talk about their paths […]. (Jessica)
>
> I don't want them [youth] to memorize anything; I don't want them to pass a test. […] I want them to feel "I can take an intro course; I'll be empowered to feel a little bit better about it; I can travel to some of these spaces and feel comfortable." […] I want them to feel comfortable hanging out with the kids who feel comfortable in these spaces. (Jessica)

Here, Jessica raised an essential point where she brought the meaning of sense of belonging to the fore in an OST setting. According to her, the feeling and the sense gained through physical events with peers made these OST learning activities profound. Plus, Jessica interpreted her OST STEM program as a springboard to promote skills like problem-solving, teamwork, and reflection. Particularly, what Jessica portrayed that she hoped to bring to youth, i.e., confidence and community building, are well mirrored in her design of physical activities in the program. Based on the data, we contribute to a different lens to discuss bodily experience inseparable from how we interact with space, including sight, hearing, touch, and beyond, and what it means for human learning. Like how body language is considered vital to facilitate knowledge acquisition, we suggest that physicality can capture other dimensions of learning, making it valuable as an innovative information channel to unpack OST learning.

Conclusion

In this poster, we present physicality, which highlights place-based physical attributes, as a potential lens to gauge *how* youth participate in OST activities. We show that although physicality may be hard to quantify, it can be a useful naturalistic indicator of student learning and engagement over time. It helped youth envision and prepare for the future, supporting what parents and providers perceived OST STEM education. A deeper look at the literature is needed to solidify the theoretical underpinning of this line of conversation. We plan to continue data collection and analysis while iterating the qualitative coding to generalize relevant results to put into practice.

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Rural Pre-Service Teachers and Social Justice Advocacy: What is the Story Behind the Numbers?

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Abstract: This sequential mixed methods study applies Lewin's (1947) force field theory as a framework to explore the childhood experiences and current perceptions of pre-service elementary teachers from rural communities regarding social justice advocacy. Results of the quantitative portion of the study indicate that their elementary teachers supporting diverse students may be a supporting factor in multiple ways. The qualitative study is underway, but initial outcomes may provide insights for pre-service teacher programs.

Background and research purposes

Rural schools face unique challenges regarding social justice advocacy (Cuervo, 2016), as teachers struggle to transfer what they learned about social justice advocacy from their pre-service training to their classrooms (Ajayi, 2017). Rural elementary pre-service teachers are more likely to resist learning about and applying practices to support diverse students due to limited exposure to diversity and a lack of awareness about systemic oppression (Han et al., 2015). The intersection of culture, learning, and equity has been a focus of the learning sciences for decades (Nasir et al., 2006). While several learning scientists have focused on social justice training for teachers (e.g., Darling-Hammond, 2002), this focus has not shifted towards social justice advocacy development for elementary teachers in rural communities. Rural schools are becoming more racially diverse (Cuervo, 2020) and these demographic shifts and unique student needs require training for teachers to not only teach diverse groups but also to advocate for students from all backgrounds. Researchers have been calling for better pre-service education on social justice for years (Cochran-Smith et al., 2009). However, many teacher preparation programs offer limited exposure to the history, needs, and methods of social justice advocacy (Cuervo, 2016). This study explores supporting and inhibiting factors that affect SJA for elementary teachers in rural communities.

Given the challenges and opportunities around social justice advocacy unique to rural elementary pre-service teachers, we employed force field theory (Lewin, 1947) to frame and conceptualize our work. Force field theory rests on the idea of an equilibrium between the driving and constraining forces faced when working toward positive change. These forces can affect behaviors in individuals and groups regarding change. Based on this framework and the existing literature on rural pre-service social justice advocacy, we devised three research questions: 1) What are rural pre-service teachers' perceptions of the need for social justice advocacy in rural elementary schools? 2) What were rural pre-service teachers' experiences with social justice advocacy when they were students in rural elementary schools? 3) What are rural preservice teachers' perceptions of barriers and supports for social justice advocacy in rural elementary schools?

Summary of quantitative data, findings, and discussion

To address these questions, we developed a sequential, exploratory mixed-methodology design (Plano-Clark & Creswell, 2008). This approach allowed for an overview of the phenomena in a rural Appalachian state through a quantitative survey and a detailed understanding of cultural, contextual, and educational supports and barriers from qualitative interviews. The survey was based on existing instruments for social justice (Ajayi, 2017; Whitaker & Valtierra, 2018). Questions were adapted to address the research questions and suit the sample. To improve content validity, all questions were peer-reviewed by an expert in survey research. The timeline was sequential, with the quantitative survey first, informing the qualitative interview protocol. The qualitative interviews will provide insights into the distribution of a phenomenon within a chosen population (Denzin & Lincoln, 2007). The survey and interviews were implemented independently but with some interactivity, as the survey results informed the interview questions (Greene et al., 1989). The results of the quantitative and qualitative studies will be presented in a mixed manner, showing areas of convergence and elaboration.

There were 58 participants who completed the survey. Results of the demographic questions showed 83.1% of respondents were between 18 and 22, 15.3% were 23-27 years old, and 1.7% were in the 39 to 49-year range. Results for gender were 86.4% female, 11.9% male, and 1.7% non-binary. The racial breakdown of participants was 93.4% White, 3.3 % Asian, and 1.6% Black or African American.

To address our aims, we examined the analysis of covariance models based on two independent variables: 1) whether students' hometown is classified as rural and 2) whether students indicated an interest in teaching in a rural setting. We examined whether these factors explained variation in 1) pre-service teachers' experiences with prior teachers' supporting social justice advocacy, 2) pre-service teachers' perceived need for social justice advocacy training, and 3) pre-service teachers' perceptions of others' support for social justice advocacy in their hometown. Findings indicated that 1) students who indicated an interest in teaching in rural settings also reported higher levels of social justice advocacy on the part of their prior teachers, and 2) students from rural hometowns reported lower support from others for social justice advocacy. These findings suggest that prior teachers' support of social justice advocacy when the pre-service teachers were in elementary school may be a promoting factor for pre-service teachers' social justice advocacy, while past experiences with less support may serve as a barrier to advocacy.

ANCOVA models were based on two factors/IVs (and controlling for the other): 1) whether students' hometown is classified as rural and 2) whether students indicated interest in teaching in a rural setting. We prioritized three variables as outcomes: 1) prior teachers' support valuing (i.e., when I was growing up, elementary teachers in my hometown valued supporting diverse students…); 2) perceived need for social justice advocacy training (i.e., social justice advocacy training for teachers in my hometown is needed); and 3) perceptions of others' support for social justice advocacy (i.e., social justice advocacy in elementary classrooms in my hometown would be supported by…).

These findings suggest that prior teachers' support of social justice advocacy may be a promoting factor, while past experiences with less supportive elementary teachers may serve as an inhibiting factor to advocacy. Differences were not observed in perceived need for social justice advocacy training based on rural teaching interest or rural hometown, but the means were high across groups (i.e., students reported a high need for social justice advocacy training irrespective of their hometown or location of interest for teaching). As rural schools face high teacher attrition (Frahm & Cianca, 2021), this could be something for rural school leaders to consider in recruiting new teachers, retaining teachers, and facilitating community support for social justice. The qualitative portion of this study will give in-depth insights into the specific supporting and inhibiting factors for rural elementary teachers as they try to engage in social justice advocacy.

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Thinking Artistically: Artistic Compositions of Interactions as a Lens for Understanding Learners Engagement

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Abstract: This poster considers the usage of *artistic thinking* to analyze interactions in learning environments. Using a moment-to-moment video analysis, several interaction dynamics were noticed among learners and with materials in a community-based science learning setting. Through two cases of six artistic compositions created from video-analysis data, we argue that visual artistic thinking serves as an investigative tool to gather and relay range of social and historical meanings of learners' engagement with peers and materials.

Introduction

Interactions as a collective of actions and reactions between individuals or artifacts are communicated through various modalities (e.g., speech, gestures, gazes, movement) when represented. A growing body of work in the Learning Sciences has been building on multimodal analysis to understand learning processes and interactions in learning environments (Vogelstein et al., 2019; Vossoughi et al., 2020). Work in the field also attuned to the ethical implications for what video analysis can communicate about learners and learning (Vossoughi & Escudé, 2016). For instance, shifting from a technocentric video analysis towards centering learners' dignity and relations building (Vossoughi & Escudé, 2016) can create opportunities to examine interactions while engaging in perspectives taking, consider power dynamics of actors, pay attention to evolving relations, and examine the embodied interactions and movement in the space. That is, the medium of image becomes not only an examination of a sequence of events, but also, the structures of interactions they communicate. Building on prior work, we consider the ways thinking artistically invites us to examine how interactions are arranged, represented, and in motion (Saldana, 2014). The purpose of this approach is to examine a range of perspectives represented in data and expand the modalities through which actions and behaviors observed are represented (Saldana, 2014). This poster explores the possibilities for how thinking artistically through artistic compositions of illustrated interactions can expand our understanding of learners' interactions in learning environments.

Methods

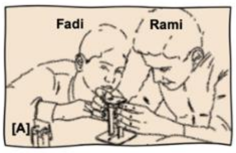
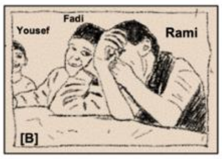
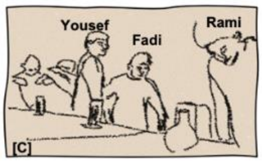
This poster is derived from a larger study conducted within a four-days transdisciplinary science program in a community-based organization of Al-Rowad for Science and Technology with Ten young Palestinian Arab learners (5th-6th grade) (Mawasi, 2021). Data used in this poster are from a moment-to-moment interaction video-analysis notes (~2 hours) (Jordan & Henderson, 1995). The analysis examined learners' human interactions and with materials. Specifically, the analysis focused on the third day of activities for learners' engagement in the space. This poster discusses examples of interaction analysis illustrations from videos screenshots and notes.

Findings

Case 1: Help and invitation for joint activity vs. noticing a different student dynamic in the background

The main participant this case focuses on is Rami (pseudonym). Across three activity contexts Rami took a different position (see Table 1): (A) Rami helped Fadi and demonstrated how to build a piece in the artifact. (B) Rami whispering to Fadi. Fadi keeping one eye towards Rami, one towards the teacher. No interaction with materials here. (C) Rami standing and invites Yousef and Fadi to look with him at the effect of light on his clothes. While in the background, two students have a different dynamic, and they are not part of the triad engagement.

Table 1
Interactions among peers and with materials across three activity task contexts

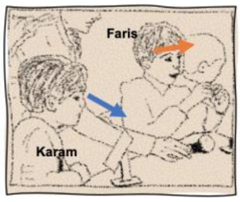
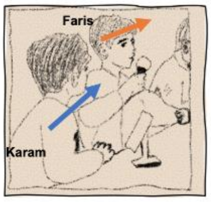
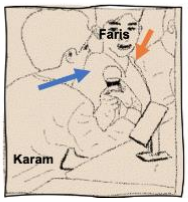
		

Case 2: Enacting power over artifacts

The teacher assistant gave Faris and Karam the light so they test it together (1st second). Faris took it to himself and began to test it (3rd second)). Karam attempted to take it, yet, Faris kept pushing it away. Even when Karam succeeded to hold the light, still, Faris kept holding the light towards himself (5th second).

Table 2

Evolving dynamics of gazes and gestures across time of interactions with artifact (light) and between actors

 Second 1	 Second 3	 Second 5

Discussion

In conclusion, artistic compositions refer to the use of creative expressions (used in visual and performative arts) to explore interactions between individuals and their environment. Such compositions offer insights into the ways in which humans interact with their surroundings and how these interactions evolve over time. By engaging with artistic compositions, researchers can attune to the fluid roles, actions, and positions of actors in learning environments thus remaining receptive to emotional experiences and diverse interpretations of learning. Artistic approaches can also be viewed as investigations into the arts themselves, aimed at comprehending the intricate layers of meaning embedded within an art form that is relevant to the learning process. Artistic approaches build on existing multimodal methods by providing additional lenses through which to examine learners' interactions with one another and artifacts. This is significant because traditional fieldwork approaches view the learning process through a single lens, which limits our understanding of the complexities of the learning experience (Leavy, 2020). The two cases illustrate the usefulness of artistic compositions in examining fluid roles and power dynamics in learner interactions with one another and with artifacts. This poster emphasizes the importance of using artistic approaches by employing visual compositions as artistic forms to gain insight into the intricate dynamics of these interactions and recognize the subtle power dynamics that are embodied within them at a micro-scale. This highlights the value of incorporating diverse methodological tools to enrich our understanding of complex phenomena in the field of education.

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Computational Thinking and Robotics in Mixed Environments

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Abstract: This study examined how educational robotics fostered college students' computational thinking skills in virtual and physical learning environments. Students from a traditional (*N* = 33) and an active-learning (*N* = 35) classroom completed surveys, problem-solving tasks, and robotics navigation challenges in virtual and physical learning environments. After one semester, students' computational thinking skills increased, but varied based on gender and performance in the problem-solving tasks. Students in the traditional classroom benefited from the virtual learning environment.

Theoretical framework

Recently different models for computational thinking (CT) have been proposed (Weintrop et al., 2016), each emphasizing concepts, practices, and perspectives to varying degrees. From an educational perspective, a CT model should include concepts that go beyond knowing a programming language and emphasize the pedagogical aspect of teaching CT (Hsu et al., 2018) with classroom activities designed for problem-solving and solutions that are reusable in different contexts (Shute et al. (2017). One way of fostering the development of CT is through educational robotics (Chevalier et al., 2020). Whereas earlier studies on educational robots (Touretzky, 2013) have focused on teaching programming, others have taught a broader set of computer science concepts and skills such as "computational thinking" requiring students to practice their abilities in abstraction, algorithm design, debugging, and generalization (Bers et al., 2014). This study is framed under the theory of constructionism (Papert & Harel, 1991), whereby knowledge is actively constructed through collaborative learning and interaction with the environment. In this approach, learners typically work on authentic problems in small groups which are beneficial at increasing students' understanding of complex systems and promoting interest, engagement, and motivation (Jacobson & Wilensky, 2006). The integration of robotics activities aimed at introducing CT concepts before learning about programming are still scarce. The current study investigates how a series of robotics activities fostered college students' CT in virtual and physical learning environments.

Research method and design

A series of robotics learning activities with Arduino microcontrollers were implemented to a physics curriculum with the goal of expanding students' CT by prompting them to think simultaneously about the completion of a robot navigation challenge in mixed learning environments: (1) as part of a simulation in a virtual platform and (2) in a physical environment (i.e., physics labs). The following research questions guided this study: (1) How do robotics learning activities foster students' CT attitudes? (2) How does instructional approach influence students' applicability of CT in virtual and physical learning environments? Based on prior research demonstrating learning gains after interacting with digital applications (Dalgarno & Lee, 2010) and simulation environments (Chichekian et al., 2022), it was expected that students who participated in the robotic activities would display increases in their CT over time. It was also hypothesized that the virtual simulation platform would be more useful for students exposed to a traditional teaching approach given limited exchanges and feedback from peers and the teacher.

Sample and context

College students (*n* = 68) between 17 and 19 years old were recruited from two Engineering Physics courses. Students were randomly assigned to two classes: 1) a teacher using an active-learning instructional approach (*n* = 35, 12F, 23M) and 2) a teacher using a traditional instructional approach (*n* = 33, 11F, 19M, 3 missing). Two-third of students (*n* = 44) had no prior coding experience and the remaining (*n* = 20) reported some knowledge of Arduino, HTML, Python, video game programming, hackathons, code academy, but no formal training.

Robotics labs

The robotic labs introduced students to Arduino programming and a final autonomous navigation challenge: Using sensor feedback, program a robot that can navigate a complex path in the shortest possible time. Students learned about hardware basics, how to test the Arduino IDE with the UNO board, and how to wire up a simple "move the robot task". They learned how to apply programming basics to learn how the hardware can be used and designed an algorithm that would use the data from the ultrasonic sensor as feedback to control the robot. The virtual challenge consisted of programming a robot to navigate a path in an optimal time, whereas the physical challenge aimed at optimizing and generalizing a solution for a hardware challenge that accounted for new changes.

Data sources

A survey composed of three subsscales measuring CT attitudes was derived from Part 1 of the *Callysto Computational Thinking test* (Cutumisu et al., 2019) and administered at the beginning (T1), during mid-term (T2), and at the end of the term (T3). This nine-item scale ($\alpha = 0.81$ at T1, $\alpha = 0.89$ at T2, and $\alpha = 0.81$ at T3) assessed students' ease using digital technology (3 items, e.g., "I find it easy to use new technology"), their problem-solving processes (3 items, e.g., "When I am solving a complex problem, I try to break it up into smaller or simpler problems"), and their attitudes toward coding (3 items, e.g., "I am comfortable writing code to solve problems.") Scales ranged from 1 (strongly disagree) to 7 (strongly agree). Assessments on the virtual and the physical robotic challenges were scored on a total of 10 based on the robot's success in navigating the challenges.

Data analysis

A one-way repeated measures was conducted to assess how the robotics activities fostered students' CT attitudes. Paired sample t-tests within male and female students were also conducted to assess the changes in CT attitudes over time. A moderation analysis assessed how the instructional approach moderated the relationship between students' performance on the robotics challenge in the virtual and physical learning environments.

Results

There was a significant increase in students' CT attitudes over time, $F(2, 65) = 15.60$, $p < 0.001$, specifically between T1 ($M = 4.97$, $SD = 0.91$) and T2 ($M = 5.31$, $SD = 0.92$), $t(66) = 3.46$, $p < .001$ and between T2 ($M = 5.31$, $SD = 0.92$) and T3 ($M = 5.59$, $SD = .0.68$), $t(66) = 2.69$, $p = .009$. Males and females experienced significant increases from T1 to T2, $t(41) = 2.23$, $p = .032$ and $t(22) = 2.53$, $p = .019$, respectively; females also experienced significant increases from T2 to T3, $t(22) = 2.23$, $p = .033$. Compared to their peers, students in the active-learning context scored significantly higher on the physical challenge ($M = 8.41$, $SD = 1.17$ vs. $M = 7.30$, $SD = 1.44$, $t(65) = 3.47$, $p = 0.001$), but significantly lower on the virtual challenge ($M = 9.65$, $SD = 0.87$ vs. $M = 10.06$, $SD = 0.17$, $t(65) = -2.73$, $p = 0.010$). Generally, as students scored higher on the virtual challenge, their grades on the physical challenge increased significantly, $b = -5.71$, $t(63) = -5.02$, $p < 0.001$. The virtual simulation benefited students in the traditional context who experienced a more significant increase in their scores on the physical challenge, $b = 7.26$, $t(63) = 6.79$, $p < 0.001$ compared to their counterparts, $b = 0.78$, $t(63) = 4.02$, $p < 0.001$.

Discussion and conclusion

Overall, the robotics activities had a significant positive effect on male and female students' CT over time, especially for females who reported a significant increase from mid to end of term which was not the case for males. The virtual simulation environment provided leverage for students to receive constructive feedback on their algorithms, test, debug, and rerun their code, and, ultimately, generalize, and apply their solutions to the physical navigation challenge. This learning experience was an optimal scenario for students in the traditional classroom as receiving real-time feedback from the simulation and incremental support when learning how to translate an algorithm into a programming language somewhat compensated for the minimal opportunities to collaborate outside of class. The individualized contribution to student learning from virtual and physical learning environments is indicative that contextualized learning activities should be designed separately and independently because although they are interrelated, they are operationalized and conceptualized as distinct.

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Exploring the Effectiveness of a Spherical Video-Based VR Intervention for Test Anxiety in an English as a Foreign Language Setting

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Abstract: Immersive virtual reality (VR) experiences enable learners to become familiar with test situations and thus become more resilient to emotional stress relating to test taking. This qualitative study aims at understanding the educational emotions triggered via and within a spherical video-based VR intervention for test anxiety in an English as a Foreign Language (EFL) setting.

Introduction

This poster is directed to gain an understanding of educational emotions triggered via and within a spherical video-based VR intervention for test anxiety in an English as a Foreign Language (EFL) setting. More specifically, it aims at (1) specifying the emergence and nature of emotions experienced when undergoing the intervention, (2) comparing screen-based and head-mounted-display (HMD)-based VR experiences in terms of perceived immersion, and (3) assessing the perceived effectiveness of spherical videos for getting acquainted with test situations and managing negative emotions when takings tests.

Taking key issues relating to test anxiety and educational emotions and VR into account (in particular (Pekrun 2006, Scherer et al. 2001 and Sherman & Craig 2019), we developed the *VR Test Anxiety English* prototype training world with the help of a 360-degree video camera and corresponding film editing software. In close collaboration with the language center staff, the typical phases of the oral English language performance test (LPT) were identified and structured into consecutive film shots. Using a 360-degree camera enabled us to capture typical stimuli of a real exam situation shaped by existing physical examination environments, fellow test takers, and examiners. Users may experience the different phases of the exam in a sensory and concrete way either by turning their heads when wearing the HMD or by clicking and dragging the material when accessing it on a desktop PC or tablet. A brief version of the learning environment can be accessed at https://youtu.be/rjjYdtNyl8w (Eisenlauer & Sosa 2022).

Research design

The sample comprised 10 students of University of the Bundeswehr Munich, Germany. All participants had prior experience of taking oral English exams at the university's language center. The participants were divided into two groups. One group first explored the test situation on a desktop PC and then accessed the material via an HMD; the other group first used an HMD and then a desktop PC. Following the intervention, participants underwent a guideline-based, problem-centered interview including 29 open-ended questions divided into four thematic clusters. After transcribing the interviews, the data were organized using MAXQDA. The interpretation and analysis of the data was based on Mayring's (2015) qualitative content analysis.

Data analysis and discussion

Concerning educational emotions before exams in general, only two of the 10 participants reported experiencing high levels of emotional tension. However, those who indicated low or average levels of test anxiety in general reported feeling comparatively more tension in exam situations with a high perceived subjective value (Pekrun, 2006). Concerning the subjective perception of the oral English LPT examination, eight participants indicated that they considered the exam to be controllable as they were introduced to the examination procedure as well as possible examination topics. The two participants with high test anxiety associated the oral English LPT examination with feelings of insecurity triggered by uncertainty over the examiner's questions as well as by linguistic barriers. It is also noteworthy that these two participants reported that tensions would have a negative effect on their motivation. They described negative emotions resulting in the attitude that one can never be prepared enough to pass the exam. Most participants (8 out of 10) reported that prior introduction to the examination form and procedure would have positive effects on the test results. In accordance with previous findings (Pekrun & Götz, 2006), the data confirm that test preparation establishes the backbone of the perception of a situation's controllability and thus can relieve tension.

Regarding the extent to which participants immersed themselves in the spherical media VR intervention, the analysis indicates a significant difference between the different media interfaces. All participants rated the

HMD-based VR experience as realistic, whereas only two participants described the desktop PC-based environment as realistic. The high authenticity via HMD was linked to head movements corresponding to the viewing directions and the authentic presentation of an examination setting and other test takers. Regarding the intervention on a desktop PC, the contents were experienced “as a video” [#Test Person 6] and external stimuli diverted attention from the simulation to the physical environment. The majority of participants reported that they could immerse themselves in the VR training world via HMD. One participant stated, “you really felt put back in this test situation so that you already started to think about possible answers to what [the teacher] asked here, because you were already a bit more in it than in the video” [#Test Person 9].

Considering educational emotions, six participants described experiencing test anxiety-specific feelings when watching the test simulation via the HMD. The experienced emotions were not perceived to be as intense as in a real exam situation, but participants still noticed signs of a faster heartbeat or sweaty palms. Equivalent feelings were not described regarding the intervention via a desktop PC. According to three participants, negative emotions in the HMD setting were especially caused by negative feedback on the performance given at the very end of the simulation by one of the examiners: “when the negative result was presented, it was somehow as if I had not passed” [#Test Person 1]. The different reactions to the negative feedback are in line with previous findings that emotions are caused by a person’s current interpretation of a situation (Scherer et al., 2001).

Concerning the effectiveness of the VR intervention, six participants stated that the controllability of an exam situation can be increased with the help of a simulated VR environment. Watching the test simulation helped the participants familiarize themselves with the exam procedure and thus made the exam situation feel more relaxing: “Habit makes serenity, so if I practice something often, I become more relaxed in it. It doesn’t matter what kind of training it is; the more often you do it, the more the skills come, the more habit comes, and from that comes serenity” [#Test Person 9]. The participants evaluated the intervention as an effective training tool for getting acquainted with the test situation. To inhibit the emergence of test anxiety, they saw the need to provide more possibilities for interaction; for example, “what I was missing for a real exam preparation would be this interactivity, for example, in the selection of topics, that you actually have two realistic topics in the situation and you can choose with the help of VR glasses” [#Test Person 10].

Summary and conclusion

In line with previous research (Alsina-Jurnet et al. 2007), the study provides evidence that the VR intervention had a stronger emotional appeal to students with high test anxiety than to those with low test anxiety. The test simulation served as an effective tool for enhancing the controllability of the situation but was only partially effective for reducing or preventing test anxiety. Though anxiety-related emotions could be triggered via and within the VR intervention, the feelings were perceived not to be as strong as they would be during a real test situation. Among other reasons, an explanation for this may be the limited interactivity. That is, the spherical media-based VR intervention afforded the immediate experience of an existing physical examination setting and examiners, but there were no options for user-driven activities, such as responding to questions or giving an oral presentation. The processing and interactive visualization of spherical media with help of a game engine or authoring tool establishes an efficient way for enhancing the immersion in VR environments to address and research test anxiety in future studies.

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Student Help-Seeking Through Utilization of Professor Office Hours

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Abstract: Help-seeking is an important self-regulation skill required for students' academic success, but students struggle asking for help when they need it. In this exploratory study, researchers interviewed professors, surveyed students, conducted observations, and analyzed course material to investigate (a) messages professors send through the structure of their course and how these associate with students' values for office hours and help-seeking behaviors, and (b) how students report knowing when to ask for help, where they turn for it, and their motivation to seek it. Findings showed that students view office hours as a last resort. Professors who promoted resources (e.g., office hours) had higher office hours than their colleagues.

Purpose

Self-regulation skills, such as help-seeking, are important for effective learning, but many students have poor help-seeking behaviors, such as knowing they need help or how to ask for help when they need it; this is especially true among college students in mathematics (Ryan & Pintrich, 1997). Although many resources are available to these students, few students utilize these resources (Gueudet & Pepin, 2018). One resource that is particularly underutilized is office hours. This may be because of students' lack of value for help-seeking and office hours as a resource (Briody et al., 2019). This is an area that is under-researched and motivates this exploratory study, which investigated the following research questions:

1. What messages do mathematics professors send through the structure of their courses and how do these messages associate with students' values for office hours and help-seeking behaviors?
2. How do undergraduate mathematics students report knowing when to ask for help, where to turn for it, and their motivation to seek it?

Perspectives

Self-regulated learning (SRL) is a major predictor of academic success (e.g., Davis & Hadwin, 2021). To successfully regulate their learning, students need to know when they need to seek help. However, students in college often struggle when deciding what to do when they need help, and reaching out to professors can be daunting (Newman, 2002). Students' values of learning affect behavior towards learning (Eccles & Wigfield, 2002). If professors could help their students increase their value perceptions for help-seeking, this may lead to an increased interest in learning the content resulting in greater student success in academic endeavors. Prior research has illuminated some ways to facilitate help seeking: professors can provide support for autonomy, provide opportunities to practice SRL through course content, and can buffer the fears of students asking for help by being responsive to student needs (Newman, 2002). One study (Briody et al., 2019) found that although students desired interaction with and had positive experiences with their professors, they were hesitant to contact faculty. Many of these students described their professors as "busy" or "important" and described their own needs as "silly" and "dumb." The researchers explain the need for a shift of power in the faculty-student relationship and identify ways that faculty can increase faculty-student interaction by making opportunities available to students to practice communication in the classroom and relationship building.

Method

Introductory math professors at a mid-Atlantic public university and their students were invited to participate in this IRB-approved study via email. Four professors (professors A-D) and 17 students participated. Two of the professors were men; none disclosed their race. Of the students, 71% were female, 53% were White, 6% Asian, 6% African American, and 6% Indian; 29% did not disclose their race. Students were distributed between classes. Faculty participated in a 20-minute interview; students participated in a survey. Questions captured professor and student perspectives of students' willingness to ask for help, utilization of office hours, and communication between faculty and students. The syllabi and canvas pages for each professor's course were reviewed for office hour information and other resources and to see how professors communicated to their students. One observation per class was conducted to note how students and professors interacted. Observations described student engagement, interactions with the professor and their peers, and the professor's promotion of resources. All data was coded qualitatively. The presence and frequency of codes were compared across professors.

Results

RQ 1: What messages are mathematics professors sending through the structure of their courses, and how do these messages associate with students' values for office hours and help-seeking behaviors?

Professor A promoted office hours to his students weekly. He encouraged students to contact him through email and ranked office hours as the number one resource for students to seek help before use of other resources. He offered office hours twice a week both online and in-person. He promoted peer interaction through the physical structure of his classroom (round tables and tutoring promotion via posters). This professor had the highest office hour attendance (nine students per month). On the other hand, professor D viewed office hours as unhelpful and as a last resort. She did not promote office hours and only offered them online, once a week. She also did not promote peer interaction like the other professors did (no group work and individual desks). She had "generally no one" show up at her office hours. The stark difference between professor A's and D's perceptions, actions, and office hour attendance implies that the potential messages that these professors send through their course structure and promotion of office hours conveys the value of office hours and help-seeking to their students.

RQ 2: How do undergraduate mathematics students report knowing when to ask for help, where to turn for it, and their motivation to seek it?

Each student completed a questionnaire to describe their perceptions of office hours and other resources. Students explained what evidence they use to determine whether they were struggling in math class. Students responded that they use exam scores, assignment grades, or class grade to make this determination. Students were asked what they preferred to do if they needed help on their math homework. Their responses were: figuring it out themselves (29.4%), using an online source (35.3%), using a tutoring service (11.8%), asking a friend/classmate (17.6%), or asking a professor (5.9%). One student said, "I think I will review the class video page and if I am still stuck I'll just struggle on my own." Overall, most students preferred figuring out their work themselves or turning to an online source if they needed help rather than asking a professor. When asked under what circumstances they would find themselves attending office hours, most students stated if they were concerned about their grade, or if they were very confused on a concept. One student reported that office hours would be their last resort, stating they would go "if no one else I knew could help me and the question was impossible to figure out." Lastly, students were asked what has kept them from attending their professor's office hours. Responses ranged from not needing to attend due to good grades, the preference to go to tutoring instead, the lack of time or conflicting schedule, anxiety, not feeling their questions were important enough, or simply forgetting.

Significance

A few implications can be inferred from the results. For example, the student surveys provided insight on why or why not students attend office hours, such as the impact their grades have on their decisions to seek help. This study also provides information on how students feel about the value of resources provided to them. Students prefer seeking help from their peers, which is a finding that aligns with previous work (e.g., Newman, 2002). This means one way to promote help-seeking in the classroom includes facilitating peer engagement to create a positive learning climate where students are encouraged to seek help from each other. Furthermore, practices of Professor A could be beneficial to consider as he had much higher office hour attendance than his colleagues. Previous research suggests professors can promote competence through meaningful activities where students can practice the skills of self-monitoring as well as questioning peers and asking for feedback from them (Newman, 2002). These practices will encourage help-seeking behaviors and normalize them as part of the learning process.

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Complexities and Contradictions in a Teacher's Activation of Epistemological Resources and Their Consequences for Student Framing

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Abstract: This research employs the lenses of epistemological resources and framing to examine the complexities of one teacher's efforts to position his middle-school biology students as sensemakers. Through interviews, classroom observations, and document analysis, we trace the teacher's activation of varied epistemological resources and how such resources positioned students' efforts throughout the lesson. While the launch of tasks was framed as an opportunity for "doing science," this framing became less stable when the teacher engaged with students in small group work and during the wrap up that were focused on the "right answer." Specific phases of the lesson served as a context that influenced the epistemological resources activated, helping us understand the varied, dynamic, and sometimes contradictory nature of the teacher's moves and their consequences on students' framing of their efforts.

Introduction

Science education reform efforts envision classrooms as sensemaking spaces where students explore natural phenomena to refine their understanding of scientific ideas and practices (NRC, 2012). Engaging students in science learning through sensemaking is "notoriously challenging" as teachers must "navigate an unpredictable terrain of student ideas" (Watkins & Manz, 2022, p. 1). With these considerations in mind, this research examines the complexities of one teacher's efforts to position his middle-school students as sensemakers in science.

Methods

Data for this case study were drawn from a year-long professional development (PD) project designed to foster teachers' abilities to support student sensemaking about science through talk. We focus on one middle school biology teacher, Jerry, and his middle school students' framing of his instructional practice. We focus on Jerry and his class because we observed that while he provided space for students' sensemaking and employed the tools introduced in the PD, his teacher-led wrap ups discussions centered on providing canonical knowledge. We wondered about the factors influencing his varied instructional moves and their consequences.

Data sources included classroom video observations of three lessons (*Cell Structure, Cell Reproduction, and Mechanism of Evolution*), classroom artifacts, teacher surveys, and a series of open-ended and structured stimulated recall teacher and student interviews. To begin our analysis, we examined the kinds of student thinking required by the task, using the categories described by Tekkumru-Kisa and colleagues (2022). Classroom videos from three, multi-day lessons were segmented to broadly characterize the different lesson phases (launch, small group work, round robin, wrap up discussion, and write up). Within each segment, we analyzed Jerry's instructional moves for evidence of epistemological resources underlying his instructional decisions. Drawing from Elby and Hammer (2010), we recognized two epistemological resources at play in Jerry's instructional moves: k*nowledge as propagated stuff* and *knowledge as constructed*. Drawing from Berland and colleagues (2016), we examined classroom videos and interviews for evidence of students' framing as "doing school" or "doing science," noting instances of interruptions of, or shifts in, how students framed their efforts during a lesson segment.

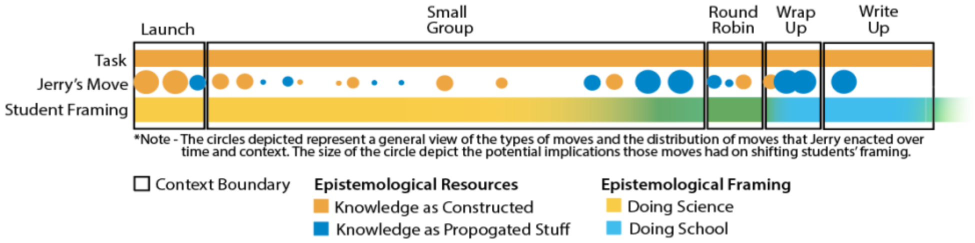
Results

Analysis of the three lessons revealed consistent patterns in Jerry's instructional moves, patterns which speak to the activation of different resources around knowledge and learning in different contexts. We came to understand that different phases of the lesson represented distinct contexts for Jerry, and influenced his activation of resources around knowledge, knowing, and learning, including those related to *knowledge as propagated stuff* and to *knowledge as constructed* (Elby & Hammer, 2010). Figure 1 depicts how the activation of these resources varied across phases of the lessons. Student interviews suggest that despite the varied framings across the lesson phases, some of the students recognized that their classroom experiences were distinct from those scientists engage in, and even given these complex dynamics, understood that scientists construct knowledge through such negotiations.

Our analysis sheds light on the dynamic nature of epistemology and framing in one teacher's efforts to engage his students as sensemakers in science. This analysis across three lessons identified variabilities in Jerry's moves across lesson phases. The launch of the task and much of Jerry's moves in small group work activated the resource of "knowledge as constructed", and many of his moves were consequential for students' framing of their efforts as "doing science" as they engaged in sensemaking about a phenomenon. The launches are particularly interesting as they highlight the role of the tasks in supporting Jerry's attempts to position his students as sensemakers. Their role in the launch and small group work was consequential for cuing "knowledge as constructed" as the prominent epistemological resource that Jerry tapped into. However, toward the end of the small group discussions, we begin to see that Jerry made very different sorts of moves that aligned with a view of "knowledge as propagated stuff". In the latter phases of the lesson, these moves were consequential for how students took up the framing of "doing school".

Figure 1

Graphic Representation of the Interplay Between the Epistemological Resources Underlying Jerry's Moves and the Task, and Students' Framing of their Efforts across the Lesson Phases, Generalized from Three Lessons.



*Note - The circles depicted represent a general view of the types of moves and the distribution of moves that Jerry enacted over time and context. The size of the circle depict the potential implications those moves had on shifting students' framing.

Conclusions

Our findings highlight the fine-grained epistemological elements that the teacher activated in different contexts and phases of the lessons examined and their consequences for students' framing of their efforts. This resource activation explanation for one teacher's moves helps account for the frequently documented shifts that occur when teachers navigate the unpredictable challenge of new practice. While this research examines the epistemological resources employed by just one teacher, this close speaks to the need to support teachers to explicitly make connections between resources, moves, and student framing. These findings are tentative and require further investigation. If the utility of the resource framework holds up, it suggests that PD should be structured to help teachers examine the consequences of their enactment of specific teacher moves throughout stages of a lesson to help them learn to activate more productive resources to engage students in sensemaking.

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Technology-Mediated Lesson Study: Facilitating Three-Dimensional Science With Rural Science Teachers

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Abstract: Rural science teachers have fewer collaborative and professional learning opportunities. To bridge the geographic isolation of these teachers, a professional learning model called Technology-Mediated Lesson Study (TMLS) has been developed. TMLS engages teachers with a team of colleagues in iterative, collaborative cycles of lesson design, teaching, observations via technology, and lesson redesign aimed at high-impact professional learning and enactment. This poster presents qualitative findings from the first year of the program.

Introduction

Science education in the United States is transforming toward a model that comprises three dimensions (3Ds): science and engineering practices, crosscutting concepts, and disciplinary core ideas (SEPs, CCCs, and DCIs; NGSS Lead States, 2013). Central to the new standards is the principle that students must make sense of science in a way that combines the three dimensions for richer, more authentic learning experiences. In one western state, urban school districts have implemented these standards for several years, including training teachers in 3D science teaching; however, most rural teachers in the state have received very little training on the new standards.

Isolation is a significant problem for many rural teachers in that they are often the only teacher of a particular subject or the only science teacher in a school. As a result, they have fewer or no opportunities for meaningful collaboration, even though collaboration is a crucial characteristic of effective professional learning (Svendsen, 2020). When professional learning is up-to-date, ongoing, collaborative, practice-based, and connected to local contexts, it is more effective at changing teaching practices (Desimone, 2009; Kennedy, 2016). Lesson study is an established professional learning model that has shown success in meeting teachers' professional learning needs by improving collaboration, helping teachers examine their practice, and enhancing student learning (Kanellopoulou & Darra, 2019). Traditionally, lesson study is conducted in small groups that meet in person to create lessons, review each other's teaching, and revise lessons together; however, the very fact of rural teachers' isolation makes such in-person collaboration impossible.

Technology-Mediated Lesson Study (TMLS) was developed to utilize technology to connect otherwise remote teachers in a novel professional learning model that engages teachers in iterative, collaborative cycles of lesson design, teaching, observation, and lesson redesign with a team of colleagues, resulting in high-impact professional learning and enactment. Through this process, teachers meet and collaborate through technology-mediated methods; they work together to improve their 3D science teaching skills and develop high-quality 3D science lessons aligned with state standards. These lessons are now ready to be shared with other teachers in the state and across the country.

Primary goals and conceptual framework of TMLS

This research has three goals: first, *principles*: an innovative model for rural teacher professional development via technology-mediated lesson study that supports translating professional learning into classroom practice through social support systems; second, *people*: building expertise, capacity, and collaboration among teachers to support 3D science teaching; and, third, *products*: creating and disseminating high-quality 3D science lesson plans aligned with state standards and the Next-Generation Science Standards to be shared with teachers across the country.

The research design is built on an ecological model described by Sallis et al. (2008) and is applied to changing teaching practices to incorporate three-dimensional science teaching. The program targets, first, personal factors (e.g., attitudes, self-efficacy) by supporting rural science teachers' development of knowledge, self-efficacy, and positive attitudes about 3D science teaching; second, social factors (e.g., peer, administrator, and student expectations) via cohorts of subject-region teams to provide a sense of community and support for the instructional changes needed for the new state standards; and, finally, contextual factors (e.g., physical, material, and time resources) to support and evaluated these lessons in a variety of settings and teaching conditions.

Research method

Twelve rural science teachers were given in-person professional developmental instruction in the principles of 3D science and the lesson study process. Groups of four teachers were formed and each developed high school biology lessons aligned with state standards incorporating 3D science elements. One teacher in each group recorded themselves teaching the lesson to their students by using a Swivl robot. Other group members reviewed and commented on each lesson and then met virtually via video conferencing to discuss the lesson they watched and revise the lesson plan. This process was then repeated for each subsequent teacher, taking turns teaching the revised lesson and coming together as a group to review and revise the lesson. Qualitative discourse analysis was conducted on TMLS meeting observations and personal interviews.

Results

Qualitative analysis of personal interviews and observation of lesson review meetings indicates that new collaborations resulting from involvement in the TMLS process positively affect making new professional collaborations and connections. This improved collaboration was also seen by observing group meetings to review lesson plans. Group conversations showed a willingness and openness to work together and enthusiasm that they are “able to focus just on the content of the lesson rather than on other school issues” (e.g., discipline problems). Through interviews, teachers indicated that the TMLS process changed their thinking regarding 3D science. One participant said, “Anytime you can build a lesson plan and then implement that lesson plan, I think that's going to encourage growth. Watching all of the other teachers on Swivl and…going through that process helped a lot in just in my own instruction.” These results show that creating, discussing, and revising a lesson plan that uses 3D science principles with a group of other science teachers can help improve how each teacher views their ability to teach with these principles in their classes, and those involved in the TMLS process are incorporating 3D science principles in their teaching beyond the lessons they created as a group.

Conclusion

Technology-mediated lesson study assists rural science teachers in developing new connections with other teachers they otherwise would not have any contact with, and preliminary data from interviews and observations of group discussions indicate that the teachers value these connections as well as the TMLS process. These otherwise isolated teachers are finding new collaborations with colleagues from around the state. Some participants indicated wanting to incorporate the TMLS process with others in their schools, suggesting they see the value of co-creating lessons. Data also suggests that the TMLS process—including watching others teach—is helping teachers learn 3D science better and improve how it is incorporated into their classes. Participants specified that this process has allowed them to thoroughly think about all aspects of 3D science for the first time and helped them improve incorporating these principles when developing new lessons. Future studies will further explore how the TMLS process helps connect rural science teachers on an ongoing basis and how teachers can integrate 3D principles to change how they teach science.

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Exploring 6th to 8th Graders' Math Play Processes and Strategies

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Abstract: Students' math problem-solving processes and strategies during math gameplay are poorly understood given its complexity. This ethnographic study examined gameplay sessions with 150 students over nine months in three design-based implementations. Findings revealed three preliminary patterns: 1) students' explanatory math play developed overtime; 2) students' cognizance to make sense of math in real-world context; and 3) students managing struggles to be productive.

Introduction and background

Math problem solving is complicated. Prior research has demonstrated that digital game-based learning (DGBL) environments can be effective platforms for doing math (Tokac et al., 2019). In DGBL, when working on in-game tasks, learners are naturally engaged in exploratory- and discovery-oriented problem solving. Game mechanics, game rules, and game tasks can facilitate learners to generate, test, and experiment hypotheses during the math problem solving processes (Ke et al., 2019). These processes are complicated and can be arduous and frustrating. *Math play* is a core to learners' engagement in game-based math problem solving; in which learners immersing in iterative rounds of math hypothesis testing and exploration, encompassed by failure or struggle (Williams-Pierce & Thevenow-Harrison, 2021). During *math play*, learners gradually develop problem-solving skills and epistemological sense toward math—by reorganizing and building up experience and by integrating new information into knowing (Kolodner, 1983). Notably, productive struggle is an important component in *math play*. Warshauer (2015) illustrated four types of struggles in middle school math classrooms: 1) get started, 2) carry out a process, 3) uncertainty in explaining and sense-making, 4) express misconception and errors.

Although research in the learning sciences has shed light on the processes of student learning in math (Warshauer, 2015), the processes and strategies that students use while playing math learning games are still vague. This murky area can hinder our understanding and theory development that fully benefit learners when they are engaging in DGBL. The purpose of this study is thus to identify the processes and strategies that middle school students' use during game-based math problem solving. Our focal research question is *what is math play and its associated strategies as perceived and enacted by middle school students in an architectural math game?*

Method

We used an ethnographic method to examine the phenomenon embedded in 6th through 8th graders' math gameplay sessions. The students played *E-Rebuild*, a math DGBL designed based on common core state standards for middle school students, and the math concepts in the game were chosen accordingly (Ke et al., 2019). The study is ongoing, we collected data from two schools with seven teachers and their 150 students through nine months long-term ethnographic participation in three design-based implementations. This study used data collected with participatory observations, interviewing, in-field notes, game artifacts, and computer logged gameplay-learning analytics. Multiple data sources ensured trustworthiness through triangulation. Open coding and constant comparative techniques (Glaser & Strauss, 1967) were iteratively conducted to construct meaning of the processes and strategies used by the middle school students during game-based math problem solving.

Results

Students' explanatory math play developed overtime

In the math gameplay-learning trajectories, students often revisit levels that they have successfully completed. Sometimes, students also tried to help other students when other students are dealing with the game math tasks that they have completed before. This iterative process has led to reorganizing and rediscovering for math conceptual development and shaping in students' memory. Students were unsure about the underlying concept related to their solution. But as they iteratively experimented with the same type of problems by trying different acts or solutions, they started to develop conscious perspectives and were able to explicate with math thinking.

For example, in one class, Ryan (pseudonym, 6th grade) was trying to solve a math task focusing on geometry and angle (folding a square-shaped paper to a target 3D shape). He approached the task without math understanding: "*Is that (angle) 45°? Cause it's half of 90...or 40?*" After three failed attempts, he used an in-game learning support and figured out the solution, but he was still pondering about the accuracy of the solution: "*I don't think it will work*." He tried the solution anyway, completed the level, and even earned all the badges. Facilitator ("F" hereinafter): "*Do you know why it is 90°?* Ryan: "*I don't know (smiling).*" After two weeks (five gameplay sessions), he helped a peer with the same level, he put "180°." This time, he failed to help his peer to solve the level. After another three gameplay sessions, Facilitator asked: "*have you learned anything?*" Ryan voluntarily mentioned this level, and was able to explain the embedded math concept by transitioning between gestures and the game interface: "*I learned the angles. It's 90° (using his hand to gesture the folding of a 90° angle).*" Computer-logged task performance data suggested that Ryan has retried and failed at least three more times with this exact level in-between different gaming sessions, until completing the final successful attempt. In this example, Ryan's math play evolved as he experienced gameplay purposefully and mathematically.

Students' cognizance to make sense of math in real-world context

Observations, interviews, and logged data of a student, who has been slacking in in-game task performance and kept gaming the system, revealed that students' meaningful math play occurred when they were cognizant of the math concepts and when they integrated real-world contextual sense-making into gameplay:

1 F: What do you like?
2 Beau (6th grade): Basketball.
3 F: Do you see any math in basketball?
4 Beau: Yes. *The arch.*
5 Other students: That's science.
6 Beau: *That's math*, you need to know *the arch*, get the ball in there.
7 F: Oh nice, did you see any connections between that and this game?
8 Beau: Oh, the basketball level, I painted the basketball court already.
9 F: Is that your favorite level?
10 Beau: Yes.

Students managing struggles to be productive

As observed, students experienced iterative struggles along the math play trajectory, they managed the struggle with diverse strategies. For example, some students were observed to manage in-game struggles *with more careful problem analysis or information processing*; for instance: "Tyson (7th grade) completed a hard level with all the badges. He cheered and thrown his hands in the air in excitement." F: "how did you feel about it?" Tyson: "it was kinda *stressful*." F: "what guided you to the completion of the level?" Tyson: "well, I was trying, and *it was always wrong*, because *I didn't notice* that 85% (discount in purchasing the materials)… I think I just kinda did it."

Discussion and conclusion

In this study, we elucidated the processes of and strategies used by middle school students during math play. The three highlighted preliminary patterns in this study demonstrate the scholarship of math play, reorganization and rediscovery for math conceptual understanding during math play, and strategic, productive struggle management in DGBL (Kolodner, 1983; Warshauer, 2015; Williams-Pierce & Thevenow-Harrison, 2021). We maintain that these patterns are important insights for designing meaningful and constructive game-based math problem-solving experience, or math play, for middle school students.

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Teaching Leadership Through Object-Based Learning

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Abstract: In this poster we are reporting the first iteration of a Design-Based Research project exploring how Object-Based Learning assists business students in developing a deeper understanding of the dynamics of leadership. Some students visited the on-campus Chau Chak Wing Museum while others engaged online with a selection of artefacts, artworks and specimens that represented different types of leadership characteristics in different cultural contexts over time. Students worked in small groups with a carefully curated group of objects to reflect on and explore what it means to be a leader for good. We conclude with an analysis of students' reflections following the workshops and invite feedback for further iterations.

Introduction and context

In a world of increasing complexity and rapid change, being a leader for good has been identified as a critical skill for graduates at the University of Sydney Business School. Conventional approaches to teaching leadership in business schools have often stressed the role of the charismatic individual, often a white man, as a transformational leader providing a compelling vision for the future that others follow (Collinson & Tourish, 2015). To support diverse expressions of leadership, we designed a new course on leadership and action research. In this course, students work on real world problems and develop solutions that are data informed, and a final individual leadership portfolio that outlines their leadership understanding, capacity, skills and approach. However, students often struggle to identify and articulate their unique and individual understanding of leadership that consider their diverse cultural and personal experiences. To help students explore leadership beyond popular tropes and challenge the normative and gendered discourse on leadership, we designed a series of Object-Based Learning (OBL) workshops. OBL is the active integration of curated objects into the learning environment to facilitate the acquisition of cross-disciplinary knowledge (Chatterjee & Hannan, 2015). The diversity of collections at the Chau Chak Wing Museum, along with the dedicated Academic Engagement Curators served to amplify this message. In the workshops, students were encouraged to examine the complexity of leadership dynamics and to question the assumption that power should be vested in the hands of few. It is not common for business courses to incorporate OBL in lessons and there is no direct link between objects and leadership in general. However, museum objects can stimulate discussion and debate and as such are excellent focal points for enhancing student engagement with the concept of leadership.

Research design and methods

In this study we are employing Design-Based Research (DBR) to explore how OBL can be implemented in Business education. DBR is an interdisciplinary mixed-method approach that studies learning activities in a naturalistic setting and facilitates data collection through a variety of methods (Barab, 2006). In our study, we are collecting data through observation of the OBL workshops, students' post-workshop reflections, and analyzing student leadership portfolios. DBR facilitates the cyclical enhancement of the learning tasks, materials, tools, and patterns of communication (Reimann, 2011). We are reporting the first iteration of OBL implementation, with the aim of applying further enhancements in future semesters. In total, 45 students were enrolled in this course during the semester with 27 students attending in-person classes and 18 attending online classes through Zoom. Following the OBL workshops, we collected student reflections using Padlets.

OBL workshops: Structure and content

We designed two OBL workshops to explore the concept of leadership. Each workshop was designed and delivered by the museum Academic Engagement Curators in two modes: in-person in the museum's learning spaces and online through Zoom. A variety of objects were selected for the workshops, including the Tin Sheds Poster Collection (Figure 1a) and other objects that represented a range of cultures, knowledge systems and social hierarchies, ranging from First Nations traditions and activists to ancient Roman Emperors and animal specimens. For example, students were challenged to connect a magpie specimen to concepts of leadership (Figure 1b). Students discussed and reflected on characteristics and qualities of a leader after being introduced to a recent

Conversation report that a group of Australian magpies, fitted with tracking devices by scientists hoping to collect behavioral data, surprised the researchers by working collaboratively to remove the devices from one another.

The activities were designed to take the students through the stages of familiarization, deep observation, critical analysis, application, and synthesis, which roughly mapped to five levels of Bloom's Taxonomy. In the familiarization stage, the students engaged in quick observation of the selected objects. Next, the students conducted deep observation of one object as a group and each student shared one unique observation, covering the visual elements. The purpose of deep observation is to build a robust and multi-perspective foundation of information on which to base the next phases. The critical analysis phase focused on purpose, motive, audience, message, and an evaluation of the effectiveness of each. Finally, the students applied their learnings by creating their own poster to communicate the main message of their own research projects (Figure 1c). In the final discussion, students connected the objects to the concept of leadership and examined how each contributed a different perspective on what makes a leader.

Figure 1

A selection of posters used in the workshop (a), Magpie specimen (b), Students creating their own posters (c)

(a) (b) (c)

Student reflections and future directions

In total 27 students responded to the reflection questions on the Padlets. We used thematic analysis (Fereday & Muir-Cochrane, 2006) to identify broad themes on 1) OBL deepening understanding of leadership, 2) facilitating communication, and 3) questioning prior assumptions on leadership. While a detailed discussion of the results is out of the scope of this poster, they indicated a strong support for the three aspects queried. Students commented on how the activities helped them draw “deeper meaning” and see leadership “in a new way”. One student added that the workshops “Deepened my understanding of creative visual cues in influencing others and conveying a message, qualities which are important to becoming an effective leader”. Students stated that the objects acted as “a stimulus which helped direct discussions” and make an abstract concept such as “leadership more concrete”. The workshops helped students question their prior assumption about leadership with one student stating “my understanding of leadership expanded to include the importance of symbolism” and another student added “the new perspectives provided alternative for views of leadership (ie. Spiritual) which I had not considered before”. While still in its early stages, the outcome of this project indicates that students were able to think critically and creatively about leadership, and most importantly, they were able to question their own assumption and formulate new and more inclusive conceptualizations of leadership characteristics (Chatterjee & Hannan, 2015). In further iterations of this project, we will incorporate more objects that represent wider perspectives from diverse cultures and throughout different points in time. In addition, we will analyze the student leadership portfolios for any evidence of the change in conceptualization about leadership for good.

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A Teaching Routine for Working With Existing Data in Science Classrooms

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Abstract: Working with existing data is central to science investigations, but students and educators have generally not had experience using existing data sets to answer their own questions. We introduce a teaching routine that makes explicit critical steps in the process of working with data to gain insight into real-world phenomena. We intend the routine to support both curriculum developers and teachers in designing and enacting lessons to support students in engaging productively with scientific data, focusing on steps that are not commonly encountered in science classes.

Working with existing data in science classrooms

Exploring real-world phenomena using existing scientific data is a powerful context for engaging students in meaningful disciplinary practices in science. (NASEM, 2019). Working with already-collected data adds complexity to the already complicated task of data analysis. While research has identified many of the supports students need for working with data (Manz et al, 2020; Rubin, 2020; Feldman et al, 2000), working with data that was collected by someone else in a different context adds considerable complexity. In this paper, we report on work in progress on a teaching routine for developers and teachers seeking to support students in working with existing data in classroom investigations in science. Teaching routines are “recurring patterned sequences of interaction that teachers and students jointly enact to organize opportunities for student learning.” (DeBarger et al., 2010, p. 225). Teaching routines can function as resources for curriculum writers as they construct sequences of lessons to engage students in science practices, as well as helping teachers adapt instruction to students’ emergent ideas.

Project context: EMBEDS

The Exploring the Mathematics of Biological Ecosystems with Data Science (EMBEDS) project investigates the potential of integrating “data excursions” for developing high school students’ competencies with data practices and data modeling into phenomenon-based instructional materials. These “data excursions” allow students to interact with datasets collected by scientists related to ecosystem dynamics to query their contexts, change the way they are aggregated and represented, and explore patterns they reveal.

An example of one such excursion we have developed takes place within a unit on ecosystems being developed for OpenSciEd, a free, phenomenon-based set of instructional materials aligned to the Next Generation Science Standards. The overarching unit question pertains to how the creation of the Serengeti National Park impacted local ecosystems. Early in the unit, students try to determine whether large increases in wildebeest and buffalo populations between 1960-75 could have been caused by an increase in available food. After learning that scientists had no data on food–but had to rely instead on rainfall as a proxy–students use CODAP (a free educational data analysis tool) to explore data on rainfall in different regions of the Serengeti during that time period.

As our project unfolded, we decided that it would be helpful to articulate a teaching routine to guide the design of our excursions and to help teachers support students’ work with existing scientific data. The routine makes explicit aspects of investigating scientific phenomena that students do not typically encounter, such as the idea that a given dataset may not be able to answer the question at hand because it was collected for a different purpose or that measurements may have been made differently by different scientists.

The data routine

Our project is studying how a data routine can support sensemaking about phenomena in science. Our high-level conjecture guiding this inquiry is that:

> *Lessons (excursions) organized around the elements of the data routine can support students’ ability to use existing multivariate datasets to help explain complex ecosystems phenomena.*

We further hypothesize that certain elements of the routine may be particularly consequential in their impact on students' facility with data, e.g. predicting what patterns in the data would imply particular answers, deeply investigating the way in which data were collected and how measures were defined, and working with a tool that facilitates the creation of multiple linked representations that support students' data fluency. We intend the Data Routine to be a resource that other design research projects might explore, particularly those connected to curriculum efforts in science, social science, and the emerging field of data science. An important set of questions pertains not only to its flexibility in other disciplinary contexts, but also what kinds of outcomes might be supported by its use, and what other embodiments might be necessary to achieve those outcomes.

Table 1
Elements in the Data Routine

Element	Student Actions
Framing Questions	● Students come to a consensus on question(s) to address related to the anchoring phenomenon and possible answers to their question(s). ● Students decide what kinds of data they need to answer their question(s). ● Students identify multiple plausible answers, and for each, students make predictions about what the pattern in the data would look like, if each answer were true.
Orienting to the Data	● Students orient to the data (what is each case? what are the variables?), discuss the source of the dataset, query who collected the data, by what methods and why, and evaluate its reliability, ● Students evaluate whether the dataset might help answer their questions, if it can answer a different related question instead, or is not relevant to their question.
Exploring the Data	● Students discuss ways to explore the data to help answer their questions. ● Students create initial representations and notice and record patterns they see. ● Students make initial claims based on patterns in the data, including how confident they are in the presence of variability.
Sensemaking about the Data	● Students present their claims and relevant representations to support them to others. ● The class engages in a discussion to decide what claims can be supported from the data and articulates limitations of the data. ● The class discusses whether they can reach consensus on an answer to the question(s) and identifies remaining and additional questions that arise from their analysis.

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The Cognitive and Behavioral Learning Impacts of Embedded Video Questions: Leveraging Learning Experience Design to Support Students' Knowledge Outcomes

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Abstract: This study is part of a series of in situ design-based research investigations within a large public university in California, assessing undergraduate science instruction while distance learning. It has become increasingly important to identify sustainable learning alternatives to support online teaching and learning while integrating educational technologies informed by evidence-based practices of pedagogical learning experience design (LXD). Consequently, this design-based research efficacy study aimed to test the effectiveness of embedded video questions in supporting or hindering students' learning experience. Results showed that learners who experienced the embedded-video questions had significantly higher quiz grades, page views, and course participation as well as increased levels of online engagement and self-regulation, while experiencing lower levels of mind-wandering and cognitive load. Implications on how institutions may iteratively design and effectively foster successful science online teaching and learning with the deployment of innovative "edtech" tools grounded in pedagogical learning experience design are discussed.

Introduction

Embedded video questions are a type of educational technology design feature that adds interactive quizzing capacities while students watch an asynchronous video. As a video plays, students watching the video are complemented with questions that aim to stimulate deeper or more active information processing (Christiansen et al., 2017; Kovacs, 2016; van der Meij et al., 2021). This is like an Audience Response System (ARS) during traditional in-person lectures where an instructor utilizes a live polling system in a lecture hall, such as iClickers, to present questions to the audience (Pan et al., 2019). However, in an online learning environment, students are assigned videos to watch on their own time and a series of questions appear on the screen that review concepts immediately, check for misconceptions, and foster a deeper conceptual understanding. Research on the use of embedded video questions has already shown promising empirical results in the field, such as stimulating students' retrieval and practice, facilitating recognition of key facts, and prompting behavioral changes to rewind, review, or repeat the materials that were taught (Cummins et al., 2015; Haagsman et al., 2020; Rice et al., 2019). Embedded video questions have also been shown to transition learners from passively watching a video to actively engaging with the video content (Dunlosky et al., 2013; Schmitz, 2020), a critical factor when considering the expediency from in-person to online instruction due to the pandemic. As a result, there is a myriad of affordances that showcase the positive effects of embedded video questions on students' learning experiences such as their engagement, mind-wandering, cognitive load, and self-regulation. As we introduce a new "edtech" design of embedded video questions to an undergraduate-level biology course, we evaluate the efficacy of our designs by examining the impacts of students' engagement, mind-wandering, cognitive load, and self-regulation as a result of our LXD. This design-based research (DBR) in situ approach applies theories of learning to evaluate the efficacy of design and instructional tools with learners "in the wild" (DBR Collective, 2003; Siek et al., 2014) to test the effectiveness of embedded video questions in supporting or hindering students' learning experience. The following research questions guide this study: RQ1) What is the effect of the treatment condition on learners' quiz grades, page views, and participation rate? RQ2) What is the effect of the treatment condition on learners' engagement, mind-wandering, cognitive load, and self-regulation? RQ3) To what extent is the effect of the treatment condition related to learners' quiz grades, and is this relation moderated by learners' self-regulation, cognitive load and mind-wandering?

Methodology

In this study, 183 undergraduate students majoring in Ecology and Evolutionary Biology at a Southern California School of Biological Sciences participated. The student demographics included 1.2% African American, 72.0% Asian/Pacific Islander, 10.1% Hispanic, 11.3% white, and 5.4% multiracial, with 69.0%

females and 31.0% males. Students self-enrolled randomly into one of two course sections with different quiz implementation methods: 1) end-of-video questions (N = 92) and 2) embedded video questions (N = 91). Survey data were collected before (Time T1) and after (Time T2) a 10-week intervention period. The study used a quasi-experimental design, where the quiz delivery method varied. In the first condition, students received quiz questions after watching assigned video scaffolds. In the second condition, questions were embedded within the video player, time-stamped to match the content. Both conditions had the same instructor, content, and conceptual questions, with the only difference being the timing and placement of the quiz questions.

Findings

A MANOVA found significant differences between learners with and without video-embedded questions in quiz grades, pageviews, and participation ($F(3, 150) = 188.8$, $p < 0.000$). Univariate tests revealed significant differences in quiz grades ($F(1, 152) = 6.91$, $p < 0.05$, $\eta 2 = 0.043$), pageviews ($F(1, 152) = 26.02$, $p < 0.001$, $\eta 2 = 0.146$), and participation rates ($F(1, 152) = 569.6$, $p < 0.001$, $\eta 2 = 0.789$). Bonferroni comparisons confirmed these differences, showing that learners with video-embedded questions had significantly higher quiz grades, pageviews, and participation. A second MANOVA compared learners with and without video-embedded questions on four variables: engagement, mind-wandering, cognitive load, and self-regulation. It revealed significant differences ($F(4, 177) = 5.09$, $p < 0.001$), indicating that students with embedded video questions had higher engagement and self-regulation while experiencing lower mind-wandering and cognitive load. A multiple regression model found that learners' treatment condition significantly predicted quiz grades ($\beta = 1.15$, $SE = 4.72$). Additionally, cognitive load ($\beta = -0.340$, $SE = 0.096$) and self-regulation ($\beta = 0.448$, $SE = 0.063$) had significant main effects, while mind-wandering ($\beta = -0.121$, $SE = 0.185$) did not. Interaction effects between treatment conditions and self-regulation ($\beta = 0.747$, $SE = 0.099$) and cognitive load ($\beta = 0.564$, $SE = 0.150$) were also significant. Together, these variables explained approximately 27.1% of the variance in quiz grades ($R2 = 0.271$, $F(3,155) = 5.62$, $p < .001$).

Results showed that learners who experienced the embedded video questions had significantly higher quiz grades, page views, and course participation. Findings further indicated that these learners also experienced significantly higher levels of self-reported online engagement and self-regulation, while reporting lower levels of mind-wandering and cognitive load. These results are in line with the literature on the affordances of embedded video questions for fostering conceptual knowledge, increasing attentional awareness, and providing interactive learning opportunities that boost the retention of course content (Cummins et al. 2015; van der Meij et al., 2021). Additionally, it suggests that learners' improved quiz performance may be linked to their self-regulation and cognitive load. These questions engage students actively, promoting information retrieval and reflection, possibly contributing to a testing effect facilitated by our embedded video question design. The embedded video question platform offers a medium to facilitate cognitive processing such that learners are recognizing and aligning what they know and identifying what they do not know.

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Self-Regulated Learning in Online Continuing Education: Managing Learning Time is a Key Challenge

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Abstract: The self-paced format of online courses requires learners to act highly self-regulated while managing their learning time. In contrast to the ample research on self-regulated learning (SRL) in online higher education, research on adult online SRL is scarce. In this paper, we present results concerning adult online learners' time management, a specific aspect of SRL. A re-analysis of survey data of 60 adult learners indicates that time management is a particular challenge in this context.

Introduction

Compared to traditional in-person learning environments, online courses offer a high level of independence in terms of when, what, and how to learn. This makes them particularly appealing to adult learners who often attend continuing education and training (CET) courses besides their regular working hours. However, this high level of independence can also entail particular challenges, as learners must be highly self-regulated and take responsibility for managing their own learning process (Kizilcec et al., 2017). Especially time management can be a critical self-regulated learning (SRL) issue in the context of work-related CET online courses, because adult learners often have to balance work, family commitments, and learning.

So far, research on adult learners' SRL, specifically in the context of work-related CET online courses, is scarce (Jossberger et al., 2020; Schulz & Roßnagel, 2010, Fontana et al., 2015). A notable exception is the SRL framework for work-related training developed by Sitzman and Ely (2011), which incorporates strategies from Zimmerman's SRL model (Zimmerman, 1989) and provides first insights into relevant SRL strategies for adult learning. To address this lack of research that captures the attributes of how adult learners self-regulate during online learning, we conducted a secondary analysis concerning SRL strategies by re-analyzing an existing dataset consisting of survey responses of adult learners who participated in a CET online course. In this paper, we focus on *time management* as one particularly important aspect of SRL in the context of CET online courses. We investigated how adult learners managed their learning time (RQ1) and further analyzed how time management was related to learning outcomes (i.e., quiz results) (RQ2). With our analyses, we aim to provide initial insights into how adult learners manage their learning time in CET online courses and, thus, to contribute to extending SRL models accordingly.

Methods and analysis

For the analyses we present in this paper, we re-analyzed a dataset that comprised survey data of $N = 60$ adult learners who participated in four iterations of the same CET online course. The analysis presented in this paper is part of a larger study with the aim to (a) extend current SRL models and (b) investigate support that addresses particular SRL challenges in the context of CET online courses. The original surveys encompassed various measures. To answer our first research question, we identified measures within the surveys that corresponded to the definition of the SRL strategy of time management outlined by Sitzman and Ely (2011). According to their definition, self-regulated learners manage their learning time by setting a schedule for when they learn, taking time to learn, and monitoring their own learning time, for example, when it comes to meeting appointments. To investigate these aspects of SRL in the CET course, we computed descriptive analyses on adult learners' amount of *learning time* spent on each module of the course in comparison to the estimated learning time provided by the course organizers. Furthermore, we quantitatively investigated measures inquiring *when learning activities mainly took place*. Given that the CET course was to be completed during working hours, a significant part of learning should ideally occur during this time.

To investigate our second research question, we evaluated how the SRL strategy of time management is related to *learning outcomes*. For learning outcome measures, we analyzed quiz scores participants achieved in six quizzes that were part of the CET online course. As it was possible to achieve different highest scores in each quiz, we standardized all quiz results to z-scores. We then computed Spearman correlation coefficients between the quiz results' scores and the scores for time management, since the variable *quiz results* was not normally distributed.

Results and discussion

Concerning our first research question (RQ1), the comparison of adult learners' amount of learning time per module and the estimated learning time provided by the course organizers indicated that adult learners managed their learning time sufficiently as they did not exceed the estimated learning time. Course organizers estimated that learning one module would take an average of 178 minutes. Participants spent M = 164.96 minutes per module. However, results also show that even though the course was supposed to be a completed during working hours, participants mainly learned in the evenings (59 %) and generally in their free time (98 %). This indicates difficulties with integrating learning time into working hours.

Regarding our second research question (RQ2), the analysis of learning outcomes revealed that learning best takes place in the evening in the context of adult online learning. We found that learning in the evening (p = .047, ρ = 0,323*) is significantly associated with learning outcomes. Additionally, we found a negative, but not statistically significant correlation between learning during working hours and learning outcomes. Even though this finding should be viewed with caution, it could indicate that learning during working hours may not be as effective compared to learning in the evening.

According to our findings and in line with previous theoretical considerations, adult learners from this online CET course faced difficulties with time management, more specifically, with incorporating time for learning into their work schedule, which is usually intended by employers that offer work-related CET online courses. Yet, our analysis revealed that learning in the evening separated from the work context was positively and significantly related to learning outcomes and hence fosters learning. This result contradicts previous assumptions and thus could be an initial indication that future research needs to rethink time management strategies in the context of adult online education.

In conclusion, the analyses presented in this paper provided initial insights into adult learners' time management as an important aspect of SRL in the context of work-related CET online courses. However, it should be noted that our findings may be somewhat limited by re-analyzing an existing dataset with regard to our research questions. In the future, it would be desirable to conduct further studies designed specifically to assess the SRL strategy time management in order to replicate our initial findings.

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Examining the Effect of Automated Assessments and Feedback on Students' Written Science Explanations

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Abstract: Writing scientific explanations is a core practice in science. However, students find it difficult to write coherent scientific explanations. Additionally, teachers find it challenging to provide real-time feedback on students' essays. In this study, we discuss how PyrEval, an NLP technology, was used to automatically assess students' essays and provide feedback. We found that students explained more key ideas in their essays after the automated assessment and feedback. However, there were issues with the automated assessments as well as students' understanding of the feedback and revising their essays.

Introduction

Engaging students in authentic science practices is central to learning and understanding science (NGSS, 2013; Braaten & Windschitl, 2011). At the core of such practices is writing scientific explanations, which researchers say should: (1) use data and/or evidence to make claims, and (2) connect scientific principles to evidence to explain the observed phenomenon (Berland & Hammer, 2012; Berland et al., 2016; Krajcik et al., 2014). Natural Language Processing (NLP) technologies can support students in writing science explanations by providing automated feedback (Gerard & Linn, 2016). This study investigated the role of an NLP technology, PyrEval, (Gao et al., 2018; Passonneau et al., 2018), to assess students' written science explanations. The research questions guiding our study were:

1. How does automated feedback help students explain key ideas in their science essays?
2. What are the opportunities and limitations of using automated feedback in classrooms?

Methods

Participants and context

A total of 264 students from three 8th-grade public middle school classrooms in the Midwestern US participated in this study. Students learned the science of roller coasters by conducting experiments in a simulation and writing essays to develop a roller coaster design based on the science they were learning. Students wrote a design essay (E1) after conducting their first set of experiments, which was sent to PyrEval for feedback. Next, students conducted additional experiments and wrote a second design essay (E2) that built on ideas and feedback in E1. They received feedback from PyrEval on their E2, based on which, they were given the opportunity to make revisions and resubmit their final design essays. We called this essay 2 revised (E2R).

PyrEval uses a wise-crowd model, where samples used to match key ideas, referred to as content units (CUs), are taken from a range of student essays. It automatically parses students' essays into propositions and creates a model of important propositions derived from a small set of reference responses. It then creates a vector representation for propositions and compares them to recognize paraphrases of similar content. In our study, 15 CUs were identified as the most important ideas for students to learn during the unit, which PyrEval applied to automatically assess students' essays.

Results and discussion

We used the number of CUs identified by PyrEval in student's essays as the measure for our analysis. We conducted a repeated measures analysis to examine changes in students' essays from E1, to E2, to E2R after receiving feedback for students who completed all three essays (*N=228*). We summed the 15 CUs into a CU total score for each student's essays and used these as dependent outcomes. Our analysis showed that students included significantly more CUs in E2R (*M=5.05, SD=3.02*) than E2 (*M=4.77, SD=2.93*), and significantly more CUs in E2 than in E1 (*M=3.68, SD=2.40*) ($F_{1,228}=82.1889$; $p<.001$; $\eta p^2=.267$). We also ran Wilcoxon signed-rank tests to understand the changes in students' essays for each CU from Essay 1 to Essay 2 Revised. We found significant differences between E1 and E2R for 6 of the CUs; this means more students included these CUs in E2R, compared to their E1. Conversely, there were no significant differences for the remaining CUs.

Our analysis showed that students included significantly more CUs from both E1 to E2 and E2 to E2R. This indicates that students included more ideas in their essays after receiving feedback, a finding also observed in other studies (Gerard et al., 2019; Tansomboon et al., 2017; Zhu et al., 2020). Our study provides evidence that PyrEval was able to expedite the 'scoring' of students' essays, which otherwise would have taken a long time to do manually for teachers, as has been observed in other studies evaluating NLP technologies to automatically assess students' science writing. However, there were some challenges: *First*, there were some challenges with PyrEval correctly identifying CUs. PyrEval looks for ideas, or CUs, in individual sentences. When students' ideas were scattered across multiple sentences or even paragraphs, the technology may not have been able to recognize the CUs. Students often write long sentences to explain and repeat ideas over several sentences, which often lack precision. They also sometimes forget to include punctuation. We found that PyrEval had difficulty recognizing ideas in sentences longer than 25 words. *Second*, we found that it is challenging to translate automatic assessments into comprehensible feedback for students.

Clearly, writing and revising explanations is not an easy task for middle school students. Using the findings from this study, we plan to make changes to our approach to ensure that we provide adequate scaffolding to students. We plan to improve PyrEval's ability to recognize CUs in students' writing by refining the NLP model, based on this year's classroom dataset. Additionally, our plan is to provide teachers with more information about students' progress through a teacher dashboard by summarizing trends about students' progress at multiple points in the unit, prior to and after essay writing. This high-level overview will allow teachers to see trends across their classes, enabling them to dynamically make titrated instructional decisions to ensure students get the support they need when they need it.

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Exploring AnnotateEdTech as an Online Collective Third Space for Developing Teachers' Learning and Humanizing Practices With Technology

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Abstract: Online collective Third Spaces can support educators' learning about surveillance-based educational technologies while simultaneously helping educators to develop humanizing practices with technology. In this paper, I discuss AnnotateEdTech, an online collective Third Space that brings together educators to use social annotation to critique educational technology companies' claims about their products. I share one case of an AnnotateEdTech gathering and discuss how participants' annotations are evidence of their learning and humanizing practices with technology.

Introduction

Students and educators in the United States are increasingly forced to learn and teach beneath the harmful gaze of surveillance technology. Hoadley and Uttamchandani (2021) offer several recommendations for addressing surveillance-based educational technology. The authors advocate for a humanizing approach to technology that considers how technology can "support learning and thriving by disrupting inequity through supporting identity development, self-expression, authorship, collaboration, and activism" (Hoadley & Uttamchandani, 2021, p. 15). The authors also argue for more opportunities for teachers to learn about these technologies.

AnnotateEdTech is a promising design innovation to support teacher learning that aligns with Hoadley and Uttamchandani's (2021) suggestions for humanizing approaches to technology; it can also be understood as a collective Third Space (Gutiérrez, 2008). AnnotateEdTech is an online professional development experience that brings together participants to use the social annotation tool Hypothesis to analyze, question, and critique the claims educational technology companies make about their products on their websites. In this short paper, I will offer a brief description of AnnotateEdTech and how it might help educators document and disrupt the creep of surveillance-based educational technologies.

Collective Third Spaces and transformative teacher learning

Gutiérrez (2008) describes a collective Third Space as a learning environment that challenges participants to reflect on who they are and imagine what they might accomplish individually and together. The learning that occurs "becomes situated, reciprocal, and distributed, leading to new forms of learning" (Gutiérrez, 2008, p. 159). While Gutiérrez (2008) discusses how a collective Third Space nurtures learning for youth from nondominant groups, other educators have used the design to support teacher learning. For example, the Marginal Syllabus is an online professional development project for K-12 teachers, university students, and university researchers that uses the social annotation tool Hypothesis to facilitate discussions about educational equity scholarship (Kalir & Garcia, 2019). The success of the Marginal Syllabus points to a need for more examples of online collective Third Spaces that realize the possibility of social annotation for educator learning.

AnnotateEdTech as a collective Third Space for teacher learning

AnnotateEdTech is founded on the belief "that annotation expresses power in ways that are productive, networked, and situated in social contexts" (Kalir & Garcia, 2021, p. 132), qualities that mirror a collective Third Space's situated, reciprocal, and distributed learning.

I first decided to create AnnotateEdTech as a way for educators to critique the narratives produced by online proctoring companies. According to companies like Proctorio and ProctorU, their software can help identify students who are cheating on an exam. Critics have labeled it a dehumanizing technology (Hoadley and Uttamchandani, 2021). To better comprehend how a group of educators worked together to understand and counter online proctoring's harms, I explored the following research question: What elements of humanizing approaches to technology did educators practice through their social annotation of online proctoring websites?

Research context and methods

Context

I worked with members of Ethical EdTech to facilitate the first AnnotateEdTech. My co-facilitators and I promoted the first AnnotateEdTech through Ethical EdTech's listserv and Twitter. On November 16, 2020, 16 higher education faculty and staff joined an hour-long Zoom call and annotated 12 websites belonging to three online proctoring companies. Participants created 96 annotations using the social annotation tool Hypothesis.

Methods

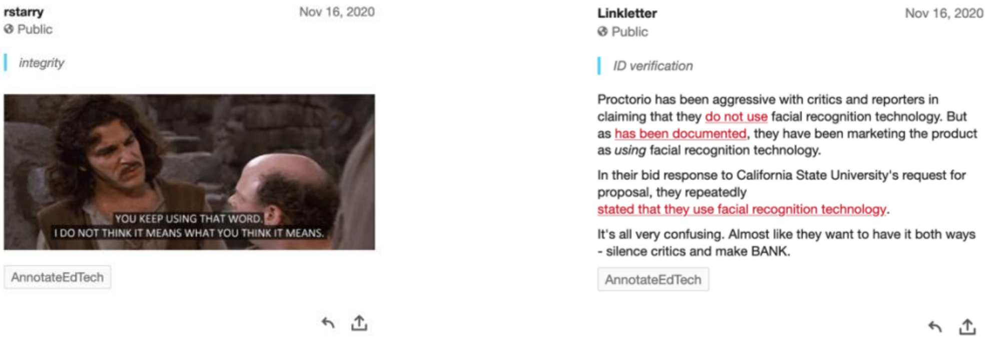
I began by developing more specific definitions of identity development, self-expression, authorship, collaboration, and activism, grounding my definitions in relevant literature when necessary. For example, I turned to Engle & Conant (2002) for help conceiving of *authorship* as producing knowledge through asserting agency to define, address, and resolve problems. Next, I conducted deductive coding (Miles et al., 2020) using my more refined definitions of humanizing approaches to technology.

Findings

The annotator with the username rstarry critiques Proctorio's claim that their technology promises "total learning integrity" (Figure 1). The annotation, playful and stinging, is a GIF from the film *The Princess Bride*. The annotator's memorable self-expression communicates the doubt and exasperation they experience as they learn more about the discourse tactics used by online proctoring companies to frame and sell their products.

Figure 1

(a) An annotator's self-expression and (b) An annotator's authorship



rstarry Nov 16, 2020
Public

integrity

AnnotateEdTech

Linkletter Nov 16, 2020
Public

ID verification

Proctorio has been aggressive with critics and reporters in claiming that they do not use facial recognition technology. But as has been documented, they have been marketing the product as *using* facial recognition technology.

In their bid response to California State University's request for proposal, they repeatedly stated that they use facial recognition technology.

It's all very confusing. Almost like they want to have it both ways - silence critics and make BANK.

AnnotateEdTech

(a) (b)

In Figure 2, the participant Linkletter authors an annotation to illustrate Proctorio's hypocrisy regarding its claim that their proctoring software does not use facial recognition technology. Linkletter refutes the claim by sharing evidence to the contrary: the second and third hyperlinks connect to tweets and a request for proposal, respectively, that show Proctorio refers to its use of facial recognition technology. Linkletter uses the networked nature of social annotation for distributive learning, a key characteristic of collective Third Spaces.

Discussion and conclusion

The harmful effects of surveillance-based educational technology require immediate action. Taking inspiration from the possibilities of a collective Third Space, I have argued for designing online collective Third Spaces to support teachers' learning and foster their humanizing practices with technology through social annotation. My initial findings show how fellow teachers work together to understand and resist the narratives sold by online proctoring companies. Online collective Third Spaces can be a nourishing context for teachers to enact and hone humanizing learning practices with technology.

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Learners' Emotion Responses: Interactive and Constructive Learning

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Abstract: We aim to use computing technologies to develop a better understanding of the level of stress/anxiety students experience during different modes of tasks in a STEM-focused interdisciplinary university class setting. Various types of classroom tasks are used to identify students' emotional responses as a means to ultimately shape classroom experiences and improve learning. The results of this projects will provide guidance for developing instructional materials to enhance students' learning.

Introduction

In order for college students to gain robust critical and creative thinking skills to solve complex problems, it is important to provide a motivating environment where students can enjoy learning and desire to develop these skills appropriately. Instructors put in a multilateral effort to design instructional materials with diverse strategies. Research shows that students are more actively engaged and interested in a subject when presented with interactive and constructive classroom activities (Chi & Wylie, 2014; Hake, 1998). As instructional materials are implemented, however, students may experience positive or negative emotional changes during activities. Anxiety and stress levels in class may negatively affect students' learning, resulting in decreased academic performance. We aim to use computing technologies to develop a better understanding of the level of stress/anxiety students experience during different types of tasks in a STEM-focused interdisciplinary university class setting. We consider various types of classroom tasks within passives, active, interactive, and collaborative modes and identify students' emotional responses as a means to ultimately shape classroom experiences and improve learning.

Interactive and constructive course design

The course is intended for first year students who are not majoring in Computer Science or Engineering. The course is designed to provide students with ample hands-on activities, discussion, demonstrations, and projects to enhance students' learning performance by practicing active learning strategies. The goal of the course is to enhance students' computing capabilities, which are necessary for computational thinking. This course includes industry 4.0 technology such as Robotics and Internet of Things (IoT) with a goal of increasing active learning and engagement. We will define classroom activities as follows:

Table 1
Classroom Activities

Category	Type of Activity
Active	Present and/or explain the works and artifacts
Interactive	Discussion with Instructor and Collaborator
Constructive	Doing Hands-on Activities
Passive	Listening Lecture

The guiding research questions that will frame the proposed research are:

1. What emotional responses will students elicit during different modes of activities?
2. How do changes to the mode of classroom activities and students' associated emotions impact learning?

This study will identify the mode of activities to which students respond more positively or negatively while learning actively. We will design the class activities with four different modes: active, interactive, constructive, and passive). A primary focus will be placed on investigating how students' emotional responses will range during these four modes. For example, hands-on practice following an instructor's explanation of the concept has shown to be an effective way to reinforce course concepts. Even though there are established positive effects for students, it is unclear how students feel during activities. The second research question seeks to understand how students' emotions affect their learning outcomes. We will compare the relationship between the result of artifact analysis and their emotional data. The following table presents the method that we will use to investigate each of these questions:

Table 2
Research Questions and Methods

Question	Methods	Data
1. What emotional responses will students elicit during different modes of activities?	Design four modes of activities in the instructional design and compare surveys and artifact data	Survey and artifact data
2. How do changes to the mode of classroom activities and students' associated emotions impact learning?	Conduct qualitative analysis to investigate relationships between students' emotions and artifact analysis.	Survey and artifact data

Method

Settings and Participants. The sites for this study are one liberal private university in the Northeastern United States and one state university in the Southern United States. These sites are different geographically, structurally (public vs. private), and demographically. The participants will be undergraduate students taking the interdisciplinary course in Fall 2023, which we designed as a general education course for each university. We will ask all students at the beginning of the semester to participate in the research as participants, with a maximum of ten participants at each university.

Data Collection and Analysis. The JAWS and Watson's emotion detection questionnaire will be employed, but we will modify the criteria to adapt to the educational environment (Van et al, 2000; Watson & Friend, 1969). Participants will participate in one pre-survey to identify his/her perception on the mode of the activities. Participants will also be required to respond to a survey after each class within 24 hours. Each participant's survey result will be compared with artifact data (Sladana, 2011). First, we will analyze preliminary survey data using inferential statistics to determine the statistical significance and the practical significance and use a chi-square test of independence to check whether two variables (the mode of activities and emotional response from survey) are likely to be related to or not. Second, we will analyze artifacts such as students' work and video-recordings to gain more understanding of the contexts and students' tasks using dyadic analysis, in which two researchers will exchange and develop ideas in the process of analysis. Physiological data (heartbeat and EDA) will be obtained while students perform each activity during class hours in real-time using the E4 wristbands. Two video cameras will record participants' group(s) during class time to track their responses by the mode of activities. The timestamps of E4 data (heartbeat and EDA) will be compared to video recording timestamps to verify the different modes of activities. Each participant's survey result will be compared with his/her data from E4 to analyze the consistency of the responses.

Discussions

The primary focus of the course objectives and activities is to increase student engagement and the development of logical thinking and creativity. The results of this project will provide other instructors with tools to develop instructional materials that enhance students' learning in consideration of emotional responses to class activities. This project will provide instructors with a better understanding of the relationship between various types of activities and related emotional responses and how they affect learning; therefore, instructors, especially for STEM areas, will gain guidance for designing and developing instructional materials that enhance learning. The proposed interdisciplinary course can be utilized as an example for STEM instructors to design and develop their own interactive and constructive courses.

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Restorying Through Design Intersecting Oppressions in Computing Education Using Black Feminist-Womanist Methodologies

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Abstract: Despite the push for engaging nondominant youth in learning computing, researchers have stressed the importance of supporting youth in understanding the sociopolitical and ethical dimensions of the design of emerging technologies. This poster presents the design and implementation of an informal workshop in which a racially/ethnically-diverse group of nondominant, 14-15-year-old youth designed interactive artifacts that reimagined or “restoried” dominant narratives about computing technologies. Through centering Black women’s knowledge and experiences with intersecting oppressions, this study framed African-American women’s quilt-making as a *restorying through design* methodology rooted in Black feminist-womanist theories. Reporting on the design experiences of 4 Black participants (i.e., 3 girls and 1 boy), I asked, *How might restorying through design using Black feminist-womanist methodologies reveal intersecting oppressions throughout computing education and culture?* Data collected and analyzed included participants’ quilt artifacts, exit ticket/final survey responses, and observation field notes. Findings demonstrated how white supremacy, heteropatriarchy, and capitalism can shape Black women’s experiences in computing education and with computational technologies. Implications for this study include the affordances and challenges of centering Black feminist-womanist methodologies in computing education.

Introduction and background

Despite the push for engaging nondominant youth in learning computing, researchers have stressed the importance of supporting youth in understanding the sociopolitical and ethical dimensions of emerging technologies. While seeming innocuous and neutral, new technologies risk uniquely marginalizing nondominant communities by reflecting and reproducing existing systems of power and injustices across society (Benjamin, 2019). However, in K-12 learning environments, youth are rarely supported in learning about the intersections of technology, ethics, and politics, as computer science (CS) and engineering curricula tend to promote narratives that reflect dominant epistemological beliefs of technology as neutral, objective, and democratic (Ko et al., 2020; Vakil, 2018). Therefore, innovative approaches are needed to support youth in making explicit connections between not only the personal, sociocultural, and political dimensions of computing, but also the speculative dimension regarding what computing and technologies *could* be.

Given that codes—both technical and sociocultural—have histories and can act as narratives telling us what to expect (Benjamin, 2019), this study drew from narrative scholarship to support youth in engaging in speculative literacy practices of interrogating and reimagining technology’s relationship to systems of power. Rooted in recent configurations of restorying describing how nondominant youth use digital tools to reshape narratives from marginalized perspectives (Thomas & Stornaiuolo, 2016), I offer *restorying through design* as an approach for supporting nondominant youth in designing computational artifacts while also interrogating and reimagining dominant narratives about computing technologies. Due to Black women’s unique knowledge and experiences with intersecting oppressions such as racism, sexism, and classism (Collins, 2002; Phillips, 2006), this conceptualization of *restorying through design* is grounded in Black feminist and womanist theories and practices.

Methodology

Using design-based research (Design-Based Research Collective, 2003), I designed and implemented a two-part, 45-hour workshop with an informal STEM program at a local science museum. Honoring the histories and storytelling practices of Black women, I centered quilt-making as a Black feminist-womanist methodology that African-American women used to restory their lived experiences (Cash, 1995). During the workshop, 16 high-school-aged youth from diverse backgrounds—14 of whom consented/assented—designed artifacts that “restoried” dominant narratives about computing technologies. More specifically, participants designed interactive quilt patches using electronic textiles, which are fabrics embedded with microcomputers, lights, and sensors stitched together using conductive thread and can be programmed to perform a wide array of actions (Buechley, Peppler, Eisenberg, & Kafai, 2013). In addition to designing interactive quilt patches, youth also participated in guided discussions interrogating dominant narratives about computing technology, particularly through engaging in restorying practices of naming and historicizing their everyday realities (Stornaiuolo & Thomas, 2018). To that point, I asked: *How might restorying through design using Black feminist-womanist methodologies reveal intersecting oppressions throughout computing education and culture?*

This study focused on the *restorying through design* experiences of 3 Black girls (Larry, Nia, and Britney) and 1 Black boy (Minaj). Data collected included participants' quilt artifacts, exit ticket/final survey responses, and observation field notes, and using conjecture mapping (Sandoval, 2014) and grounded theory (Charmaz, 2006), findings demonstrated how white supremacy, heteropatriarchy, and capitalism can shape Black women's experiences in computing education and with computational technologies. Implications for this study include the affordances and challenges of integrating Black feminist-womanist epistemologies and methodologies in computing education.

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An Analysis of the Design and Pedagogy of *DragonBox Algebra*

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Abstract: Game-based learning has been applied to solving algebraic equations with the games *DragonBox Algebra 5+* and *12+*. The developers claim that players can learn to solve algebraic instruction just by playing the games, yet there is little research to verify this. Additionally, existing literature does not speak to the experience of playing *DragonBox Algebra*. Here, we present a preliminary analysis and discussion of the design and pedagogy of *DragonBox Algebra* via the Design, Play, Experience framework. We provide a discussion of the design elements and the pedagogy apparent from the game, the publicly-stated pedagogical principles, and the extent to which they align with relevant learning theories.

Introduction

Serious games are games which are designed to achieve some purpose beyond providing entertainment (Winn, 2009). The design elements of a serious game, then, are critical to consider in analyzing and understanding the effectiveness of serious games (Winn, 2009). Therefore, as the first part of a larger research project, we carefully considered the design elements of a commercial serious game, *DragonBox Algebra* (DBA). In our poster, we will briefly present our analysis of the most salient design elements in the game, as well as the extent to which those elements align with the pedagogical principles stated by the designers (Kahoot!, n.d.) and theories of learning. In particular, we note that while the designers articulate a belief in the efficacy of discovery learning, the design of their app seems to be more strongly informed by behaviorist learning principles.

Game-based learning (GBL) is a popular approach in mathematics education (Byun and Juong, 2018). The commercial serious games *DragonBox Algebra 5+* and *12+* together are an example which applies GBL to the essential skill of solving algebraic equations. The Google Play store description of the 5+ version claims that "[c]hildren as young as five can begin to grasp basic processes involved in solving linear equations in an easy and fun way, without even realizing that they are learning." Despite the strong claims made by the developers, quantitative research paints a more nuanced picture (Long & Aleven, 2014; Siew et al., 2016; Supriandi et al., 2020). While some of these studies suggest playing DBA alone or in conjunction with instruction produces positive results (Siew et al., 2016; Supriandi et al., 2020), Long and Aleven (2014) found that it was less effective than gamified and non-gamified versions of an intelligent tutoring system for solving linear equations.

Analytic framework

We determined that Winn's (2009) DPE framework would be an appropriate analytical tool in our work with *DBA* because it is intended to be used both in the design *and* analysis of serious games. Under the DPE framework, Design, Play, and Experience represent three interrelated but distinct components of a game: "[t]he designer designs the game; the player plays the game; which results in the player's experience" (Winn, 2009, p. 1014). Across these three components, the DPE framework includes four "layers" of game elements: Learning, Storytelling, Gameplay, and User Experience (Winn, 2009). The full framework is depicted in Table 1 below.

Table 1
The DPE framework (Winn, 2009)

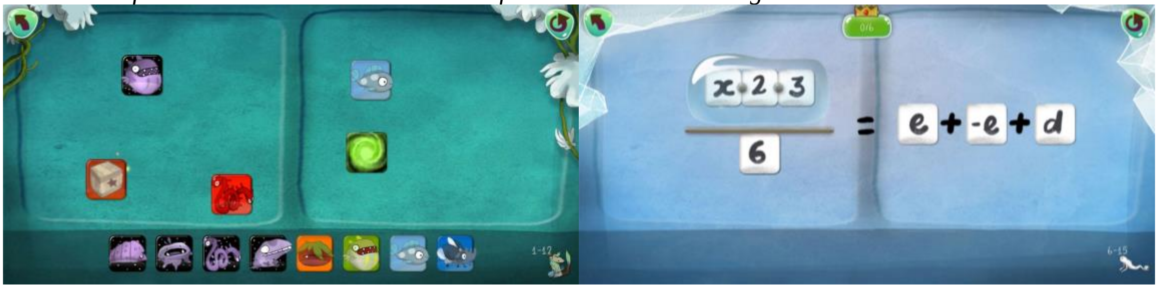
	Design	Play	Experience
Learning	Content and Pedagogy	Teaching	Learning
Storytelling	Character, Setting, and Narrative	Storytelling	Story
Gameplay	Mechanics	Dynamics	Affect
User Experience	User Interface	Interactivity	Engagement

The design of DragonBox Algebra

DBA is organized into chapters, each with 20 levels. Figure 1 below shows two example levels. The content of *DBA* is the rules and methods of solving algebraic equations. Throughout the game, players are introduced to concepts and skills that are key to solving and simplifying algebraic equations. *DBA* relies on just-in-time information (Kester, et al., 2001) and immediate feedback in order to develop players' ability to solve algebraic equations. Additionally, the game minimizes formal mathematical notation when introducing new rules. These pedagogical elements draw from the seemingly contradictory approaches to learning of discovery learning (Hammer, 1997) and behaviorist (Skinner, 1961) learning pedagogies.

The characters, setting, and narrative of DBA are minimalistic. The player is able to choose an avatar for themselves and each chapter is defined by a dragon which lives in the titular DragonBox. The setting and narrative are sparse. Mechanically, the game is oriented around the player using "powers" which correspond to rules for solving algebraic equations. Players use the powers, at first individually, and then in conjunction, in order to get the DragonBox alone on one side of the screen. In terms of the user interface, the game is designed for tablets and mobile devices and optimized for touch screen interface.

Figure 1
Screenshots from DBA 12+ - Ch 1 Lvl 12 on left and Ch 6 Lvl 19 on right.



Next steps

We present our poster without making definitive claims on the effectiveness of *DBA*, as it represents only the first step of our work. Our next step is to consider the remaining elements of the DPE framework using data from learners in 5th through 9th grade, analyzing how these learners Play the game in response to these design elements and what sort of Experience they have as a result of this.

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Districts Helping Districts: Facilitating a Community of District Leaders to Develop Computing Pathways

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Abstract: We explore how to best facilitate a community of district leaders from six districts across the United States as part of a research practice partnership to design and implement K-12 computing learning opportunities. We found that developing a shared vision, conducting a needs assessment, and encouraging follow up interactions were helpful in facilitating a community of collaborative learning for district leaders.

Introduction

Educational systems are working diligently to adopt policies and practices to increase offerings for computing education in order to equip all learners with essential skillsets to succeed in our increasingly technological world and workforce. In the United States, district leaders have been uniquely challenged to restructure K-12 systems to provide computing learning opportunities for all learners. While states have adopted standards and frameworks as a guide to design and implement computing learning opportunities, district leaders must adapt these resources to be used within the unique contexts of their school communities, considering their students and families, available resources, competing priorities and ongoing initiatives. In previous work, our team has partnered with districts to develop inclusive computing pathways (Mills et al., 2021). As this work scales, we seek to understand how collaboration between school districts in unique contexts can support them to design and implement K-12 computing learning opportunities, which may also inform supports for other shared problems of practice.

We conceptualize the group as a community of practice (CoP; Lave & Wenger, 1991) where all districts learn from each other. Indeed, in our prior project, we led an RPP that interconnected districts in three states and we were consistently surprised at how helpful districts were to each other despite varied locales. While CoPs have been successfully facilitated for many geographically dispersed professional groups, we seek to expand knowledge about these collaborative learning networks between educational district leaders focused on computing pathways. In this study, we explore how to best facilitate a community of district leaders from six districts across the United States as part of a research practice partnership. Specifically, we ask "What practices support district leaders to productively collaborate as part of a community of practice to design and implement inclusive computing pathways?"

Methods

We engaged in a research-practice partnership (Coburn et al., 2013) between 2018-2021 to develop computing pathways in districts from three states ("core districts"). Collaboratively, we developed a toolkit articulating a shared process, best practices, and useful resources for districts to develop computing pathways (Mills et al., 2021). In 2021, we piloted this toolkit in four additional districts ("pilot districts"). In November 2021, all districts attended an in person convening to share processes and strategies for their computing pathways. All districts indicated that they learned significantly from other districts and would benefit from continued connection. Therefore, they began participating in a CoP with 2-3 members of each leadership team to address problems of practice at the leadership level, such as scaling implementation, generating buy-in, and securing continued funding. Researchers adopted a design-based research approach, entailing iterative cycles of design and analysis, to adopt best practices to facilitate the community of district leaders.

Districts attend bi-annual, in-person convenings (three to date: November 2021, June 2022 and November 2022) and participate in regular virtual calls. Participants (N=21) include district leaders (n=6), curriculum/instructional specialists (n=6), building leaders (n=3) and practicing teachers (n=6). We used qualitative research methods (Miles, Huberman, & Saldana, 2014) to analyze project artifacts, meeting notes and field note observations from each of our meetings within the networks including the collection of design and planning documentation, identifying features of the peer-collaborative networks and supports that they provided.

Findings

We describe how three facilitation practices of the district leader CoP contributed to collaborative learning related to developing computing pathways. One practice that contributed to community building was developing a shared vision among district leaders. Given the nature of this project as an RPP, district leaders were included in the proposal process and helped to develop short-term and long-term goals of what they sought to get out of the CoP, management practices, and the expertise they brought to and wanted to receive from the CoP. This established a shared purpose amongst the group to disrupt patterns of inequity in computing education in all districts and share resources and best practices – particularly around professional development, teacher recruitment and retention, and computational thinking integration. Another facilitation practice that enhanced collaborative learning was co-designing and conducting an assessment of the current district landscape and needs. Discussing specific indicators across districts enabled them to provide consultancy to each other as they develop strategies and processes to scale their computing pathways and disrupt inequity within them. Finally, districts indicated that they learned from connecting with other districts about specific issues outside of the cadence of regularly scheduled virtual and in-person convenings. We attribute these interactions to the facilitation practice of encouraging follow up activities (e.g. email communication, meetings, resource sharing) between districts that are addressing similar challenges and creating shared platforms for interactions that were not moderated by the research team.

Table 1
Demographics of Each District and What They Hope to Share and Learn in CoP

District	Context	Demographics	Hope to Share in CoP	Hope to Learn in CoP
Core 1	Urban 28 schools 14,000 students	Title I: 37% Black: 19% Latinx: 12%	-Equity-focused data analytics	-Navigate competing initiatives
Core 2	Suburban 34 schools 28,000 students	Title I: 17% Black 9% Latinx: 12%	-Shared leadership with school/classroom	-Teacher professional development
Core 3	Rural 18 schools 7,000 students	Title I: 71% Black: 33% Latinx: 2%	-Teacher buy-in -Content integration	-Assessment of implementation
Pilot 1	Large Urban 329 schools 269,098 students	Title I: 58% Black: 39% Latinx: 35%	-Teacher support for existing CS/CT initiatives	-Evaluation/observation tools -Alignment with industry certification
Pilot 2	Suburban 5 schools 3,606 students	Title I: 13% Black: 3% Latinx: 31%	-Elementary integration	-Middle and high school integration
Pilot 3	Rural 2 schools 1,019 students	Title I: 3.9% Latinx: 7%	-Alignment with existing initiatives -Teacher buy-in	-Teacher resources for integration -Professional learning

Conclusion and implications

Although each district made many different choices about their computing pathway, we discovered many commonalities in best practices for pathways development that were invaluable and warranted fostering for future district-to-districts connections. Specifically, we found that developing a shared vision, conducting a needs assessment, and encouraging follow up interactions were helpful in facilitating a community of collaborative learning for district leaders. In future iterations of our CoP, we will facilitate “on the ground” learning among district leaders, traveling to one district for classroom visits and student/teacher conversations in order to experience an existing computing pathway and collectively consider where their own goals and plans may overlap or differ. Through our ongoing process of design and refinement, we plan to use our learning to develop empirically-supported resources, tools, and measures to support a growing network of school districts nationwide to engage in sustained, regular conversation and collaborative problem solving about computing pathways.

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Sewing and Weaving Data: Analyzing Fiber Crafts as Context for Performing Data Processing and Storing

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Abstract: Fiber crafts, including sewing, are connected to the history and future of computing. Yet, they are underrepresented in computing education. This qualitative study analyzed performed an iterative thematic analysis of artifact analysis sessions in which computer science experts examined middle school students' craft projects for evidence of challenging computer science concepts. This paper shows a weaving and sewing craft as context for performing data processing and storing with implications for computing education.

Introduction

Tangible manipulatives enable exploration of unfamiliar concepts through culturally-relevant body-based interactions (Horn, 2018). Using tangible manipulatives to facilitate computational learning is particularly compelling for students who are new to computing because the tools can readily provide access to complex computational ideas at an early age (Bers, et al., 2019). Materials like looms and fabric are traditionally associated with practices of people who are underrepresented in computing and are strongly connected to the history of computing (Abbate, 2012) as well as more recent computational development (Devendorf & Di Lauro, 2019). Yet, fiber crafts are often overlooked in computing education–apart from examples that the present study leans on an seeks to expand. Within educational research, electronic textiles (Buechley, 2006) have consistently proven to be a cogent context and notable exception for introducing youth—especially girls—to STEM disciplinary concepts, including accounts of circuitry learning (Pinkard et al., 2017). Fiber crafts have the potential to disrupt how we think about computing education especially because they introduce materials that are typically linked to decorative practices (Kafai et al., 2021; Keune et al., 2020).

Work is needed in the learning sciences to consider how the specific materials of fiber crafts (in this study weaving and fabric manipulation) align with computational ideas. Understanding how fiber crafts are aligned with computation can inform the creation of more diversity-oriented contexts. To investigate fiber crafts as a context for computing, I asked: *How do weaving and fabric manipulation support engagement with computation concepts (especially data processing)?* This qualitative study aligned fiber crafts with computational ideas through artifact analysis sessions of fiber artifacts by computer science experts. Craft projects were translated into pseudocode, a description of an algorithms in plain language, to illustrate computational concepts required for the crafts. The findings provide empirical evidence that crafts require engagement with processing and storing data with material parts and other computational concepts relevant for computational learning.

Methods

This qualitative study investigated fiber crafts for computational learning. The context of the study were university settings within which artifactual analysis (Pahl & Rowsell, 2019) of craft projects were conducted with computer science instructors at research-focused universities who were identified through university websites and recruited via email. Data sources came from the recorded artifactual analysis sessions with the instructors and focused on the instructors' experiences teaching computer science courses followed by a close look at fiber crafts artifacts to surface how fiber craft projects included computation. The analytical focus lay on understanding how the aspects mentioned by the instructors related to K12CS concepts (i.e., algorithms, variables, control structures, modularity, and troubleshooting) and beyond (e.g., data processing, memory). The explanations further served to translate the fiber crafts artifacts into pseudocode to highlight computational concepts. Some of this translation process was started by the instructors but expanded to illustrate how the crafts' material doings relate to computation.

Findings: Processing and storing data with material parts

Findings showed that instructors aligned the crafts with processing and storing data through material parts. The instructors recognized weaving as the organization of data in memory and the production of fabric rows as the exploration of data structures that were written into the memory of the fabric. One example of this was the gap that crafters produced by weaving with two separate shuttles, as if processing "two data structures at once," as one instructor explained. To produce the pattern, crafters wove mirroring row-by-row patterns. In the example project, the crafter passed blue yarn from right to left and yellow yarn from left to right to the center of the threads on the loom. When heddle positions changed (i.e., the loom threads changed positions), both yarns were moved in opposite directions toward the outer edges of the loom. The data that was stored within the fabric functioned like memory of the state of the computer and one instructor explained: “The state of the computer basically means, what is in the memory right now . . . This is useful for tracing what the algorithm did over time.” According to the instructor, the fabric showed the evolution of the computer state over time, one horizontal thread at a time. Typically, this kind of memory gets overwritten in the computer.

The instructors also recognized the organization of data in memory with fabric manipulation. The crafting process in fabric manipulation depended on the number, location, and distance of visible intersection points on the matrix that were sewn together. Instructors identified the intersection points as variables that crafters had to engage to produce a pattern. For example, an instructor explained: “The dot . . . can be represented as a variable. And their coordination change[s] over time as you’re sewing. Or their relation[ship], their distance changes, so they move around.” The instructor proceeded to write a list of variables that would be filled as crafters selected which intersection points on the matrix (i.e., dots) to sew together. The sewing process changed the position of the intersection points as well as the distance between points, which produced folds. The instructors recognized the produced fabric folds as writing data to memory. One of the instructors said: “This is how the processor and memory work together. All they know about are locations of data, [its] coordinates, and what operations we can do on this data.” Instead of producing machine-state memory, the graphic sewing pattern presented data that could be transposed onto the fabric through the language of stitches.

Discussion

Looking across how fiber crafts that the computer science instructors identified as computational presents fiber crafts as a promising context for computational learning, especially learning about data storage and processing. The machine state memory woven into the fabric made it possible for crafters to retrace, undo, and redo parts of their fabric designs. This further suggests alignment with troubleshooting that would need further investigation. Additionally, altering matrix structures can show how structures–whether grid points on fabric or thread arrangements on looms–direct performance. The contrasting engagement across two matrix-based crafts highlights the potential of designing for matrix play as a way to make computing a linear as well as a spatial artifact transformation process. Matrix play can make it possible to think three-dimensionally from the start, which can be useful for programming and algorithmic thinking that takes place in three-dimensional space with structures and matrices rather than on a flat plane (e.g., computational architecture, construction engineering).

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Does the Emergency Switch Make a Difference in STEM Motivationally Supportive Instruction? Comparing Instructors' Motivational Support Across Pre-Pandemic In-Person and During-Pandemic Online STEM Learning Environments

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Abstract: Due to the global pandemic, universities experienced an emergency switch from in-person to remote teaching, which likely prompted changes in instructors' motivationally-supportive instruction. The present study investigated how instructors supported students' motivation through relevance statements, supporting autonomy, and showing their enthusiasm in pre-pandemic in-person and pandemic online STEM learning environments. Findings from lecture recording segments in 2019 and 2020 demonstrated instructors' in-class motivational support differed across the two learning conditions.

Introduction

Prior empirical studies offered a promising clue that teachers' teaching practices can have a positive influence on students' motivation outcomes in postsecondary school contexts, but little is known about how teachers supported students' motivation in different contexts (Canning et al., 2019). Previous findings indicated that teachers might change their instructional strategies in different learning environments or over time (De Meyer et al., 2016). Hence, it is imperative to detect what specific strategies they chose in different environments corresponding to the changes in instructional practices.

Due to the outbreak of the pandemic, the major delivery method in university-level STEM education has experienced an emergency change from in-person to online. The sudden shift in the learning environments, together with the COVID stress (Arslan & Allen, 2021), exacerbated the challenges for both students and instructors. Therefore, there is a need to explore whether instructors have offered adaptive motivationally supportive instruction in class to tackle the negative impacts brought by the social circumstances.

To build a foundation of knowledge about instructors' in-class motivational support in two learning environments, this study focused on capturing evidence of instructors' in-class motivational support observed from the lecture videos. Toward that end, the proposed study addresses the following research questions: a) How did instructors support students' academic motivation in pre-pandemic in-person and pandemic online university-level STEM courses? b) What similarities or differences can be observed in instructors' in-class motivational support across pandemic online and pre-pandemic in-person learning environments?

Theoretical framework

Classical motivation theories, including self-determination theory (Ryan & Deci, 2000) and situated expectancy-value theory (Eccles & Wigfield, 2020), have offered theoretical guidance for supporting students' motivation from different but associated perspectives. Grounded on those theories, autonomy-supportive teaching, relevance statements, and teacher enthusiasm in class are effective in motivating students. Comparing instructors' motivational support between online and in-person learning environments by analyzing the observational data and investigating how instructors' instructional strategies might change under the transition of learning environments filled the research gap by regarding instructors as important socializers and demonstrating how instructors' motivational support worked in real-world educational settings.

Research design

The lecture video recording data was gathered during two separate years for one introductory chemistry course at a large university in Canada during Fall 2019, when instruction was conducted in person in a large lecture hall, and Fall 2020, when instruction was conducted online via Zoom platform due to the COVID-19 pandemic.

For analysis, lecture recordings were divided into segments of approximately 10 minutes each, then matched across 2019 and 2020 by the topic and instructor. This resulted in a total of 173 video segments, 107 from Fall 2019 and 66 from Fall 2020. Preliminary analyses started with descriptive statistics using the dataset directly obtained from the coding results so as to gain an overview of instructors' motivational support in two semesters. To further investigate the differences and similarities across two learning environments, this study conducted a repeated-measures MANOVA and paired sample *t*-tests as post-hoc tests to examine the specific differences of every coding item under the three main measures.

Findings and discussion

From the qualitative evidence, instructors' motivational support varied in different environments. For example, the most frequently used domains in relevance were connecting to routine activities and everyday life (32%) in 2019. However, instructors often connected the content to previous knowledge (28%) in 2020, while connecting to the routine events (21%) ranked second. Results also revealed the similarities across the two years. For instance, no evidence has been found that instructors have built connections between chemistry learning and students' career choices, displayed patience, and responded to students' negative emotions in both teaching scenarios.

Overall repeated-measures MANOVA demonstrated that instructors supported students' motivation differently by using differing amounts of relevance statements, autonomy support, and enthusiasm across the two learning environments. Specifically, instructors made more relevance statements and demonstrated more enthusiasm in the pandemic online learning environments than in pre-pandemic in-person learning environments. Instructors' autonomy-supportive teaching obtained higher scores in pre-pandemic in-person learning environments than in the pandemic online learning environments. Paired-samples *t*-tests were conducted to explore which detailed supporting strategies have the most salient differences. For relevance statements, bridging to understand a concept in the current chemistry class and providing explanatory rationales for procedure across two semesters experienced a significant change, meaning that instructors were more likely to connect the current learning materials to prior knowledge and identify the value and utility for students in 2020 online learning environments. Significant differences were also detected in the specific sub-facets of autonomy supportive teaching, where the rating scores were significantly higher for caring about students during in-person schooling.

In alignment with prior studies (e.g., De Meyer et al., 2016), this study revealed a homogenous conclusion that instructors' motivationally supportive strategies varied based on the learning environments. However, differently, instructors tended to have more relevance statements and show enthusiasm, but less autonomy-supportive in pandemic online schooling. Considering that the Zoom platform has become a lifeline for students and instructors during the global pandemic, this emergency and necessity might have various impacts on instructors, including negatively affected their motivational job characteristics but improved their teaching abilities (Beardsley et al., 2021). Thus, further research is needed to identify the differences and similarities of motivational support among pre- and post-pandemic, and during-pandemic online teaching. By examining the final grades across two semesters, students in pandemic online learning environments achieved higher academic performance in their final grades than in the pre-pandemic in-person settings ($M_{2019} = 80.06$, $M_{2020} = 91.84$). It worth noticing that even though global pandemic introduced additional challenges for instructors to support students' motivation in online learning, adjusting the utilization of various motivationally supportive strategies and making the maximum use of them appears to be possible.

Given the differences and similarities between pre-pandemic in-person learning environments and pandemic online learning environments in undergraduate STEM disciplines, it is essential to provide STEM faculty with a holistic overview of how they supported students' academic motivation. Such rigorous descriptions might also encourage them to implement more targeted and effective in-class motivationally supportive instructions in both learning conditions.

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Developing Undergraduate Students' Competence in Reasoning About Bodies of Evidence

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Abstract: Citizens are vulnerable to biased claims in social media based on *cherry-picked evidence*—i.e., claims supported by one or two studies when most studies support a different claim. We report results of an instructional study that investigated whether undergraduate students can improve their reasoning about such bodies of evidence and thereby make epistemic judgements that give preference to claims supported by larger bodies of evidence rather than one or a few studies. Results show that students who received instruction were more likely to prefer claims supported by larger bodies of evidence and also rated sources that cited such evidence as more trustworthy.

Introduction

Citizens often face situations in which they need to seek answers on a topic (such as the safety of vaccinations) but soon discover that information sources present conflicting claims (Lewandowsky et al., 2017). However, sources often present an incomplete picture of what the evidence says—citing just one or two studies when there may be dozens or even hundreds of relevant studies. Furthermore, when sources present just one or two studies, they may misleadingly cherry pick one of the few studies that support one position, ignoring the majority of studies on the other side. Our previous research has demonstrated that Japanese undergraduate students frequently favor positions supported by single studies over positions studies by a large majority of all studies, and they also pay little attention to whether evidence is cherry picked or not (Oura et al., 2022). In this study, according, we developed and examined a one-week instructional program to foster a preference for basing judgments on larger bodies of evidence rather than on just one or two studies.

Method

Participants were 150 undergraduate students in an online introductory education course at a public university in Japan. The students engaged in all procedures individually. The design was experimental with two conditions (no-instruction versus instruction), and students were randomly assigned to one condition. The experiment consisted of two instruction and one assessment phases as follows. The first instruction set aimed to develop students' competence in basing epistemic judgments on larger bodies of evidence instead of one or two pieces of evidence. To this end, we developed three documents (A, B, and C) on the topic of whether a drug (called "IFC") has a positive effect on curing a tropical form of hepatitis. In Document A, an expert author claimed that it is effective based on two described medical experiments. In Document B, another expert made the same claim based on the description of one experiment. In contrast, the expert author of Document C made a conflicting claim that IFC has no effects on curing hepatitis, based on a meta-analysis. Students in the *no-instruction* condition read and summarized each of these three documents. In contrast, students in the *instruction* condition were given PFL-based instruction with an invention task followed by formal instruction (Schwartz & Martin, 2004). Specifically, they were first asked to read the three documents and rank them based on the strength of evidence each presented; then they developed as many characteristics and criteria for the strength of evidence as possible. After the invention task, they were given text-based formal instruction in which one student and teacher discussed conversationally how to evaluate the strength of evidence.

The second instruction set aimed to develop students' competence in evaluating the trustworthiness of authors who cite evidence to support their claims. We developed four tweets (A, B, C, and D) by four different authors on the topic of whether sucratame, a "fictitious" artificial sweetener, increases the risk of cancer. The author of Tweet A claimed that it increases the risk of cancer based on "one large-scale study." The author of Tweet B claimed conversely that it does not increase cancer risk based on "most of studies" with no specific studies cited. In contrast, the author of Tweet C claimed that it increases cancer risk based on 25 studies in which 72% of them showed some increase of cancer risk. Lastly, in Tweet D, the author claimed there was no increase of cancer risk based on "a study conducted in 2008" stating that he "read various studies." As with Instructional Set 1, students in the *no-instruction* condition read and summarized major points of the four tweets. In contrast, students in the *instruction* condition read and ranked the four tweets in terms of strength of evidence and built on their previous list of invented criteria to decide which claim is supported by stronger evidence. After the invention task, they were given text-based formal instruction in which the same student and teacher discussed how to evaluate the trustworthiness of authors based on their expert knowledge in the focal topic.

Our assessment examined whether students could make judgments about claims based on larger bodies of evidence (i.e., all the studies available), rather than on one or a few studies, which might further be cherry picked. For the assessment, we developed three documents (A, B, and C) making conflicting claims on the relationship between rewards and work performance. The author of Document A, a business journalist, claimed that rewards increase work performance (*pro-rewards* claim) based on two studies whose evidence supported their claim. In contrast, the author of Document B, a business researcher, made a conflicting claim that rewards decrease work performance (*anti-rewards* claim) based on a meta-analysis analyzing 91 studies. Document C, by an experienced business journalist, also made the *anti-rewards* claim but based this conclusion on a single study. The assessment was conducted one week after the two instruction sets. Prior to reading the three documents, students answered two pre-survey items to measure their prior positions on both pro-rewards claim that rewards increase work performance and the anti-rewards claim that rewards decrease work performance. After this pre-survey, students read the three documents and answered seven post-survey items to measure their post positions on both claims, the strength of evidence on both positions, and the author trustworthiness on each document. All the responses were on 7-point Likert scale (1 = strongly disagree and 7 = strongly agree).

Results

There were no significant differences between the conditions in the variables before reading the three documents. Prior to reading the documents, students in both conditions strongly endorsed the *pro-rewards* position and were strongly against the *anti-rewards* position. In contrast, significant differences were found for most post measures with the p-value thresholds adjusted by the Bonferroni correction. Specifically, students with instruction rated the *pro-rewards position* significantly lower than no-instruction students ($\eta^2 = 0.07$). They also rated the anti-rewards position higher than no-instruction students ($\eta^2 = 0.03$), although this difference was not statistically significant. For strength of evidence, in comparison with no-instruction students, instructed students gave significantly lower ratings for *pro-rewards strength of evidence* ($\eta^2 = 0.11$) and significantly higher ratings for *anti-rewards strength of evidence* ($\eta^2 = 0.06$). For ratings of trustworthiness of the three sources, instructed students gave significantly lower ratings for *trust in Documents A and C* (both of which cited just one study) ($\eta_A{}^2 = 0.15$, $\eta_C{}^2 = 0.14$); they gave significantly higher ratings for *trust in Document B* (that reported a meta-analysis) ($\eta_B{}^2 = 0.07$).

Discussion

The instruction produced important changes in students' epistemic judgments. In comparison with uninstructed students, instructed students found Document B—the one document that presented a synthesis of research (a meta-analysis) rather than one or two studies—more trustworthy, and the documents that presented just one or two studies less trustworthy. In addition, in comparison to uninstructed students, they viewed the evidence for the pro-rewards position to be weaker, and the evidence for the anti-rewards position to be stronger. These results indicate that students can improve their reasoning about larger bodies of evidence our instruction based on Preparation for Future Learning, which scaffolded students to attend more to the bodies of evidence rather than one or two studies only. Further research also is needed to investigate ways of instruction in other situations, for example, when descriptions of evidence are insufficient when reading multiple documents.

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Building a Science Concept Recognition System Using NLP From Elementary Students' Science Storybooks

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Abstract: Despite the benefits of reading instructions, limited studies exist on recommending suitable learning resources for children's science education. To create a recommendation framework, identifying science learning resources that encompass science concepts that are adequate for the grade level is vital. In this study, we collected 52 science books for grades 3 to 5, extracting science concepts using named-entity recognition algorithms. Our findings could identify close to 3,000 science concepts entities across various science topic categories.

Introduction

Troubling trends in recent statistics and research evidence stress the need for improvement in reading comprehension skills for upper elementary school students in the U.S. (NAEP, 2022). The 2017 administration of NAEP revealed that 65% of 4th-grade students are not proficient readers. Studies further indicate that close to 15% of grade 5 students' achievement in science can be attributed to their reading comprehension of science passages (Taboada, 2012). Taken together, these results underscore the critical need for effective reading instruction for science performance. As an indispensable tool for doing and learning science as noted by the Next Generation Science Standards (NGSS) and The Common Core State Standards (CCSS), reading enhances the content understanding, promotes inquiry and conceptual change, contributes to knowledge building, and cultivates scientific habits of mind. However, providing appropriate science resources that satisfy students' needs is a challenging task. Oftentimes, the issues stem from the inability to locate appropriate science storybooks in a timely manner (Goldman & Bisanz, 2002), and the difficulties in connecting various science concepts to specific book contents (Pearson et al., 2010). To identify the appropriate resources that introduce adequate and diverse conceptual information for children's science learning, our study focuses on analyzing children's books to understand the underlying science topics. We demonstrated the use of the natural language processing approach, named entity recognition algorithm (Shelar et al., 2020) that is specifically trained to extract science concepts. The following research questions were addressed to guide the study:

1) *What are the common science concepts introduced in science storybooks for grades 3 to 5 students?*
2) *To what extent the use of the natural language processing approach, specifically the entity recognition algorithms, can identify and extract varying science concepts from storybooks?*

Methods

Our analysis was conducted in three stages. First, a total of 52 STEM-focused children's books for grades 3 to 5 were randomly extracted from publicly available repositories using a Python package, *PyPDF2*. To reduce the noise in the text data, we skipped the publication content (e.g., year, author, publisher) that commonly presents in the first two to three pages. We then preprocessed the data by applying sentence tokenization, removing redundant space, punctuations, symbols, and stop words, and applying lemmatization. Second, we created bi- and tri-gram models to train a science concept extractor using the named entity extraction approach. Given that most science concepts are presented in noun phrases, we utilized Part of Speech (POS) tagging to match all possible noun phrases as our science concept candidates, then computed the word similarities for each candidate using the science glossary resources. If the maximum similarity score exceeds the conventional cut-off of 0.3 (Rekabsaz et al., 2017), we categorized it into the concept category with the highest score. Table 1 provides an example of the glossary resource we created that was used to identify the science concepts from the children's books. Last, we compared the results with the naive named entity extraction results qualitatively. A quantitative evaluation involving two human raters will be provided.

Table 1
An Example of Science Concepts and Definitions

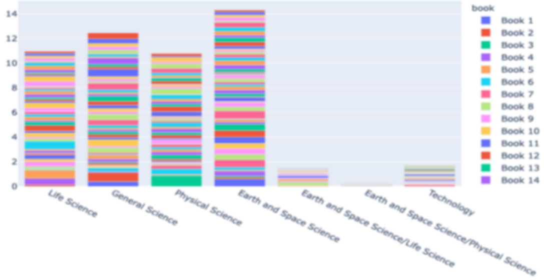
Source	Grade	Year	Category	Term	Definition
STEMscopes Alabama	5	2015	Earth and Space Sciences	Atmosphere	The layer of gas surrounding planet Earth, held in place by gravity and composed of a limited number of elements, primarily nitrogen and oxygen.

Results

A total of 3,620 unique science concepts were identified (see Figure 2b) from the children's storybooks. Figure 1a shows the proportion of science concepts identified from the 52 training books. We calculated the proportion of concepts in each science category and added them to determine the dominant representation of science concepts among the training sets. Results indicate that children's books frequently introduced science concepts from the "earth and space sciences" category (27.5%), followed by general science (23.9%), life sciences (21.1%), and physical sciences (20.7%). Relatively small concept entries were identified from the earth and space sciences/life sciences (0.29%) and earth and space sciences/physical sciences (0.0%), and technology (0.33%) categories.

Figure 1

(a) Science Concepts Categories in Storybooks (left) and (b) Total number of science concepts identified (right)

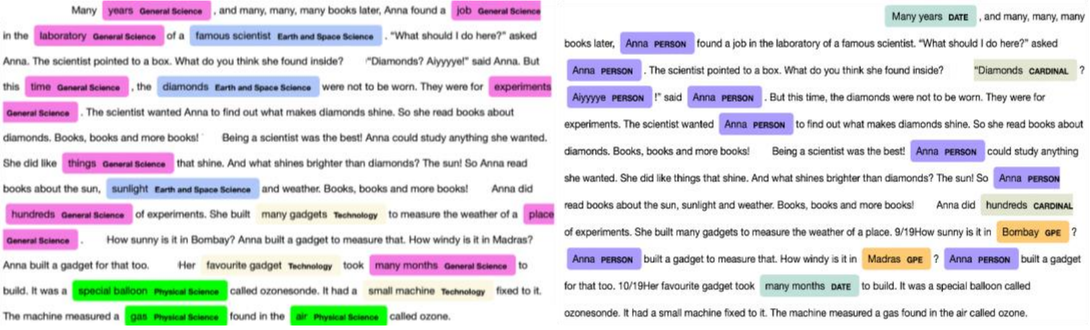


Category		
Life Sciences	Frequency	N books
General Science	738	48
Physical Sciences	965	48
Earth and Space Sciences	769	49
Earth + Life sciences	900	52
Earth + Physical Sciences	94	23
Technology	19	16
Total	135	35

We also compared our concept extraction approach with a widely adopted named entity recognition system (Spacy; Vasiliev, 2020) to show the shift in focus of entity extraction. Figure 2 shows this side-by-side comparison where our approach categorized words such as "years" and "months" as general science concepts, while the entity recognition algorithm classified them as "date" information. We believe this is because general science concepts often include concepts that are related to experiments and collecting information over a period (years or months) to draw conclusions. Further quantitative evaluation will be conducted and provided to support the accuracy and effectiveness of our approach.

Figure 2

An Example science concept (left) and named entity extraction (right) results.



Many years General Science , and many, many, many books later, Anna found a job General Science in the laboratory General Science of a famous scientist Earth and Space Science . "What should I do here?" asked Anna. The scientist pointed to a box. What do you think she found inside? "Diamonds? Aiyyyye!" said Anna. But this time General Science , the diamonds Earth and Space Science were not to be worn. They were for experiments General Science . The scientist wanted Anna to find out what makes diamonds shine. So she read books about diamonds. Books, books and more books! Being a scientist was the best! Anna could study anything she wanted. She did like things General Science that shine. And what shines brighter than diamonds? The sun! So Anna read books about the sun, sunlight Earth and Space Science and weather. Books, books and more books! Anna did hundreds General Science of experiments. She built many gadgets Technology to measure the weather of a place General Science . How sunny is it in Bombay? Anna built a gadget to measure that. How windy is it in Madras? Anna built a gadget for that too. Her favourite gadget Technology took many months General Science to build. It was a special balloon Physical Science called ozonesonde. It had a small machine Technology fixed to it. The machine measured a gas Physical Science found in the air Physical Science called ozone.

Many years DATE , and many, many, many books later, Anna PERSON found a job in the laboratory of a famous scientist. "What should I do here?" asked Anna PERSON . The scientist pointed to a box. What do you think she found inside? "Diamonds CARDINAL ? Aiyyyye PERSON !" said Anna PERSON . But this time, the diamonds were not to be worn. They were for experiments. The scientist wanted Anna PERSON to find out what makes diamonds shine. So she read books about diamonds. Books, books and more books! Being a scientist was the best! Anna PERSON could study anything she wanted. She did like things that shine. And what shines brighter than diamonds? The sun! So Anna PERSON read books about the sun, sunlight and weather. Books, books and more books! Anna did hundreds CARDINAL of experiments. She built many gadgets to measure the weather of a place. 9/19How sunny is it in Bombay GPE ? Anna PERSON built a gadget to measure that. How windy is it in Madras GPE ? Anna PERSON built a gadget for that too. 10/19Her favourite gadget took many months DATE to build. It was a special balloon called ozonesonde. It had a small machine fixed to it. The machine measured a gas found in the air called ozone.

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The Effects of AI Feedback on Students' Epistemic Emotion and Performance in Engineering Design: An Exploratory Study

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Abstract: One of the affordances of AI (Artificial Intelligence) for professionals is that AI can explore a much wider solution space to arrive at creative solutions that surprise them. This study explored the epistemic emotion of surprise and its effect on students' performance as they used AI feedback to assist their engineering design. Specifically, we examined 43 high school students' emotional reactions and their changes in design solutions after receiving AI feedback. Multinominal regression was performed to find that AI feedback did not have a significant influence on the level of surprise students experienced. However, most students made more positive changes to their designs when they found that AI feedback was much better than their original solutions. This study suggests that integrating AI elements in engineering design could help students optimize their designs.

Introduction

There is a trend of integrating AI elements into STEM (i.e., science, technology, engineering, and mathematics) education for cultivating students' cross-disciplinary knowledge and creative thinking to solve authentic problems in real life. However, students find it challenging to understand how AI works and how AI feedback could benefit their learning process (Touretzky et al., 2019). This is particularly true in the context of engineering design. Engineering design involves the integration of relevant STEM knowledge and the constant development of design outcomes (Zheng et al., 2020), during which surprise may occur and may affect students' iterative modification and refinement. However, there is limited research exploring students' epistemic emotions in engineering design. Thus, this study aims to examine the occurrence of the epistemic emotion of surprise and its effect on students' learning and performance when they use AI feedback in engineering design.

Methods

Figure 1
Interface of Aladin

This is part of a larger study where 43 students from two suburban Midwestern high schools learned science concepts, performed engineering design, and utilized AI feedback in a simulated learning environment (i.e., Aladdin). In the current study, students were asked to redesign a profitable solar farm, which generated more annual revenue from the produced electricity and less annual cost caused by installing and maintaining solar panels. In Aladdin (see Figure 1), students can have access to a variety of construction, visualization, and analysis tools (Zheng et al., 2020). More importantly, AI feedback leads students toward a comprehensive understanding of all design variables. The AI feedback is produced through an evolutionary computation process that systematically searches through various variables or parameters to identify optimal solutions under certain criteria and constraints (Xie et al., 2022). As displayed in the bottom left of Figure 1, the AI presents a dynamic graph to show how AI achieves the optimal design through a series of evaluations and generations. Students were encouraged to refine their designs after receiving AI feedback. We then used two open-ended questions to examine students' feelings of surprise. i.e., *If you are surprised by how AI changed the design variables, can you explain why? If you are not surprised by how AI changed the design variables, can you explain why you are not surprised?* To categorize students' responses, we designated them as "surprised" if they reported solely surprised variables, "not surprised" if they reported exclusively unsurprised variables, and "partially surprised" if they indicated surprise towards some design variables but not others. Finally, students' performance change was calculated by subtracting the student's final design profit (after receiving AI feedback) from the student's original design (before receiving AI feedback).

Results

After receiving AI feedback, most students were partially surprised (N = 24). However, some other students felt either not surprised at all (N = 8) or totally surprised (N = 11). Students felt totally surprised when the AI design was much better than their original design, whereas some other students were not surprised when the AI design only made a slightly more profit or made the same profit. For example, student CP5S9 said, *"I am surprised because I didn't realize how much the tilt angles could change through the seasons. There is a sort of spot that is the greatest, but that more appropriately has the tilt angles."*. In contrast, student *CP5S7* commented, *"I am not surprised because the AI did not change anything to my final design."*. In addition, we found that students' performance change was positively correlated with AI feedback. The majority of students made more positive changes to their design when they found that AI design was much better than their original design.

Discussion and conclusion

This study explored the epistemic emotion of surprise and its effect on students' learning and performance when they received AI feedback in engineering design. We found that AI feedback did not have a significant influence on the level of surprise students experienced. This unexpected finding may be due to students' different epistemic beliefs on AI feedback. Students' epistemic belief is a significant antecedent of epistemic emotions (Muis et al., 2018). Students who valued AI feedback would be surprised when AI provided limited design suggestions about their design. Meanwhile, students who had high belief in their original design may not feel surprised at a mild change made by AI.

Furthermore, most students made more positive changes to their design solution when they found AI feedback was much better than their original solution, whereas a few students failed to make significant changes to their final design. This finding suggested that a larger change made by AI induced more effort from students in iterative design and better final performance. Therefore, instructors and designers should present AI feedback in a way that highlights the improvement made by AI to maximize its utility. In addition, some students still need assistance in understanding AI feedback and making corresponding changes to their original design. This suggests the necessity to increase students' AI literacy so that students can use AI feedback effectively (Long & Magerko, 2020). In summary, the findings of this study corroborate the effectiveness of AI feedback on students' design performance, regardless of the level of surprise experienced by students. More research is needed to investigate the interplays of epistemic beliefs, epistemic emotions, and AI feedback in engineering design.

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Do Thinking Styles Change With Task Complexity in Problem-Solving?

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Abstract: In this study, we analyzed the differences in the three types of thinking styles (i.e., analytical thinking, dichotomous thinking, and metacognitive thinking) between tasks of varying complexity. The participants consisted of 31 medical students who were asked to think aloud while diagnosing two virtual patients in an intelligent tutoring system. We applied text mining on the participants' think-aloud transcripts to extract the metrics of analytical thinking and dichotomous thinking. We manually coded monitoring and self-reflection activities from the think-aloud transcripts as indicators of metacognitive thinking. The results showed no significant differences in participants' analytical and dichotomous thinking between a difficult and an easy task. However, participants demonstrated a significantly higher level of metacognitive thinking in a difficult task than in an easy task.

Introduction

Researchers and educators unanimously acknowledge the crucial role of thinking styles in learning and problem-solving. Despite its central importance to learning, the conceptualization and instrumentation of thinking styles/ skills are rarely treated explicitly by researchers. In this study, we take the initiative to examine the three types of thinking styles, i.e., analytical thinking, dichotomous thinking, and metacognitive thinking, based on several considerations. First, the three types of thinking styles, especially analytical and metacognitive thinking, are considered vital to our research context of clinical decision-making (Li et al., 2020). We are particularly interested in dichotomous thinking, which was deemed useful for quick decision-making (Oshio, 2012). Moreover, the three types of thinking styles involve strong linguistic components; therefore, standardized analytical techniques can be developed and applied to study those thinking styles of different samples.

In this study, analytical thinking is defined as the degree to which people use formal, logical, and hierarchical thinking patterns in problem-solving (Pennebaker et al., 2014). Pennebaker et al. (2014) proposed a categorical-dynamic index (CDI) to quantify analytical thinking across contexts. In terms of dichotomous thinking, it refers to a style of thinking that tends to be over-generalized and be in extremes (Boyd et al., 2022). Dichotomous thinking is also referred to as black-or-white thinking, right-or-wrong thinking, and all-or-none thinking (Oshio, 2012). Metacognitive thinking is the ability to "think about one's thinking". Metacognitive thinking involves monitoring one's thought processes and the resources, constraints, and progress in a learning or problem-solving condition. Through monitoring, learners establish the basis for self-reflection, whereby they (1) ask questions to themselves to check their understanding of learning products, (2) make attributional judgments about their performance, and (3) express their views, concerns, and emotions toward the task.

To our knowledge, no effort has been made toward examining the changes in the three types of thinking styles in tasks of varying complexity. Therefore, the overarching goal of this study is to examine whether and how task complexity affects the three types of thinking styles in clinical reasoning.

Methods

The participants comprised 31 medical students (67.7% females) from a large North American University. The average age of the participants was 23.45 (*SD* = 3.02). Participants were asked to diagnose two virtual patients in BioWorld, an intelligent tutoring system designed to foster self-regulated learning and clinical reasoning skills of medical students (Li et al., 2020). BioWorld is an inquiry-based learning environment, which allows participants to gather evidence, make inferences, and raise hypotheses in the process of diagnosing virtual patients.

Prior to the task, participants completed a consent form and a demographics questionnaire, followed by a 15-minute training session to help them get familiar with the BioWorld environment and think-aloud protocols. Participants were tasked to solve the *Pheochromocytoma* case (difficult) and *Diabetes* case (easy) independently, during which they were instructed to think aloud.

We analyzed participants' thinking styles (i.e., analytical thinking, dichotomous thinking, and metacognitive thinking) based on their think-aloud transcripts. Specifically, we used LIWC (Linguistic Inquiry and Word Count), a text-mining tool (Boyd et al., 2022), to extract students' analytic thinking and dichotomous thinking. Analytical thinking was assessed by the categorical-dynamic index (CDI), which captures the degree to which learners use formal, logical, and hierarchical words. Regarding dichotomous thinking, it was assessed by participants' use of absolutist language such as all, none, and never. Moreover, we used two strategies (i.e., topic representations and verbs) to segment the think-aloud transcripts into 2,792 meaningful idea units. We coded whether or not each unit involved metacognitive thinking (i.e., monitoring and self-reflection). In total, there were 1,048 units coded as involving metacognitive thinking. The inter-rater reliability was .813. We used paired t-tests to compare the differences in the three types of thinking styles between the two task conditions.

Results

As displayed in Table 1, there were no significant differences between the two tasks in analytical and dichotomous thinking. Nevertheless, the difficulty task yielded a significantly higher level of metacognitive thinking (*M* = 18.32, *SD* = 7.88) than the easy task (*M* = 14.23, *SD* = 6.85), *t* (30) = -2.97, *p* < .01.

Table 1
Paired t-tests for comparing students' thinking styles in the two task conditions

Thinking styles	Easy task		Complex task		t-test
	M	*SD*	*M*	*SD*	
Analytical thinking	16.47	12.12	16.01	9.84	.20
Dichotomous thinking	0.99	0.47	1.04	0.62	-.62
Metacognitive thinking	14.23	6.85	18.32	7.88	-2.97**

Note: ***p* <.01

Discussion and conclusion

We found that the participants did not differ significantly in analytical thinking and dichotomous thinking when solving a difficult and an easy task. However, the level of participants' metacognitive thinking increased significantly as the task complexity increased. One possible explanation is that analytical thinking and dichotomous thinking might be more trait-like personality variables, whereas metacognitive thinking is a more state-like construct. In this regard, task complexity could hardly affect how an individual typically thinks (i.e., thinking patterns). Future research is needed to investigate the nature of the three types of thinking. Moreover, there are two approaches to clinical reasoning: analytic reasoning and non-analytic reasoning (Li et al., 2020). At the heart of analytic reasoning is the objective analyses of a patient's symptoms, medical test results, and the probabilities of different diagnostic hypotheses. In non-analytic reasoning, physicians and medical students use personal experience and intuitive knowledge to diagnose patients. The two approaches of clinical reasoning also provide a potential explanation for our research findings. Despite differences in task complexity, participants' preference for a specific approach to clinical reasoning might to be relatively stable. As a result, no significant differences were observed in their analytical and dichotomous thinking skills.

This study has methodological importance and practical implications. First, this study represents an initiative to simultaneously examine different types of thinking styles in empirical research. While the basic notion that thinking styles are important to learning is not new, the attention given to thinking styles has often been in an abstract sense. We provided a clear definition of the three types of thinking styles. Furthermore, the techniques presented for capturing the three types of thinking styles inform future research of different disciplines and contexts. Pedagogically, findings from this study highlighted the important role of metacognitive thinking in tasks of varying complexity. For optimal teaching and learning, more focus might be needed on the scaffoldings of metacognitive thinking than analytical and dichotomous thinking.

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Assessing Computational Thinking Attitudes in Empirical Research: A Systematic Review

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Abstract: This study investigates how affective, behavioral, and cognitive components of computational thinking (CT) attitudes are measured in empirical studies. Findings show that (1) surveys were the most commonly used tools for measuring CT attitudes; (2) all three components were measured in CT studies; and (3) the affective component of CT attitudes was less likely to be measured compared to the behavioral and cognitive components. This review reframes the assessments of CT attitudes and provides a reference for researchers interested in measuring the attitudinal dimension of CT. Future studies are suggested to explore the alignment among the three components and the relationship between different components and CT skills.

Introduction

Computational thinking (CT) has been regarded as an essential ability for individuals in this technological age (Wing, 2006). Compared to the mastery of CT knowledge and CT skills, participants' CT attitudes have seldom been explored in the existing literature (Tikva & Tambouris, 2021). CT attitudes can be conceptualized as either the dispositional dimension of CT or the psychological antecedents/consequences of CT-related activities (e.g., programming, robotics, game play; Hooshyar, 2022). Regardless of conceptualization, a systematic understanding of CT attitudes is needed, as participants' internal states play a vital role in CT development (Tang et al., 2020; Tikva & Tambouris, 2021).

The current study aims to investigate how CT attitudes are measured in empirical studies. The following questions guide this study: What assessment tools were used to measure CT attitudes? What components of attitudes were measured in CT studies? What were the most frequently measured components of CT attitudes?

Methods

The present literature search was conducted using the Boolean expression "computational thinking" AND "(attitud* OR disposition* OR perspective* OR perception* OR affect*)" in six databases. First, the researchers screened the titles and abstracts of the 920 records (372 duplicates), excluding the publications that were not related to CT or not empirical (n = 379). Second, the researchers reviewed the full text of the remaining 161 publications independently, extracting those that met the inclusion criteria (n = 25). The reasons for exclusion were: publications that (1) measured STEM attitudes instead of CT attitudes (n = 76); (2) did not include the measurement of CT attitudes (n = 31); and (3) did not include details about the CT attitudes instrument (n = 29). The present study adopts Ostrom's ABC framework (1969), which has been used to explore students' states about digital data (Chi et al., 2018), to analyze the CT attitudes measured in empirical studies. In the ABC model, three components, namely affective, behavioral, and cognitive, are identified to represent different aspects of attitudes.

Findings

Assessment tools of CT attitudes

In the selected studies, surveys were the most commonly used tools for measuring CT attitudes (n = 20). Example items included "I think learning CT is interesting and valuable", "I can use CT to understand the problems in the real world", and "It is worth learning CT well". In addition to Likert-scale items, open-ended questions were used in two studies. While surveys typically served as the single assessment tool of CT attitudes, interviews, observations, and participant work samples were usually combined to provide evidence of CT attitudes (n = 4). Besides statistical analysis and qualitative content analysis, machine learning techniques were also employed to explore participants' CT attitudes (n = 1). The change in CT attitudes was assessed in seven studies, with the primary purpose of evaluating the benefits of CT instruction/intervention. The attitudinal change was measured by comparing participants' responses on the pre- and post-surveys (n = 6) or was inferred from participants' verbal responses and engagement patterns (n = 1).

Components of CT attitudes

The affective, behavioral, and cognitive components of attitudes were all measured in CT studies. In 17 of the selected studies, all of the affective, behavioral, and cognitive components were measured using surveys (n = 15), written reflections (n = 1), or multiple qualitative tools (n = 1). In six studies, only two components of attitudes were measured using surveys (n = 5) or multiple qualitative tools (n = 1). Two studies measured the single component of attitudes. Compared to the behavioral component (n = 24) and the cognitive component (n = 24), the affective component of attitudes was less likely to be measured (n = 17).

The *affective* component was typically measured by the items related to participants' interest, enjoyment, and confidence in learning, applying, and teaching CT, such as "I am interested in integrating CT in my teaching", and "I am excited to express new ideas through programming". The *behavioral* component was typically measured by the items related to participants' likelihood and tendency to apply CT (e.g., "When I am solving a complex problem, I try to break it up into smaller or simpler problems"), perceived capacity of applying and teaching CT (e.g., "I can use CT to understand the problems in the real world"), willingness to learn more about CT (e.g., "I will actively search for more information and learn about CT"), and intention to integrate and teach CT (e.g., "I will voluntarily teach kids CT if I were given the opportunity"). The *cognitive* component was typically measured by the items related to participants' perceived CT ability and knowledge (e.g., "I know how to connect new problems with acquired coding knowledge"), perceived importance and usefulness of CT (e.g., "It is important for everyone to take the CT course"), and CT teaching self-efficacy (e.g., "I know the steps necessary to teach CT effectively").

Discussion, implications, and conclusions

Although all three components were measured in CT studies, few studies examined the alignment and synergy among them. According to the principle of attitude consistency (Haddock & Maio, 2004) and findings from a meta-analysis (Glasman & Albarracín, 2006), a strong alignment among multiple attitudinal components can predict and guide future behaviors. In CT research, examining the alignment among the three attitudinal components may be conducive to predicting participants' future CT learning and teaching behaviors. Additionally, while the majority of the selected studies included CT-related activities and assessed both CT skills and attitudes, few of them investigated the relationship between CT skills and attitudes. Future studies are suggested to examine how each component of CT attitudes is associated with CT skills, which may help to design effective CT interventions and create personalized CT learning opportunities. Theoretically, this review examines the assessments and instruments used in CT studies, potentially advancing the operationalization and understanding of CT attitudes. Practically, this review presents a summary of the measurement of CT attitudes and serves as a reference for designing the assessment tools for the attitudinal dimension of CT.

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A Design-Based Training on Teachers’ Math Knowledge for Teaching

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Abstract: The current in-situ, descriptive case study explored the nature of the teachers’ involvement in game-based math task analysis and design, in relation to their potential portrayal and evolvement of pedagogical content knowledge and epistemic beliefs for teaching. Data were collected from 12 in-service math teachers at three suburban middle schools, through in-field observation, screen video archives, and semi-structured interviews. The study findings indicated that teachers’ design reflected their math knowledge for teaching. In addition, teachers were given opportunities to develop pedagogical content knowledge and epistemic beliefs for teaching.

Introduction

There is an increasing recognition of viewing teachers as designers (Li et al., 2019), particularly as learning experience designers. Strong evidence of the existing studies suggests that training teachers as designers of the learning environment and experience not only play a prominent role in teachers’ professional development (Bressler & Annetta, 2021; Li et al., 2019), but it also provides their students with opportunities to enhance creativity and problem-solving competence when teachers infuse design thinking in their lessons (Retna, 2016). Specifically, prior studies suggest that there are implicit and explicit associations between teaching and design. For instance, Henriksen et al. (2017) explored how teachers applied design techniques to their professional practices through an in-depth qualitative analysis of a graduate-level teacher education course. They found that design thinking is one of the most essential factors that determines creativity capacity to address teaching challenges in the real classroom practices.

Unfortunately, prior research suggests that teachers cannot automatically transfer the obtained knowledge of design into classroom practice (Bressler & Annetta, 2021). Therefore, we conducted the current study to explore the implementation and impact of a design-based training program that aimed to make teachers cognizant of designers of an active learning experience. We conjectured that having teachers experience the design process will activate their reflection on design and teaching. We engaged and studied teachers in test-playing and designing game-based mathematics tasks, aiming to make and examine the practice of design as both the means and outcome of teacher training. Specifically, the current study explored the nature of the teachers’ involvement in game-based math task analysis and design, in relation to their potential portrayal and evolvement of pedagogical content knowledge and epistemic beliefs for teaching.

Methodology

We adopted a descriptive case study approach (Yin, 2017) to explore how in-service teachers designed and developed a learning environment, in relation to their pedagogical content knowledge and epistemic beliefs for teaching. We enrolled 12 in-service math teachers at three suburban middle schools in the southeast United States. We held an 8-hour workshop which included the program orientation, the game test-playing, and the post-game discussion. We collected data via (a) screen video archives, (b) in-field observations, and (c) semi-structured focus group interviews to reach triangulation. We conducted systematic coding followed by thematic analysis for the qualitative data (Attride-Stirling, 2001). After transcribing all the screen-recorded videos and interviews, we developed an initial open-ended coding protocol highlighted notable patterns of coded narrative and the associations between contexts and learners’ actions. Meanwhile, a cross-case pattern analysis of the individual case was conducted to verify the validity of the coding system.

Findings

Learning environment design reflected teachers’ math knowledge for teaching

The first major theme emerging was in relation to math knowledge for teaching. Two subthemes were as follows: (a) systemic thinking incorporated by horizon content knowledge, and (b) interface design by considering students’ cognitive load.

Systemic thinking incorporated by horizon content knowledge

When a dyad of teachers at School C were engaged in designing the game-based math tasks for students, they intended to design multiple consecutive game levels for different graders (from 5th grade to 8th grade) with the same scenario. They increased the level of complexity by considering students' knowledge level at each grade. One of the two teachers articulated their design philosophy in the interview: "*We are actually doing a whole level [for students in different grades] because…um… we said for sixth graders they can use all four quadrants and solve one-step equations. And then the eighth grader does the reflection of the axis, so we can build each grade on that level*."

Interface design by considering students' cognitive load

Our data indicated that teachers paid attention to students' cognitive load and were able to apply the cognitive theory of multimedia learning to design instructional content when they were engaged in game-based math task analysis and development, particularly for the interface design of the learning environment. For instance, many participants commented on an example of interface design that violated the contiguity principle of multimedia learning, "*When you are looking at it, without the number system, and then when you get back without having that image and you go to the 'Challenge Me', that's too difficult*." In addition, they were able to point out which design followed the principle, "*I like this better with the explanation (i.e., texts) and the picture (i.e., graphics)*."

Evolution from uncertainty to certainty about using games for math teaching

According to the analysis of the teacher-researcher interactions during the game testing play, we found teachers' epistemic belief of using games for math teaching evolved from uncertainty to certainty. At the beginning stage, teachers demonstrated their uncertainty about using games for math teaching since they may not embrace game-based contextual math problems as a type of word problems that they used in the traditional classrooms, by commenting: "*We haven't really seen a word problem (in the game)*." On the contrary, at the final phase (i.e., the post-game discussion), many participants expressed their appreciation of using a game to help students learn mathematics and discussed how they will use it in practical teaching. "*I am teaching fractions. The problem that I come across is that whenever they are having to do the procedures of finding the denominator, having to line up, having to take a mixed fraction and make it into a proper fraction, the procedures of that and having that actually do these full steps are… that's the hardest thing to have them really buy into [the other female teacher: that's true] umm. I think this [E-Rebuild] can help*."

Discussion and conclusion

The findings indicated that teachers better developed their knowledge for design and teaching when they were actively engaged in test-playing and designing game-based math tasks for their students. In particular, their design solutions reflected their math knowledge for teaching. This is in line with the prior studies suggested that there were associations between teaching and design (e.g., Henriksen et al., 2017). Furthermore, we found that teachers were given opportunities to build new pedagogical content knowledge for teaching and to help develop their epistemic beliefs of teaching. Therefore, the design-based workshop could be a potential way of knowledge building and skill development for effective teaching practices.

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Identifying Pre-Service Teachers' Cognitive Engagement Patterns Using Time Series Clustering in a Programming Activity

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Abstract: Learners' cognitive engagement has been identified as a key factor affecting learning outcomes. However, limited research has focused on how dynamic cognitive engagement patterns influence learning outcomes. In this study, ninety-three pre-service teachers participated in an online computational thinking (CT) activity. Four patterns were identified using time series clustering: (1) low-engagement; (2) high-engagement; (3) early-engagement; and (4) late-engagement. The findings revealed that high- and late-engagement learners displayed significantly higher CT skills than low-engagement learners.

Introduction

Cognitive engagement is defined as the psychological investment students make toward learning, which ranges from simple memorization to the use of self-regulatory strategies for deep understanding (Fredricks et al., 2004). Several studies found that students exhibiting higher cognitive engagement are more likely to achieve higher learning performance (Putwain et al., 2018). Learning analytics techniques using log data have been applied to identify learners' engagement patterns in recent years to provide feedback to learners, instructors, and administrators (Abdullah et al., 2020).

Computational thinking (CT) is regarded as a thinking process of "formulating problems and solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (Wing, 2011). Cognitive engagement could influence CT because individuals who are more engaged in a learning task could potentially recognize patterns more readily and devise appropriate solutions. Therefore, this study developed an online CT activity and collected pre-service teachers' answers to several learning tasks. This study aims to: (1) extract learners' cognitive engagement from their responses; (2) group learners based on their cognitive engagement; and (3) investigate whether there is any difference in learning outcomes among learners with different cognitive engagement patterns. This study addresses the following research questions:

RQ1: Which types of cognitive engagement patterns can be identified in the learning activity?

RQ2: How do learners that display different cognitive engagement patterns vary in their learning outcomes?

Method

Ninety-three pre-service teachers were recruited from the Faculty's Research Participant Pool program at a large research-intensive University in Western Canada. The consent form and surveys were both administered online using the Qualtrics platform and distributed through the SONA system according to the ethics protocol Pro00112720. The participants completed the online consent form and pre-survey for an average of 20.1 minutes. To prevent fatigue, participants completed the intervention and the post-survey one week after the pre-survey, for an average of 45 minutes.

During the CT training section, participants were provided with four block-based programming learning tasks that included multiple-choice, sorting, and ranking items. After completing each task, participants were asked to briefly explain their responses.

The data sources consisted of the explanations that the participants were prompted to provide after each learning task. The Interactive, Constructive, Active, Passive (ICAP) cognitive engagement framework proposed by Chi and Wylie (2014) was adopted as the coding scheme because it is often applied in analyzing discussions in online courses. However, there were no interactive behaviors among participants or between participants and researchers. Thus, engagement was coded as constructive ('2'), active ('1'), and passive ('0') in this study.

A K-means time-series clustering technique was conducted to group participants by pattern similarity using R. The elbow method was used to determine the optimal value of K (i.e., 4 in this case) and then the K-means clustering algorithm for K = 4 was applied to the data. Then, a one-way ANOVA was conducted to examine the differences in learning outcomes (i.e., CT skills) among the four groups.

Results

The time-series clustering classified the participants into four groups: (1) Early-Engagement Learners: the learners displayed active or constructive engagement in the first two learning tasks, but they switched to passive engagement in the last two learning tasks; (2) High-Engagement Learners: the learners mostly displayed constructive engagement across all four learning tasks; (3) Late-Engagement Learners: the learners were more likely to display passive engagement in the first two learning tasks, but they tended to display active or constructive engagement in the last two learning tasks; and (4) Low-Engagement Learners: the learners mostly displayed passive engagement across all four learning tasks.

The results of a one-way ANOVA analysis revealed significant differences in pre-service teachers' CT skills across cognitive engagement patterns ($F = 3.13$, $p = .030$). The multiple comparisons on CT skills of different groups of participants revealed that high- and late-engagement learners significantly outperformed low-engagement learners. However, there was no significant difference among early-, late-, and high-engagement learners.

Discussion and conclusion

In this study, learners were categorized into early-, late-, high-, and low-engagement groups based on their written responses following several learning tasks and their CT skill differences among these groups were compared.

The cognitive engagement patterns identified are consistent with those identified in a study by Kuromiya et al. (2021), given that high-engagement groups significantly outperformed the low-engagement group on CT skills. This result suggests the importance of engagement for learning in CT activities. It was expected that high-engagement learners would achieve higher learning performance (Martin & Dowson, 2009). Thus, passive engagement learners could be identified as at-risk learners, so that teachers could provide them with appropriate guidance (Chamberlain et al., 2014) or apply load reduction instruction (Martin et al., 2021) to boost these learners' engagement and to eventually help them succeed in the learning activity. In contrast to other studies showing that early-engagement learners performed better than late-engagement learners (Kuromiya et al., 2021), the present study found that late-engagement learners performed better on CT skills compared to early-engagement learners. This could be explained by the duration of the learning process. For example, in Kuromiya et al.'s (2021) study, students' engagement during the summer vacation was measured using log data. In their study, early-engagement students completed the assignment and generated interaction data mainly in the first half of the vacation. The current study revealed that, although the late-engagement group was more likely to engage passively in the early stage of the learning activity, this group gained similar CT skills as the groups who engaged actively or constructively all the time. One potential reason could be that the difficulty of learning tasks was increasing and learners engaging in more difficult tasks were more likely to perform better (Lynch et al., 2013). Future studies could explore the interaction effects of task difficulty and cognitive engagement on learner performance.

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A Systematic Review of Automated Feedback Generation in Empirical Educational Research

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Abstract: Automated Feedback Generation (AFG) has gained much attention as a way to revolutionize online feedback provision. This paper reviews 30 publications to systematically analyze the effectiveness of AFG in empirical educational research. Pre-defined templates, natural language processing, and comparison with correct answers are commonly used AFG methods. Results show that AFG positively impacts student learning and feedback quality. However, gaps in current AFG research were identified, and suggestions for improvement include expanding the use of AFG from higher education to K-12 education.

Introduction and conceptual background

Feedback is defined as "information about one's performance or understanding provided by an agent, which can be a person, book, experience, or computer" (Hattie & Timperley, 2007). Behaviourist learning theory argues that students should be provided with feedback and reinforcement to nudge their behaviours in a desirable direction (Chen, 2011). Several studies have acknowledged the benefits of feedback on student achievement. For example, students who receive immediate, tailored feedback display significantly larger learning gains than those in traditional group-based instruction (Wu & Chang, 2020). However, students claim that the quality and the quantity of feedback they receive are often not matching their expectations (Krause et al., 2005). Concomitantly, it is impractical for instructors to provide individualized feedback to each student, given the ratio of students to teachers, especially in massive online learning environments (Wu & Chang, 2020). Thus, AFG has the potential to solve these issues, as it could help scale instructors' efforts to design and deliver feedback to students that would address their individual misconceptions and knowledge levels.

The existing literature reviews on AFG have some limitations, such as restricted search databases, specific time spans, and insufficient focus on AFG methods, feedback types, and appropriate domains. To fill these gaps, the present review aims to answer the following research questions: (1) What are the characteristics of the existing applications of AFG? (2) What methods are often used to generate feedback automatically? What are the effects of different methods of AFG on learning outcomes?

Methods

This systematic literature review follows the PRISMA framework (Page et al., 2021) to screen and select studies. The databases selected for this review are ScienceDirect, SCOPUS, ERIC, and SpringerLink, which cover a broad range of topics, from education and computer science. The search string used was (automat* OR immediate OR individual OR formative OR adaptive OR intelligent OR student OR learner) AND (feedback OR hint) AND generat*, with no restrictions on domain or time span. Results were limited to peer-reviewed publications in English. Multiple rounds of exclusion resulted in 30 eligible studies for final coding. This review only includes empirical studies in education, focusing on the effects of AFG tools on learning.

Results and discussion

Characteristics of the existing applications of AFG

This review found that most AFG tools predominantly target higher education levels (N = 22), with less focus on primary and secondary education. The reason for this finding could be that most AFG tools are designed for programming and essay-writing domains, and students often start learning these two skills in higher education through formal courses. However, applying AFG in K-12 will benefit far more students as well as their teachers. The current success of AFG in its relatively short development history indicates unlimited future possibilities, such as designing scalable just-in-time adaptive formative feedback that addresses and combats student misconceptions and helps instructors identify and approach material that is more difficult for students to understand.

Methods and effects of AFG

Pre-defined templates commonly used for AFG have been employed by Quigley and Kiely (2021) to fill in a pre-defined feedback matrix using MS Excel functions and present it to students. Another method employed a graph to represent problem-solving steps, such as the procedural knowledge model (i.e., probabilistic graph) used by Fossati et al. (2015) to extract student interaction history with the system. Another method is to compare student submissions with correct answers, where correct answers are obtained from previous student submissions (Price et al., 2017) or provided by instructors (Kim et al., 2016). NLP methods are also prevalent in AFG applications, as most feedback is text-based. Most studies found positive evidence (N = 28) of their tools for student learning based on the quality of provided feedback. Two studies found no evidence or contradictory results about their tools facilitating student learning. Some reasons might be the small sample size (N = 18; Lodder et al., 2021) or teachers being skeptical about the feedback provided by their tools, even though students perceived feedback as being helpful (Gu et al., 2021). Nineteen studies reviewed present experimental evidence for the effects of their tools on student performance.

Contributions and implications

This study provides a comprehensive overview of empirical studies on AFG and suggests directions for future improvements, especially in the context of classroom formative assessments. The present study extended the existing AFG reviews by adding more databases for the search, removing domain restrictions, and summarizing AFG methods and the effect of feedback on learning for the two most frequently applied domains: programming and essay writing, thus informing further AFG development. The findings of this review can inform the development of new AFG tools and improve the implementation of existing tools for feedback generation, with the potential to ultimately enhance student learning outcomes. The findings of this study can contribute to ongoing discussions on how to leverage technology to improve education and the learning experience, making it a valuable addition to the conference program.

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Integrating Perspectives to Promote Knowledge Integration: How Knowledge Integration, Learning Progressions and Instructional Science Can Complement Each Other

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Abstract: Science education aims at equipping students with an integrated knowledge base that enables them to comprehend phenomena and draw evidence-based conclusions. The knowledge integration perspective, however, is domain-independent and lacks insights that offer guidance for designing learning environments. This conceptual paper seeks to bridge knowledge integration with learning progression and instructional science, exploring the potential for better understanding science learning and creating effective, evidence-based learning environments that support integrated knowledge development and knowledge-in-use.

Introduction

Modern science standards and international organizations emphasize K-12 students demonstrating knowledge-in-use where learners apply their knowledge to explain phenomena and draw evidence-based conclusions (Harris et al., 2019). Knowledge-in-use is based on well-developed knowledge networks that are organized around core ideas (Linn et al., 2015). Designing instruction that fosters integrated knowledge requires combining domain-specific content models and domain-general instructional models (e.g., Koedinger et al., 2012). The challenge lies in meaningfully connecting these perspectives. This contribution aims to bridge these perspectives by exploring how knowledge integration, learning progressions, and instructional science complement each other.

Promoting knowledge integration in the science classroom

The goal of science learning is to engage learners with scientific phenomena so that they can develop a scientific understanding of the world and apply their knowledge to the problems they encounter. To this end, students need to develop knowledge-in-use (Harris et al., 2019) which rests on a well-integrated knowledge base (Bransford et al., 2000). The idea of integrated knowledge draws from the notion of semantic networks that represent explicit declarative knowledge in long-term memory. One way to promote a normative understanding of scientific phenomena are guided-inquiry activities which confront learners with novel (normative) ideas that challenge their current (often non-normative) understanding. In the best case, this process leads to conceptual change in which learners restructure their semantic network of ideas. Linn et al. (2015) propose that knowledge integration is more likely if teachers can elicit students' existing ideas about a phenomenon, help students add new, normative, ideas, help learners distinguish between their own and the normative ideas, and finally reflect on their ideas. The knowledge integration perspective is a domain-general approach; it does not define which ideas constitute resources or can be considered non-normative. Additionally, it emphasizes adding ideas to existing knowledge networks but does not offer guidance on identifying core ideas, a sequence for integrating these ideas to develop scientific understanding, or appropriate instructional activities that lead to integrated knowledge. To gain insights into the structure of a domain, the ideal sequence for teaching concepts, and the most effective instructional activities, one can turn to research on learning progressions, while research on instruction can provide insights into suitable instructional activities that promote a sustainable integration of new ideas.

Learning progressions in science education hypothesize how students' understanding of concepts develops with instruction (Corcoran et al., 2009). These progressions have starting and endpoints with intermediate stages in between. Lower anchors represent prior knowledge, while upper anchors denote desired competence. Although learning progressions assume a limited number of potential trajectories and outline expected knowledge and skills transitions and potential instructional approaches, they lack specifics on effective instructional activities, which can be found in instructional science. Knowledge integration and knowledge-in-use are central to science education, with learning progressions guiding the scope and order of knowledge and skill integration. *Instructional science* provides insights into learning activities that help learners acquire and integrate new ideas by focusing on cognitive-constructive processes, learning strategies, and the effectiveness of pedagogical interventions (Linn et al., 2015). Techniques like self-explanations, peer-tutoring, and concept maps have been shown to be effective learning techniques that serve these goals (Dunlosky et al., 2013; Rittle-Johnson et al., 2017). However, not all learning activities suit all learners; instructional designers must consider learners' cognitive development when selecting appropriate activities (Rittle-Johnson et al., 2017).

Synergies between the perspectives

Science learning aims to engage learners with scientific phenomena, develop scientific understanding, and apply knowledge to real-world problems. Students need knowledge-in-use (Harris et al., 2019) which relies on well-integrated knowledge (Bransford, 2000). Integrated knowledge stems from semantic networks representing declarative knowledge in long-term memory. In classrooms, guided-inquiry activities confront learners with normative ideas that challenge their often-non-normative understanding, thus potentially promoting conceptual change. Knowledge integration is more likely when teachers elicit students' existing ideas, introduce normative ideas, help differentiate between them, and encourage reflection (Linn et al., 2015). In the following we highlight potential synergies between the three fields of research and identify open questions for future work. A first synergy exists between knowledge integration and learning progression research. The knowledge integration perspective emphasizes accumulating ideas but lacks specifics on which concepts (i.e., ideas and their relations) learners should integrate in their knowledge. Learning progression research can provide insights into the core ideas and the sequence in which these ideas may be best presented to learners so that they can construct an integrated knowledge base. Learning progression research, in turn, benefits from instructional science's which provides insights into learning processes and instructional activities that are suited for learners on different developmental levels. Viewing learning and teaching from these three perspectives allows us to react to challenges that learners experience on different levels. For example, we may select alternative instructional activities for individual learners, revise the structure of a learning progression, or modify the placement of the progression within the curriculum. Furthermore, incorporating learning process measures that are employed by research on instructional science into the evaluation of learning progression can help disambiguate results and compare effectiveness across different classrooms. For instance, the learning processes promoted by different instructional activities within the same learning progression may provide alternative explanations for learners' performances. Lastly, the knowledge integration perspective can benefit from instructional science's micro-level view, helping select appropriate activities to trigger different knowledge integration processes. This integration expands the scope of instructional science with expertise from knowledge integration and learning progression research.

Conclusion

This article advocates for synergies between knowledge integration, learning progression research, and instructional science to holistically design science education. These perspectives offer different lenses for understanding prior knowledge, topic sequencing, idea connections, and instructional activity design. Closer collaboration between these fields can enhance validity and generalizability of findings, requiring meaningful connections between theoretical models and consideration of macro- and micro-perspectives. To better understand science learning and provide evidence-based guidance, interdisciplinary work between these research areas is necessary.

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Learning at Work: Visual Learning Analytics to Upskill Aerospace Engineers in Advanced Manufacturing

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Abstract: The study focuses on how learning sciences and visual learning analytics can be used to design, and to improve, online workforce training in advanced manufacturing. We analyzed the data from a cohort of 900 professionals enrolled in an online training course regarding additive manufacturing. The results inform strategies for instructors to better align the course assignments, learning objectives, and assessment measures and argues for a synchronized data structure for use across online learning platforms.

Introduction

Research on pedagogy and practice for effective online instruction has boomed in recent years, abruptly accelerated by the COVID-19 pandemic (Anang, 2020). At the same time, educators and trainers are woefully underprepared for the needs of designing for this space. What is needed are more systemic approaches to scaffold high-quality online learning outcomes, grounded in the science of how people learn (National Academies of Sciences & Medicine, 2018) and how to design for online skill development for the future of work. This study builds upon prior approaches in learning sciences to support learning in the workforce through research partnerships with industry partners (e.g., Dede, 2006). Particularly, educational data mining (EDM) and learning analytics (LA) as a set of emerging practices have been used to examine learners' trajectories, activities, proficiencies and provide useful information for instructors to understand employees' learning (Ginda et al., 2019). To combine the latest understandings from the learning sciences with data visualization to scale high-quality learning outcomes to the gamut of online skills development offerings required by rapidly accelerating industry developments, this study illustrates the potential of applying learning design to a course focused on upskilling employees of a large aerospace manufacturer, offered via a leading research university's Massive Open Online Course (MOOC) platform. In line with current learning theory, an iterative approach to design-based educational research was applied to design online certificates and tested a learning objective-based approach to professional online education. Our aims are to support not only the intersection of the learning sciences and workforce training research, but also to the scientific process of exploration, discovery, confirmation, and dissemination. In this study, we ask: How can visual learning analytics (VLA) reflect students' engagement, learning outcomes, and the intersection of both with learning objectives? By answering the research question, we aim to provide a course design guide that incorporates the findings of students' engagement, learning outcomes, and learning objectives to inform the design of online courses.

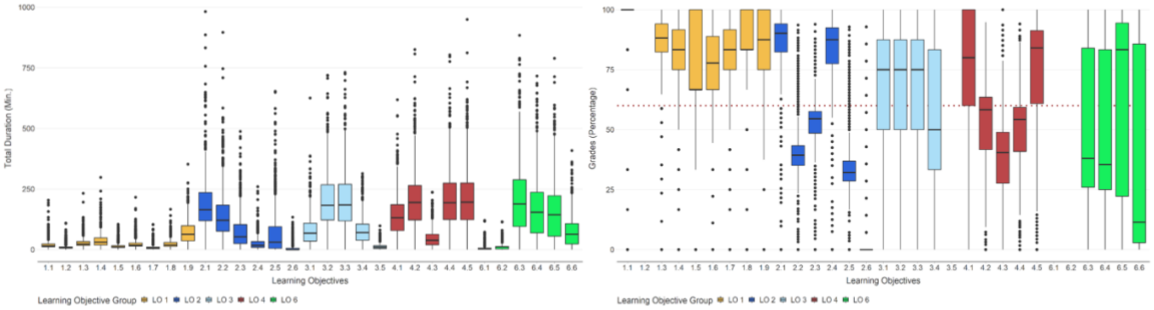
Methods

A nine-week online course focused on Additive Manufacturing (AM) was developed by aerospace employers as well as experts and scholars in AM and launched in 2017. We worked with the company to examine the learning outcomes and trajectories of 900 engineers to advance the upskilling process. We captured log file data from the course's learning management system (i.e., time an individual spends on videos or assignment), and analyzed employees' performances with course activities from week 1-6. In this poster, we removed the data from week 7-9 because employees used a 3D CAD modeling design platform, OnShape, which provides little information on the course site regarding learning activities and performance. We then qualitatively coded 31 learning objectives from weeks one to six to examine the relationship between the content of course modules and assignment and employees' performances. We visualized the results to cross compare the performance data and learning objectives. The purpose of the analyses was to examine if the content of the course modules and assignment were well designed to evaluate employees' learning which can be reflected on their performances.

Results

To understand how the instructional design supported employees' learning, the study examined the learning modules with learning objectives analysis, and then applied visual analytics and qualitative coding to investigate the relationships between learning objectives, performance, and engagement. Overall, our linear regression modeling confirms that time spent engaging course content positively correlated to student performance (r^2 =.4527, $p < .01$, n = 880). While these results are not surprising, it is an important measure to run at the end of any course to ensure that students, regardless of background knowledge, can perform well if they invest an adequate amount of time in the course. Examining the intersection of student performance, assessment measures, and intended learning outcomes yielded additional insights into how students engaged with the content. First, by providing VLA dashboards, this analysis helps to establish where students spent their time in the course content and more accurate estimations of time toward completion of each module. Second, the VLA clarified the amount of time it should take for students to accomplish a specific learning objective. Figure 1a presents the time students spent on each learning objective. This view makes salient how much time proportionately is dedicated to a learning objective, either in terms of time each student spent to complete a task, or how much extra time is dedicated in terms of learning activities to specific learning objectives. Furthermore, analyzing overall distribution of student performance within each LO and longitudinally can yield additional insights (see Figure 1b). For instance, certain LOs produce very low scores, instructors can look for correlation between performance and time spent. If more time spent on a LO leads to a low score, instructors can infer that students are putting forth effort, but the course content could be improved in future iterations.

Figure 1



(a) Engagement Time by Learning Objectives

(b) Percentage Grades by Learning Objectives

Discussion

This study examined the learning processes and outcomes of aerospace engineers through an online course which focused on the topic of additive manufacturing. Based on the analyses of learning objectives, processes and outcomes, the results informed modifications of future course content and assessment. This work took a fair amount of time to develop the training and courses, and it could be automated if the MOOC platform was designed with simple supporting workflows aimed to articulate learning objectives and tag them in the course assignments and assessment metrics. These key components could be fixed in advance and improve the overall course. Although the data and analyses were drawn from a single case, they provided a springboard to establish field standards across online courses and platforms in using LA and data structure for the purposes of adaptive assessment. To move forward, the process of upskilling employees requires close collaboration of learning scientists, data scientists, security experts, learning platform developers, and industry to design and develop learning materials and environment which lead to measurable improvements in work performance. This study helps to connect learning sciences to the increased focus on the upskilling issue in the workforce by applying EDM and LA approaches through practices.

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“Our Result Corresponds With Our Assumption”: Students’ Biased Interpretation of Data Gained Through Mathematical Hands-On Experimentation

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Abstract: The present paper explores whether students who subjectively confirmed their initial assumptions during mathematical hands-on experimentation interpret their results in a biased way that confirms their initial assumption. We also assess whether these students judge their own performance higher than students who experimentally disconfirmed their initial assumptions. Our results indicate biased interpretation for the majority of the students who subjectively confirmed their initial assumptions. Furthermore, these students tend to judge their own performance higher.

Introduction

The implementation of inquiry-based learning methods in the classroom and the goal of improving students’ scientific literacy is increasingly emphasized in STEM education. With regard to mathematics education, mathematical hands-on experimentation seems to be a promising possibility to implement the phases of inquiry learning. Specifically, the steps of mathematical hands-on experimentation are highly comparable to the following core features of the inquiry learning process, namely hypothesis generation, experimentation, data interpretation, conclusion, and reflection (Pedaste et al., 2015). During mathematical hands-on experimentation, students have to make assumptions, plan and conduct an experiment, deduct a mathematical model from the real world (e.g., by noting the measured values and transferring them to a coordinate system), answer mathematical questions within this mathematical model, interpret the mathematical results in the real situation, validate the solution, and reflect on their approach (Geisler, 2021). However, research on inquiry learning in science contexts has demonstrated that students tend to stick to their initially generated hypotheses, leading to a biased interpretation of their data and, thereby, an impaired effectiveness of inquiry learning (e.g., De Jong & Van Joolingen, 1998). Based on the commonalities between inquiry learning and mathematical hands-on experimentation and, especially, against the background that students often only rarely work with real data in mathematics classes but rather with artificially generated data which already fit an intended model (e.g., Engel, 2010), it is likely to assume that the issue of biased data interpretation is also relevant for mathematical hands-on experimentation. Therefore, the present paper explores whether students who subjectively confirm their initial assumptions during mathematical hands-on experimentation tend to (mis)interpret their collected data in a way that confirms their initial assumptions (research objective 1). According to the cue-utilization framework (Koriat, 1997), an additional problem might be that students who subjectively confirm their initial assumptions may use this success as an inappropriate cue to assess their performance, leading to overly high self-confidence. Thus, we further investigate how students judge their own performance when they have either subjectively confirmed or disconfirmed their initial assumptions (research objective 2).

Methods

To achieve our research objectives, we analyzed the lab booklets of 28 students ($M_{\text{age}} = 15.04$, $SD = 0.43$, 64% male, 32% female, 4% divers) who either subjectively confirmed or disconfirmed their initial assumptions during mathematical hands-on experimentation. These students are a subsample (i.e., those who actually compared their experimental results with their initial assumptions) of three German secondary school classes that participated in a day-long project in an out-of-school lab at a large German university between August and September 2022. The students visited the out-of-school lab with their whole classes together with their mathematics teacher. In the first learning phase of the day-long project, the students had a total of 55 minutes to work in groups of three on a mathematical hands-on experiment on beer foam decay following the steps mentioned above. In addition to filling in the lab booklets, we asked the students to provide us with judgments of performance after the learning phase. For this purpose, the students had to rate on a scale from 0% to 100% how well they can do certain mathematical activities similar to the activities of the learning phase, especially the interpretation and validation of the results.

For the present analyses, we focus on the phases in which the students were asked to analyze and interpret their results and to compare them with their initial assumptions. We classified the students into the following categories: *subjective (partial) confirmation of the initial assumptions* (*n* = 16) and *disproof of the initial assumptions* (*n* = 12). The students who subjectively (partially) confirmed their initial assumptions during mathematical hands-on experimentation formulated, for example, the following conclusion in their booklet: “Our result corresponds with our assumption”. In contrast, the students who experimentally disconfirmed their initial assumptions, for instance, concluded: “[Our assumption] was completely wrong”.

Results and discussion

With regard to research objective 1, our results show that twelve out of the 16 students who subjectively (partially) confirmed their initial assumptions through their experiment made assumptions that did not fit the actual decay process of beer foam. Thus, only four out of the 16 students confirmed their initial assumptions correctly, while the majority of the students confirmed their initial assumptions incorrectly. We identified such an incorrect confirmation, for example, in a group of three students who focused their interpretation on very general aspects of their results that were consistent with their initial assumption. These students initially assumed that “the foam decreases proportionally”. The results of their experiment clearly showed no linear decay, but instead an approximately exponential decay. However, the students did not describe the actually observed beer foam decay, but only their graph in a very general way as follows: “We have noticed that the graph has decreased.” Thus, the students ignored that the decay process did not correspond with their initial assumption of a linear decay and they erroneously concluded that the results of their experiment support their initial assumption: “assumption confirmed through experiment!” With regard to research objective 2, descriptive statistics show that the students who subjectively (partially) confirmed their initial assumptions reported higher judgments of performance (*M* = 69.35, *SD* = 18.42) than students who experimentally disconfirmed their initial assumptions (*M* = 63.07, *SD* = 18.15).

Although the small sample size of the present paper limits the scope and generalizability of our findings, the results indicate that students tend to interpret their results in a biased way and, consequently, falsely confirm their initial assumptions during mathematical hands-on experimentation. Our results further suggest that subjectively confirming the initial assumptions can lead to a higher judgment of the students’ own performance than disconfirming. This is especially problematic because the majority of the students who subjectively confirmed their initial assumptions falsely confirmed them due to biased interpretation. It is likely that these students overestimated their own performance which can have detrimental effects on learning outcomes (see, e.g., Dunlosky & Rawson, 2012). Further research is needed to investigate ways that help both to prevent students’ biased interpretation and to foster students’ use of appropriate cues for judging their own performance.

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Evaluating Peer Collaboration in Higher Education: Behaviorally Anchored Rating Scales

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Abstract: Today's challenges are better faced together than alone, highlighting that collaborative working and learning are of particular importance in the 21st century. However, research shows that graduates often do not feel well-prepared in this regard. Appropriate measurement approaches might be helpful for students to reflect their collaborative learning processes and to monitor their skill development. The current study describes the process of constructing an instrument for evaluating the quality of peer collaboration in higher education. Based on theoretical conceptions and in-depth observations of student groups, ten initial Behaviorally Anchored Rating Scales (BARS) were developed. Containing unequivocal behavioral anchors for high, medium and low levels of collaboration, the instrument has the potential to support evaluation processes in higher education. The contribution discusses enriching aspects of the approach but also what is still missing, and depicts potential fields of application.

Introduction

Collaboration is one of the most desired skills in the 21st century. Therefore, students transitioning from higher education into the workforce will be expected to collaborate with others in order to solve complex problems. However, the study by Wilson et al. (2018) highlights that many undergraduate students do not feel well prepared to work collaboratively and do not develop appropriate skills to do so. The existing soft skills gap between graduates' competencies and organizational demands (Abbasi et al., 2018) supports these findings. With regard to this, suitable measurement approaches would help students to reflect their own as well as the groups' learning processes and to monitor their skill development. Behaviorally Anchored Rating Scales (BARS) might be a promising approach to this end. BARS include behavioral anchors as response options that represent different quality levels of a construct with high values representing highly effective behaviors (Debnath et al., 2015). While they are particularly developed and used in terms of job performance ratings (Bernardin et al., 1976), their application in the context of performance in higher education courses also led to promising findings in terms of utility and applicability (e.g., McIntyre & Gilbert, 1994). Moreover, BARS have been found beneficial in similar areas of application, namely for the assessment of team member effectiveness (Ohland et al., 2012) and team adaptation processes (Georganta & Brodbeck, 2020). Respecting the promising findings on their feedback potential (Hom et al., 1982) and their use for self- and peer-evaluation purposes (Ohland et al., 2012), BARS might be a beneficial complementation to existing rating schemes primarily used by trained observers (e.g., the rating scheme for assessing collaboration processes by Meier et al., 2007). Hence, the aim of the current study is to construct an initial system of BARS for evaluating peer collaboration in higher education.

Method

Different procedures and formats for developing BARS have already been used (Bernardin et al., 1976) indicating that the development process is very flexible (Debnath et al., 2015). The procedure described in the current study is comparable to the one used by Georganta and Brodbeck (2020, Study 1). Based on a systematic literature review, we identified four core facets of collaboration including several sub-facets (Schürmann et al., 2022). Second, this coding scheme was pre-tested and used to derive and classify behavioral anchors from observations of student collaboration. The pre-study showed that the facets were suitable and applicable. Additionally, the findings enabled a deeper understanding of favorable behaviors and led to the enrichment and refinement of example indicators for each facet. In line with the method used by Georganta and Brodbeck (2020) the definitions and examples guided the following development stages and serve as description of each sub-facet in the BARS. Next, critical incident analysis (Flanagan, 1954) and frequency analysis were combined in order to derive and classify behavioral anchors for each of the ten sub-facets. Therefore, the video recordings of two collaborating student groups were observed. The recordings stemmed from an experimental field study where 38 undergraduate psychology students (in 14 teams of two to three) participated in a collaborative problem-solving task in a digital setting. In order to maximize variance, a group with a low level of collaboration and a group with a high level of collaboration (based on self-reports) were selected. Comparing two contrasting cases aimed to identify example behaviors from poor to excellent. The observation was systematically conducted by one rater (second author) using a combination of bottom-up and top-down approach to integrate quantitative and qualitative insights on the student peer collaboration. Critical incident analysis (Flanagan, 1954) was used to develop behavioral examples reflecting a spectrum from desirable to undesirable behaviors for each sub-facet. This process was supported by using frequency analysis to examine the prevalence of behaviors in both groups.

Results and discussion

In line with Ohland et al. (2012), we decided to use a 5-point scale with anchors for high, medium, and low levels of the respective sub-facets of collaboration. The “5”, “3” and “1” ratings each comprise four behavioral anchors, reflecting excellent, satisfactory and poor behaviors, respectively. Level “2” and level “4” do not contain behavioral anchors but can be chosen if behaviour is demonstrated which fits to both adjacent levels. In total, ten initial BARS (one for each of the sub-facet) for measuring student peer collaboration were developed. These scales are both based on theoretical concepts and derived from observations of natural and typical collaborative behavior. With respect to the second, combining critical incident analysis and frequency analysis turned out to be a suitable and fruitful approach as qualitative and quantitative data could be integrated and synthesized. While the frequency analysis provided indications of the differences between groups in terms of the distribution of facets, the critical incident technique helped to clarify these analysis results more precisely. Besides these strengths, there are also noteworthy limitations with regard to the development process. The observation and the assignment of the behavioural examples to the sub-facets were primarily done by one rater limiting objectivity and reliability. Although the current version needs to be further developed and evaluated to prove its psychometric characteristics, it already has the potential to be used beneficially. For example, it could be given to students as an instrument to support joint reflective processes about their collaboration (i.e., groups use it as self-evaluation instrument to detect areas of improvement). Thus, students might feel better prepared to work collaboratively and to develop appropriate skills to do so. Supplementary, this approach would allow to get insights into whether students are comfortable or having problems with using the BARS format. Taken together, future research is encouraged to investigate the potential of BARS in higher education context.

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Expanding the 'Personally Meaningful': Engaging in Sound Making to Support Engineering Practices

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Abstract: Personally meaningful design activities, such as sound making, can provide contexts for engineering education. Sound is personally meaningful because it connects to histories of a person's experiences and represents them. Building on constructionist perspectives, this qualitative study investigated engineering practices while youth created sound with conductive materials inspired by personally meaningful objects. Findings suggest that personally meaningful design activities should include materials with personal histories.

Introduction

The STEM field faces dropout issues internationally (e.g., Chen et al., 2018). Alternative approaches to STEM (Science, Technology, Engineering, and Mathematics) education are needed to counteract this trend. We focused on engineering education, which can be a path toward STEM education (Simmaro & Couso, 2021). Engineering education in K-12 is still not widely implemented, but early exposure could provide youth with positive experiences to inform their decisions to choose to stick with STEM. A promising approach toward early engineering education is through personally meaningful projects (Papert, 1980). Personal projects provide meaning beyond intended use, they evoke experiences that tie domain learning and interests (Turkle, 2007). One meaningful context in this area is sound making. Sound can have personally meaningful properties because we experience sound in everyday life and attribute meaning to sound through memories and emotions (Cambrón, 2005). Sound can become an object-to-think-with that provides a link between abstract and sensory knowledge at the intersection of cultural presence, embedded knowledge, and the potential for personal identification (Papert, 1980, p. 11). Despite these promises, we know little about the utility of sound making for engineering learning. Thus, we asked: *How does sound making tie personally meaningful objects and engineering practices in middle school students, and what electronic kits can support this better?* This qualitative study investigated the engineering design practices as youth engaged in sound making with electronic maker kits and conductive and non-conductive materials inspired by personally meaningful objects. We understand sound as vibrations transported through waves that can carry meaning. We found that sound making can evoke engineering design practices especially when it is possible to combine several conductive materials and build on personally meaningful objects. We close with implications for designing for engineering learning through sound making.

Methods

To address the research question, we used a qualitative approach with two groups of ten-year-olds in two 75-minute-long sessions for each group at a makerspace in Bavaria. The first group consisted of five girls and five boys and the second of seven girls and four boys. Every participant brought a personally meaningful object to the workshop (e.g., toy car, plant, house keys). Participants used the Playtronica Playtron, MIDI controllers that can be connected through smartphone or computer to play an instrument, and Squishy Circuits kits, which included battery packs, buzzers, motors with propellers, and switches, usually connected through conductive playdough. All participants had access to additional materials, including graphite pencils, copper tape, conductive thread and paint as well as other non-conductive craft materials. The participants had to produce sound with their personally meaningful object, electronic kits, and crafting materials. The data sources were: (1) Videos captured with three cameras (280 minutes) to show the interactions of all participants and (2) semi-structured interviews (123 minutes) that asked about their experiences with sound making, engineering, and crafting throughout the sessions. To answer the research question, we analyzed the video data and interviews following an iterative thematic approach to understand the engineering design practices (see National Research Council, 2013) that participants performed while creating personally meaningful sound. Additionally, the engineering design practices were coded as instances to compare how students engaged with the kits.

Findings

We found that engineering design practices through personally meaningful sound making were supported differently. Due to space constraints, we focus on Squishy Circuits. We identified two themes with Squishy Circuits: (1) Physical sound tinkering as conducive of engineering practices, which involved creating sound with movable objects powered with Squishy Circuits, and (2) filtering sounds as conducive of engineering practices, which involved using the buzzer as a main sound maker, but tinkering through filtering it with materials on top of it to modify its sound (e.g., foam, paper, dough, fabric). Squishy Circuits allowed youth to experiment with materials and to approach their sound creating task in different ways. They were able to design, iterate their designs, come up with new designs, and showed understanding of how materials worked and were connected.

Barney, a boy in the first group, brought a fidget spinner to the course as his personal object. He aimed to recreate its plopping sound. He tried replicating the sound of removing the lid of a metallic container remotely by using the Squishy Circuits propellers to create air pressure from inside. Barney iterated by adding propellers, battery packs, and adjusting the placement of the materials. When this did not work, he tried alternatives and understood that his design would not allow for his desired result due to not being airtight, the lid being too heavy, and the propellers not having enough force. Barney finished his project tapping the side of the can with the propeller and added the possibility of putting an ear inside the can for extra detail on the sound (see Figure 1). He showed engineering design principles through planning of his design, developing possible solutions, iterating multiple times on these solutions, and constructing explanations of the materials and their interactions. Barney used his personal object to guide his design and engage him to stay with it until the end.

Figure 1

Barney's four material explorations for his artifact representation: (1) Squishy Circuits buzzers with playdough, (2) xylophone being hit by the propeller, (3) propeller inside a plastic bottle, and (4) metallic can.

Discussion

This study points to the possibility of sound making with construction kits that connect to a range of materials as for engineering engagement. Also, providing a spectrum of materials for playing with resistance and conductivity as well as including physical materials enables experimentation with a range of sounds (e.g., tapping, sliding). This study suggests considering personal histories when designing personally meaningful activities. Beyond design activities being personally meaningful because people can choose what they want to design, bringing material objects (e.g., a plant, house keys, a toy car) from a persons' past and designing with them as an inspirational source can expand the personally meaningful toward including personal histories in activity designs. Such sound making can provide opportunities for early engineering education.

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Expansive Learning in a Team of Middle Leaders Responsible for a Public School Network: Enthusiasm vs. Control

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Abstract: This article describes an intervention that was carried out with an intermediate leadership team of an department of education responsible for a group of schools in a low-income community in Chile. The intervention takes the form of a Change Laboratory. The results indicate that the team was able to identify a major tension and has since sought and tested new ways of thinking and solutions through collective agency.

Introduction

Faced with an educational system that perpetuates social inequalities, there is a pressing need for change and improvement initiated by the educational community itself. Therefore, a training intervention based on the Change Laboratory (CL) strategy was conducted in a low-resource community in 2022. The goal of this intervention was to strengthen intermediate leaders who bridge State agencies, such as the Departments of Education (DAEM), and the educational communities. The current study outlines an intervention-action conducted with an intermediate leadership team responsible for seven public schools and four kindergartens in the Education Department. The context and conditions of the leading middle team, their transformation demands, and their need for expansive learning are briefly described. Then, we will explain the concepts of activity theory and the change laboratory that inform the process. Next, we will outline the objectives and methodology utilized. Finally, we will present the preliminary findings and conclusions, as well as the references cited in this report.

Context and challenges of the intermediate leader team

The municipality where we conducted our work has a population of nearly 100,000 residents (INE, 2021), and their economic resources distribution is widely heterogeneous. This disparity extends to educational institutions in the region, resulting in significant inequality in the quality of education that students receive (Herrera, Munizaga, López, Jorquera, & Hernández, 2008). The DAEM of the municipality addresses this issue. The department is tasked with directing and promoting leadership, ensuring the attainment of learning goals, facilitating school relations, and managing available resources (PADEM, 2022). In this specific case, the DAEM collaborates with nearly 800 professionals who ensure the education of more than 3000 students and more than 400 preschoolers, all of them managed by an intermediate team composed of 12 people. The presented intervention targets these professionals and seeks to strengthen the relationships they have with other professionals in the municipal system in order to face the new educational needs in a post-pandemic context, among which it is possible to count serious problems of non-attendance (MINEDUC Study Center, 2022) and dropout (Murillo and Duk, 2020), emotional exhaustion and stress (ECLAC and UNESCO, 2020), and teachers' mental health (Caballero-Domínguez and Campo-Arias, 2020). With the emergence of new demands, it has become clear that the education system needs to change in several aspects that seem unsustainable. Given these new social scenarios, an educational intervention like CL became the most appropriate way to address concerns. The proposal is to provide a mediated space for creating expansive learning and collective agency.

Activity theory, laboratory of change, objectives and methodology

The Cultural Historial Activity Theory (CHAT) enhances comprehension of individual and collective transformation processes. Its minimum unit of analysis is the Activity System (AS), a triadic system comprising a subject, an object, and the activity that mediates the relationship between them (Leontiev, 1978/1984). In this theory, a community is formed through the sharing of rules and generation of a division of labor among community members (Sannino & Engeström, 2018). Mobilization of the SA is driven by internal contradictions, which manifest as dilemmas, conflicts, and paradoxes rather than direct observation. In the attempt to resolve these contradictions, new modes of action emerge (Engeström & Sannino, 2011).

Starting from the premise that the CL adopts a dialectical approach, the current study is qualitative and exploratory, situated within a dialectical epistemology that aims at capturing the richness, depth, and quality of the produced outcomes (Virkkunen & Newnham, 2012). The purpose of this study is to facilitate a collaborative transformation process to promote innovative solutions with a mid-level leadership team of the DAEM through a

CL. To this end, an initial organizational immersion was executed to collect relevant data. Following this, seven group work sessions and two follow-up sessions were conducted. Twelve participants were selected based on their association with the creation of conditions for educational improvement and their voluntary participation.

Data collection was conducted using semi-structured individual and group interviews, participant observation, artifact collection, and field notes. The CL sessions were video- and audio-recorded and are part of the material analyzed. The data analysis took place at two different levels: (1) the material used as working data for the CL sessions, and (2) the information chosen for the production of scientific knowledge framed in the CHAT and CL toolkit (Virkkunen & Newnham, 2012). For the analysis of initial data, weekly meetings were conducted, while work meetings with international experts will be held for the second stage to contribute to knowledge construction and scientific dissemination. Regarding ethical considerations in this research, the research design was sent to the university's ethics committee before the fieldwork began, and approval for the research and related documents was granted.

Preliminary results and conclusions

Early in the process, a tension emerged that the team saw as a dichotomy: either the leader would be charismatic and foster the professional growth of his team, or he would focus on defining and fulfilling rules. As a result, they perceived a trade-off between motivating their team and improving control of the institutional organization.

In the initial sessions, a historical reconstruction of this tension was developed, analyzing it from public policies to the teacher-student relationship within their educational community. Thus, in the fourth session, they initiated the construction of two tools to resolve this dichotomy: the first tool aims to increase student attendance while minimizing teacher absenteeism by making the community interested in attending school; the second tool aims to establish a management system that incorporates the purpose and strategies of community mobilization.

Although we have not completed the process, we can claim that this approach offers ways to address traditional actions that perpetuate the main tensions of the educational system, proposing the generation of new solutions focused on the main tensions or contradictions. Simultaneously, it permits the development of practical and pertinent solutions, crafting tools for the community. In the context of educational research, participating in interventions and research in change labs can provide valuable insights and opportunities for problem-solving utilizing theory and methodology, resulting in the acquisition of rich data sets. These experiences may even inspire the development of new longitudinal interventions and research..

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Systematic Literature Review With PRISMA and NLP on Co-Creative Learning in Higher Education

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Abstract: Teachers in higher education design and develop (blended) lessons and learning activities. At the same time, it proves difficult for teachers to develop competences in designing lessons. This poster is a literature study method with a focus on co-creation process of designing lessons by teachers following the PRISMA method and an examination trough a Natural Language (NLP) analysis. The NLP analysis added a different dimension to explore conceptual development in factors underlying the co-creation in the existing literature.

Introduction

Teachers create and develop lessons and curricula, which might be strongly supported by knowledge creation, collaboration, thinking and creativity through dialogue. Designing lessons requires more innovative and creative behavior from teachers. Until now, it is not investigated how teachers act while being collectively creative, albeit without identifying important roles that could support co-creation within the creative process Factors like openness to the unexpected, curiosity and confidence in risk-taking during work affect de creatively designed lessons and the design competences of teachers. These factors should be explored, given the critical importance that the lesson designs of teachers play in transforming schools and classrooms.

In the present systematic literature review (LR), we investigated the underlying factors needed to co-create, for example, to design more creative lessons. These determined factors, such as shared vision, dialogue and inquiry, collective action and reflection are investigated. To enlarge and support this method of reviewing, an analyzing technique from Natural Language Processing (NLP) (Velazquez et al., 2017), is added to investigate and visualize new models and incorporate them into a LR. The possibilities of computational analytic techniques, such as NLP, opened new opportunities for modelling and coding methods with big data, such as a large number of journals and articles (Wise & Schwarz, 2017).

Methodology

The Preferred Reporting Items for Systematic Reviews (PRISMA) guidelines (Page et al., 2021) provides a standard peer-accepted methodology when followed strictly, it contributes to the quality of the selection of articles used and the revision process and its replicability (McInnes et al., 2018).

The articles, collected following the guidelines of PRISMA, are analyzed further to extract information such as location and topics. Using Topic Modelling, we are able to automatically discover topics in the selected articles. We ran a series of experiments to find the more coherence topics in our dataset. We used the topics distribution over each article to determine its principal topic. Thus, articles can be grouped by the topics generated automatically. Topic modelling is commonly used to analyze large volumes of data in relation to specific settings (e.g. conversations about collective learning) (Wise & Schwarz, 2017).

Data sources and search strategies

The literature was systematically collected on the databases (EBSCO Host (including ERIC, PsychInfo, PsychArticles, and Academic Search Premier; ERIC *n*=83) and (Google Scholar *n*=8) between the years 2012 and 2022. These databases are chosen because of the focus on education. To identify as much as eligible studies as possible, the search terms were modified together and combined with the Boolean operators as follows: (("knowledge building" OR "co-creation" OR "collective learning" OR "collaborative learning" OR" joint work")) and ("higher education" AND "instructional design").

Constitution of the corpus of analysis

First, we converted the original format of the publications into text files to use them for the topic modelling technique. During such a process, some noisy characters may have been included in the text. Then we applied the topic modelling technique. We use the Latent Dirichlet allocation (LDA) algorithm. While working with topic modelling, a capital question is how we determine the better number of topics for a model. As in previous research (Bent et al., 2021), we automatically determine the number of topics by measuring the semantical cohesion of the group of words in each topic. Semantic word representations were used, also known as embeddings from Spacy.oi, to assess the semantic cohesion. For the computation part, we used two measures, one based on the average of word semantic similarity and a second one based on the average distance of the words in the topic. We created 20 models starting with two topics.

Findings

To determine the support of PRISMA by NLP, the studied articles and outcomes from the PRISMA method (Table 1) are related to the four topics (Table 1).With the topic modelling method, the articles were ranked on which factor, from high to low the support the topic they are related to.

Table 1
Four determined topics

Topic	Words_raw (first 10)	Topic name	Description
1	Learning, education, teacher, teaching, students, teachers, research, technology, design, development,	Learning and technology	Learning and technology and learners
2	Learning, knowledge, collective, team, teacher, collaboration, individual, social, study, teachers	Collective learning	Collective learning and teachers
3	Education, learning, vocational, knowledge, students, epistemic, vet, teachers, educational,	Epistemic learning	Epistemic learning VET education
4	Learning, teachers, research, school, students, teacher, study, virtual, world, development	Learning and development	Learning and research and development

The findings show that the found concepts from the PRISMA method are related to the classified topics. For example, the NLP analysis showed that the designs of the articles in topic 1 are more related to literature reviews or methodological reviews. The articles ranking on topic 1 showed indeed more on technology and education like topic 1 suggested, but while going deep in the table of the PRISMA method also about professional learning. It seems to show a greater understanding of the concepts found in the PRISMA method.

Conclusion and discussion

PRISMA fosters a broad set of criteria for literature review and the need for expanding the possibilities to find more concepts (Gough et al., 2012) and a better understanding of answering questions. Using topic modelling to discover more concepts to find design factors needed to co-create for creative lessons helps to see if more patterns are found. In the determined principles of co-creation such as shared vision, dialogue and inquiry, collective action and reflection emerge in topic were there seems a connection between reflection in the manual findings and that technology could also be related. This supports determining better to find patterns needed for finding factors. The subjectivity of manual reviewing decreases with the support of machine learning.

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Fostering Productive Uncertainty Management in Engineering Problem-Solving Through Reflective Prompts

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Abstract: Engineering problem-solving often involves managing uncertainties arising from various unanticipated issues and novices tend to ignore them or manage them unproductively. They require support to articulate uncertainties and build tolerance to manage them. The current study explores the role of reflective prompts in uncertainty management among novices. The analysis presents a promising role of prompts in not only acknowledging uncertainties but also in acknowledging relevant and productive uncertainties.

Introduction

Engineering practitioners typically encounter complex ill-structured problems in which they face unanticipated issues leading to uncertainties (Jordan & McDaniel, 2014). Thus, managing these uncertainties productively (Manz, 2018) become an integral part of engineering design. However, the skill to think, reason and manage uncertainties is found to be uncommon and challenging to learn (Dym et al., 2005). And previous work has shown that novices tend to ignore uncertainties or jump to conclusions immediately contrary to experts who manage uncertainties productively by acknowledging, maintaining and prioritizing them (Kaur & Dasgupta, 2022). In this regard, novices require support to identify and articulate uncertainties and build tolerance towards them. This requires higher-order thinking skills such as critical evaluation of the situation to identify productive uncertainties. Previous research finds reflective prompts to foster these skills in science projects by facilitating critical thinking and knowledge integration for sensemaking among middle school learners (Davis, 2003). Current work explores the role of such reflective prompts in fostering productive uncertainty management among undergraduate engineering students as they solve an engineering problem.

Method

Study design

A quasi-experimental study was designed to investigate the role of reflective prompts. Two teams of undergraduate engineering students were given the task of programming an educational robot to interface the line and color sensors. They had to program the robot to autonomously follow a black line path on a 7x7ft arena and correctly identify color patches along the nodes (black-colored square markers on the path). Teams were also given additional tools and equipment such as studs & screws, black chart paper, clamps, etc. for effective sensor interfacing. All the participants were from third-year electronics engineering with a similar academic performance history (CGPA>8.5) and a basic understanding of microcontrollers. They were provided a workshop of two hours to get them acquainted with the robot as they had no prior experience working on such a task. They were also provided code on analog to digital conversion (ADC), LCD, color sensor initialization, etc. to help them solve the task in the given time. The major challenge for students in this activity was thus integrating various elements and calibrating sensor values to solve the task. One team (prompts team), consisting of three boys and one girl received the prompts while solving the task. They received prompts such as "we have the following components" or "we wonder.."or *"regarding this we think.."* to trigger reflection (Davis, 2003). The other team (no-prompts team), consisting of one boy and two girls did not receive prompts. This team did not receive prompts but was given direct instruction to help them solve the task and overcome frustration if the team struggled too long with an issue.

Data collection and analysis

Both teams were given 90 minutes to complete the task and their audio and video were recorded to capture their activities. Qualitative content analysis (Mayring, 2015) was done on transcribed data using coding schemes from existing literature to identify uncertainty (Jordan & McDaniel, 2014), its category (productive or unproductive) (Manz, 2018) and the reflective behavior of participants (Davis, 2003). Due to poor audio quality during the first 23 minutes for the no-prompts team, their activities from 24th minute onwards only are analyzed.

Findings

Team activities

Both teams could not complete the task in the given amount of time. They faced a major problem of line following with the robot failing to identify nodes along the line. Within this larger issue, both teams faced various uncertainties and attempted to manage them. For example, teams faced uncertainties regarding the behaviour of the robot on the line and around the node as it misses the line or regarding the effect of velocity on line following. We found the no-prompts team to face more uncertainty episodes (28) than the prompts team (16). However, the no-prompts team spent less average duration per uncertainty (1.7 minutes) and more duration on uncertainty management (2.6 minutes). This is in comparison to an average of 2.4 minutes per uncertainty and 1.9 minutes of uncertainty management for the prompts team. Thus, we found that ***the prompts team did not jump to conclusions immediately but spent more time identifying uncertainties before attempting to manage them.*** We found some of these uncertainties and uncertainty management activities to be productive while others to be unproductive. The categorization is based on the discussion with subject matter experts regarding best practices to solve the given task. Uncertainties such as anticipating robot behaviour in the arena, changing value of the threshold, etc. are identified as productive as these relate to relevant aspects of the problem. Uncertainties such as changing the given ADC conversion or LCD code and changing the velocity are categorized as unproductive to solving the given task as they do not relate to relevant aspects of the given problem. We found the no-prompts team engaged in productive activities, for approximately 35% of the recorded duration. In contrast, the prompts team engaged in productive activities, for approximately 56% of the duration. ***Thus, the prompts team engaged more in productive activities compared to the no-prompts team.***

Role of prompts in productive uncertainty management

We analysed different episodes of prompting the team to further understand the role of prompts in productive uncertainty management. During the prompting episode at around 33rd minute, the team members identified black chart paper as potentially useful material (acknowledging uncertainty). In the episode at around 63rd minute, the team develops an understanding that ambient lighting may affect node detection and in the episode at around 77th minute, the team refers to the previous understandings (2nd episode) and relates it to the given material (1st episode) and follows a new approach, of using the given material to tackle the issue. Thus, at the end of 3rd episode, the prompts team understands the role of ambient lighting in line and node detection and decides to use the black chart paper to cover the sensors to avoid noise due to lighting. ***Through this analysis of prompting episodes, we see that reflective prompts are found to affect the team's approach to help them acknowledge and manage uncertainty productively.***

Conclusion

The current work identifies the potential role of using reflective prompts in productive uncertainty management. We found prompts to help teams identify productive uncertainties and spend more duration in productive activities towards managing them. Further research on evaluating the role of prompts from a lens of epistemological and positional framing of participants will lead this exploration towards generalization.

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Characterizing Students’ Performances for Interactive Instructional Decisions Making to Meet Individual Needs

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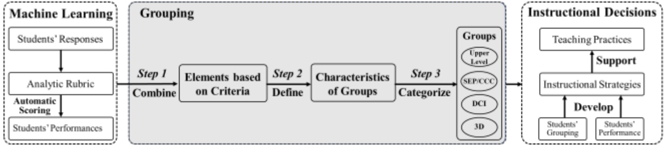
Abstract: With the increasing emphasis on the goal of knowledge-in-use in science learning and the growing research of machine scoring on science assessment, teachers can provide feedback to meet an individual student’s needs. The results were used to characterize students’ performances and interpret students’ challenges in knowledge-in-use. This study presents an approach of using the information of machine learning assessment to provide student difficulties for supporting teachers’ decision-making and providing feedback on students’ needs.

Conceptual framework: Characterizing students’ knowledge-in-use

Providing timely feedback on students’ performances is essential in successful knowledge-in-use teaching. However, teachers face challenges assessing and providing student feedback, particularly in large and diverse settings. Researchers have used machine learning to assess students’ responses to knowledge-in-use tasks (Zhai et al., 2021) and have shown the effectiveness of machine learning in scoring tasks and providing timely feedback to learners. However, only a few studies examine supporting teachers in making instructional decisions and designing instructional strategies based on students’ performances via machine learning. To overcome this barrier, this study characterizes and categorizes students’ performances on knowledge-in-use assessments to reduce the cognitive load on teachers interpreting the results from machine scoring. Figure 1 illustrates the process we used to build a system for characterizing and grouping students’ performance on knowledge-in-use assessments to support instructional decision-making. Our approach has three phases: machine learning, grouping, and instructional decisions. This paper focuses on the *grouping phase*. The research questions are: (1) How to characterize students' responses to knowledge-in-use science assessment to allow teachers to more efficiently and productively provide feedback to meet student needs and promote student learning? (2) How do students perform when applying scientific knowledge and scientific practices on knowledge-in-use assessments?

Figure 1
The Framework of Process of Grouping Based on Machine Learning Assessment



Method

Subjects and procedures

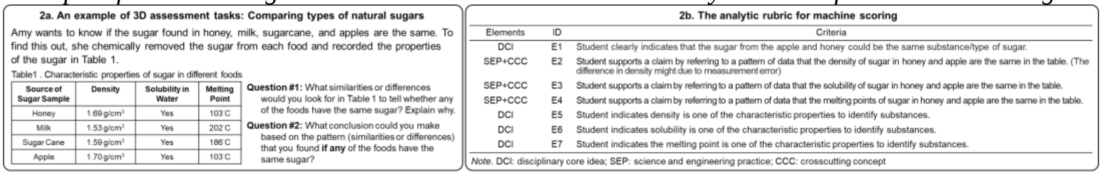
The participants were middle school students (11-13 years old) in the U.S. who completed knowledge-in-use assessment tasks from the Next Generation Science Assessment [NGSA] portal. The NGSA tasks, designed as formative assessments, assess students’ proficiency in using knowledge to make sense of phenomena. We selected three tasks aligned with the middle school physical science standards (Figure 2a). We randomly collected 1,200 students’ responses for each task from the database. Then, we used analytic rubrics for human and machine scoring of responses. The interrater reliabilities using Kappa values are higher than 0.7 between humane raters and 0.89 between the human and machine scoring. Finally, we followed a process for grouping (Figure 1) to categorize students’ performances based on students’ challenges in applying three dimensions -disciplinary core ideas [DCIs], science and engineering practices [SEPs], and crosscutting concepts [CCCs]- and present this information to teachers.

Analytic rubric

We developed analytic rubrics to measure different aspects of knowledge-in-use assessment tasks (He et al., in press). There are seven elements in the analytic rubric, and each element presents an aspect of knowledge in use learning (Figure 2b). The analytic rubric allows for characterizing proficiency in the DCIs, SEPs, and CCCs.

Figure 2

Example of the Knowledge-In-Use Assessment Tasks and the Analytic Rubric for Machine Scoring



2a. An example of 3D assessment tasks: Comparing types of natural sugars

Amy wants to know if the sugar found in honey, milk, sugarcane, and apples are the same. To find this out, she chemically removed the sugar from each food and recorded the properties of the sugar in Table 1.

Table1 . Characteristic properties of sugar in different foods

Source of Sugar Sample	Density	Solubility in Water	Melting Point
Honey	1.69 g/cm³	Yes	103°C
Milk	1.53 g/cm³	Yes	202°C
Sugar Cane	1.59 g/cm³	Yes	186°C
Apple	1.70 g/cm³	Yes	103°C

Question #1: What similarities or differences would you look for in Table 1 to tell whether any of the foods have the same sugar? Explain why.

Question #2: What conclusion could you make based on the pattern (similarities or differences) that you found **if any** of the foods have the same sugar?

2b. The analytic rubric for machine scoring

Elements	ID	Criteria
DCI	E1	Student clearly indicates that the sugar from the apple and honey could be the same substance/type of sugar.
SEP+CCC	E2	Student supports a claim by referring to a pattern of data that the density of sugar in honey and apple are the same in the table. (The difference in density might due to measurement error)
SEP+CCC	E3	Student supports a claim by referring to a pattern of data that the solubility of sugar in honey and apple are the same in the table.
SEP+CCC	E4	Student supports a claim by referring to a pattern of data that the melting points of sugar in honey and apple are the same in the table.
DCI	E5	Student indicates density is one of the characteristic properties to identify substances.
DCI	E6	Student indicates solubility is one of the characteristic properties to identify substances.
DCI	E7	Student indicates the melting point is one of the characteristic properties to identify substances.

Note. DCI: disciplinary core idea; SEP: science and engineering practice; CCC: crosscutting concept

Characterizing student performances on knowledge-in-use assessment

To support teachers with meaningful information based on students' performances, we combined the elements within the analytic rubric based on the use of scientific ideas (DCIs). For example, we combined E6 and E7 using expert reviews and statistical analysis. First, from a content perspective, density (E5) is a critical and more challenging property for students. Second, based on the results of statistical analysis, the Kappa value of the agreement between human and machine scoring increased when E6 and E7 were combined. Similarly, we made the two elements with SEP and CCC (E3 and E4) into a new element. We used these new elements to classify students' performances and defined the characteristics of groups according to performances on the updated analytic rubric. In the last step, we categorized students into four groups: students needing support to (1) move upper level, (2) use SEP and CCC, (3) understand DCI, and (4) use DCI, SEP, and CCC. For example, if a student responded that Apple and Honey are the same, they considered that the density, solubility, and melting point provide characteristic properties to identify substances. Moreover, the student shows that Apples and Honey have the same melting point and solubility. The student performed adequately based on elements of DCIs but insufficiently on the elements of SEP and CCC because they did not discuss the data related to the density. Thus, we categorized this group as needing support on SEP/CCC.

Results

The pattern of the distribution indicates that students who need support on the DCIs, SEPs, and CCCs had the highest percentage across the three tasks. For example, more than 80% of students were categorized into the group needing the DCIs, SEPs, and CCCs support, and the remaining students were grouped across the DCI group (10.01%), the upper-level group (3.08%), and the SEP/CCC group (0.05%) in task one. Although the percentage of groups differs among the three tasks, the distribution pattern is similar. The results indicated that students need help integrating the dimensions in solving problems or explaining phenomena. Students need support in using the dimensions, and teachers need to design effective strategies to promote students' proficiency.

Discussion and conclusion

We illustrated our approach for characterizing and grouping student performance on knowledge-in-use tasks: (1) combining the elements of the analytic rubric, (2) defining the characteristics of groups, and (3) designing the process of categorizing students. This approach can provide teachers with students and the whole classroom's performances categorized by areas needing support so that teachers can adjust their instruction to support student and class needs in a timely manner. We presented preliminary results of human and machine scoring to show the process of grouping. We are conducting further research to explore how groupings and associated information on students' performances support teachers and what and how additional information generated from machine learning scoring of assessments can be provided and used for making instructional decisions.

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Proof of Concept and Design Principles for Culturally-Sustaining Educational Assessment

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Abstract: Despite broad scholarly agreement supporting culturally-responsive education, uptake remains sporadic because of multiple forms of resistance. We contend that educational assessment is a crucial locus of resistance *and* inclusivity. We introduce an approach to formative and summative assessment that responds to multiple forms of resistance and is organized around four levels of increasingly formal assessment. We present new assessment design principles based on an initial proof of concept from a graduate course on assessment.

Introduction

Despite recent suppressive legislation, there is broad support for asset-based responses to diversity and discrimination in education. These include *culturally relevant education* (CRE, Aronson & Laughter, 2016), and *culturally sustaining pedagogy* (CSP, Paris, 2012). But uptake of asset-based responses has been sporadic in K-12 schools (Neri et al., 2019) and universities (Hanesworth et al., 2019). We argue that educator-created assessments are a significantly under-explored obstacle. In response, we offer a conceptual contribution and initial evidence for *culturally sustaining educational assessment* (CSEA).

Potential resistances to more inclusive educational assessment

Neri et al. (2019, p. 202) argued that school resistance to CRE is a "multi-level" problem that stems from (a) limited understanding and belief and (b) a lack of know-how. We agree, extend the argument to higher ed, and suggest that these challenges persist in the design of inclusive assessment. A second source of resistance is the aforementioned legislation limiting or prohibiting the discussion of race and gender. We assume that this resistance is likely higher when grading, assessment, and testing are involved. A third source is the challenge of creating "culturally valid" assessments, partly because educator-chosen representations that reflect the life context and values of minoritized youths may be rejected by those learners (Solano-Flores & Nelson-Barber, 2010). A fourth related source of resistance is that some students may feel pressured to speak for their communities.

Our final potential source of resistance is the most complicated and potentially contentious. This resistance is rooted in Paris' (2012) argument that pedagogy should “support young people in *sustaining* the cultural and linguistic competence of their communities while simultaneously offering access to *dominant cultural competence*" (p. 95, emphases added). We acknowledge the long history of blatantly racist use of standardized tests (Cunningham, 2019) and worry that prevailing summative assessments can encourage erasure and assimilation. But we also agree with Paris that all students must have access to the valued opportunities for educational advancement, admissions, and employment that are constrained by existing assessments created without attention to systems of power and privilege.

Introducing culturally sustaining educational assessment

CSEA emerged in an extended program design-based research of online courses and assessments (Hickey & Rehak, 2013; Hickey et al. 2020). This work embedded situative educational design principles for *productive disciplinary engagement* (PDE, Engle & Conant, 2002) within a situative multi-level assessment framework (Hickey & Zuiker, 2012). This resulted in a comprehensive framework that aligns learning across four increasingly formal levels of assessment that capture learning over increasingly lengthy timescales. These include (1) very informal *immediate* instructor analyses of student discourse, (2) informal *proximal* engagement reflections, (3) semi-formal *proximal* self-assessments, and (4) formal *distal* automated multiple-choice achievement tests. Iterative refinements in a range of online settings aimed to (a) maximize public interaction via threaded discussions of course resources and student work, (b) minimize private instructor-student interaction, (c) avoid dreary discussion forums that are removed from student work, and (d) preserve the validity of scores at each level as evidence of learning by avoiding teaching directly to those assessment items.

Starting in 2019, we began extending this framework to sustain diverse cultures in a way that helped all students master targeted course concepts, with the five potential sources of resistance in mind. This work was primarily carried out in an online course on educational assessment taught for many years by the first author and completed by the second and third authors as Ph.D. students. The course is a useful testbed because it typically includes students who identified with minoritized communities and who identified as politically-conservative (and sometimes expressed resistance to CRE, Hickey and Lam, 2022). We gradually extended the course using Agarwal and Sengupta-Irving's (2019) critique of PDE for ignoring the influence of power and privilege and their suggestion to include sociopolitical uncertainties (SPUs) that invite (without requiring) minoritized students to position themselves as having valuable experience and (therefore) expertise.

Our presentation demonstrates how each of the four assessment levels was extended to be more culturally sustaining. These included (1) adding an SPU in each assignment as one of two student-choice options and encouraging students to share unique expertise in informal instructor feedback, (2) adding a prompt for *cultural engagement* in the reflections, (3) including facts (but not opinions) regarding most of the SPU in the self-assessments, and (4) including facts (but not opinions) regarding some of the SPUs in the achievement tests.

We summarize evidence from 2022 as initial proof of concept. This includes analyses of 155 weekly e-portfolios (including instructor and peer comments), self-assessment and test performance, an interview with one of two African-American students in the course, and responses from the anonymous course evaluations.

We concluded that the expansion of CSEA in the 2022 section was promising, but more work is be needed for truly honest and productive dialogue (e.g., Vakil et al., 2016). We further concluded that these initial results support our proposed CSEA design principles:

1. **Include optional SPUs that invite, but do not require, students who identify with minoritized communities to position themselves as having valued relevant experiences and expertise.**
2. **Instructors' informal assessment of disciplinary discourse should position *all* students as having valued experiences and expertise and carefully introduce additional SPUs.**
3. **Encourage students to reflect on how social and cultural factors impacted their engagement without requiring them to speak for their community.**
4. **Instructors should read cultural reflections and directly respond to particularly compelling ones in public or private feedback as appropriate.**
5. **Include formative self-assessments for all controversies to efficiently foster familiarity.**
6. **Include exam items that assess the achievement of some (but not all) of the controversies and SPUs and ensure that those items function appropriately.**

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International Society of
the Learning Sciences

The Perceived Benefits and Pitfalls of a Hybrid Course Learning Modalities From a Self-Determination Theory Perspective

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Abstract: This study aimed to shed light on students' learning preferences post-COVID19. One hundred and thirty-four undergraduate university students attended physics hybrid courses and could participate by attending synchronously face-to-face, synchronously online, or asynchronously online. Most students initially preferred to arrive face-to-face but shifted to online modalities and were generally inconsistent in their attendance. The perceived benefits and pitfalls of different learning modalities were identified, and their relationships to self-determination theory are discussed.

Introduction

While some studies pre-COVID-19 show that most students preferred learning F2F (e.g., Jaggars, 2014), current studies suggest that the pandemic online learning experience may have changed their preferences (e.g., Castro & George, 2021).

Research shows that students' motivation is a critical factor in engagement in online learning. Self-Determination Theory (SDT) regards the conditions that can affect an individual's self-motivation. SDT points to three basic psychological needs are autonomy, competence, and relatedness (Ryan & Deci, 2019).

This study aims to analyze students' learning modality preferences by answering the following questions: (1) How would students learn, allowing them to choose between synchronously F2F, synchronously online, or asynchronously online?, (2) What are the reasons for students' preferences, and their relationships to SDT?

Method

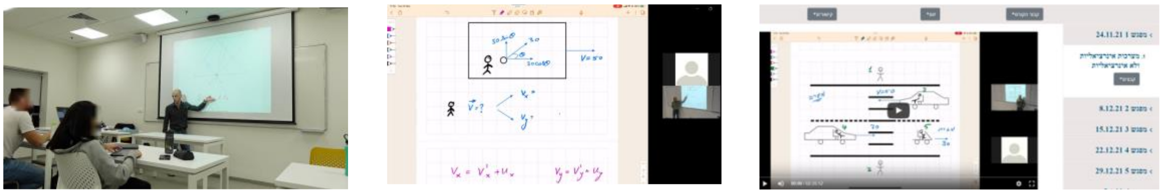
Participants

One hundred and thirty-four university undergraduate students in Israel enrolled in one of the hybrid physics courses and signed a consent form. One hundred and four answered all the questionnaires (51 males, 53 females, age mean=22.85, SD=2.07).

Material

Students could choose to participate in one (or more) of three learning modalities (F2F, Zoom, lessons' recordings) and could change their learning modality during the course (see Figure 1).

Figure 1
Photos/Screenshots of: (a) Synchronous face-to-face lesson, (b) Synchronous online lesson via Zoom, (c) Webpage for an asynchronous online lesson.



(a) (b) (c)

Research tools

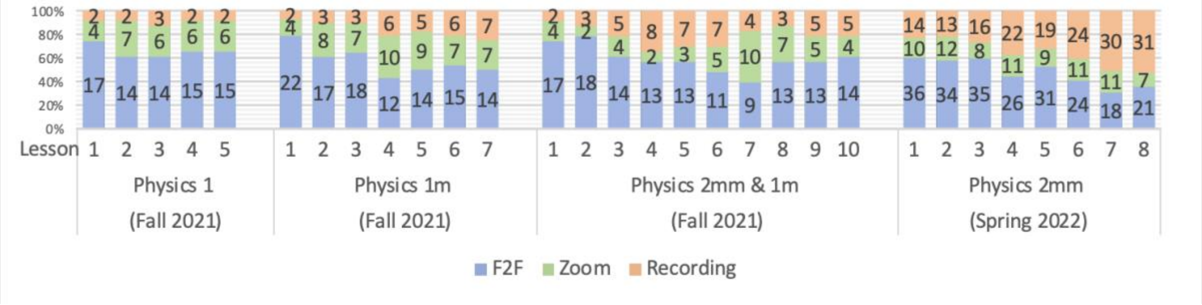
Students filled out a questionnaire including (a) learning attendance modality per each lesson and (b) open-ended questions regarding their reasons for their attendance, i.e., for each learning modality they attended they were asked: "what were the reasons for attending via F2F/zoom/lesson recording?". Thematic analysis was conducted on their answers (Braun & Clarke, 2006). In addition, the participants filled out a demographic questionnaire.

Findings

At the beginning of the course, most students arrived F2F, but the number of participants attending via zoom and recordings increased throughout the semester (see Figure 2).

Figure 2

Students' attendance sorted by courses with the same amount of lessons and hours. Physics 1/1m is Mechanics. Physics 2/2mm is Electricity & Magnetism.



At the end of the course, students answered open-ended questions regarding their learning attendance.

The benefits and pitfalls of learning F2F. Students reported several benefits of learning F2F: (a) increased concentration, (b) decreased distractions, (c) better understanding, (d) increased sense of commitment, (e) Social learning support, and (f) educational atmosphere. Nevertheless, students also reported pitfalls of learning F2F: (a) losing track of the lecturer, (b) losing concentration, and (c) no time/space flexibility.

The benefits and pitfalls of synchronous learning via Zoom. Students reported several benefits of learning via Zoom: (a) learning individually, (b) reduced travel time, flexible space, and (c) health benefits. Nevertheless, students also reported pitfalls of learning via Zoom: (a) decreased concentration, (b) increased distractions, (c) discomfort asking questions, and (d) technological problems.

The benefits and pitfalls of asynchronous learning via lesson recordings. Students reported several benefits of learning via lesson recordings: (a) controlling the pace of the lesson, (b) time/space flexibility, (c) allowing repetitions after the synchronous lesson, (d) lowering pressure during the synchronous lesson, (e) health benefits. Nevertheless, students also reported pitfalls of learning via lesson recordings: (a) requires self-discipline, (b) lack of social support.

Discussion

Students' initial preference for learning F2F is consistent with other pre-COVID19 studies (e.g., Jaggars, 2014). Nevertheless, their pre-learning preferences are not entirely met with their actual attendance; some students shifted to online learning modality, and some were inconsistent in their learning modality choice.

Overall, six main categories were found through all benefits and pitfalls. SDT can be linked to the themes: Attention, self-discipline, and learning efficiency can be linked to competence, self-support to relatedness, and time/space flexibility and health to autonomy.

The research is limited to students learning in a technological institution, and students had a particular motivation to participate in the course (they were willing to pay to join the course).

In conclusion, the era of post-COVID19 has transformed online learning into a necessity for all higher education. The benefits and pitfalls of each learning modality should be considered in designing learning modality post-COVID19. For students to choose between the benefits and pitfalls of each learning modality, it may not be trivial.

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Visualizing Funds of Identity: Using Network Software to Model Collective Identity in a Classroom

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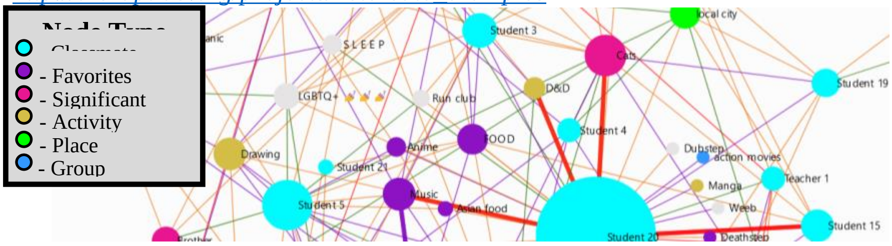
Abstract: Funds of Identity is a valuable way of understanding the resources learners bring to the classroom from home and that are relevant to them. In the present study, we supported learners in using the Net.Create network visualization software to support 5th- and 6th-grade students in representing their collective funds of identity as part of a data literacy unit. We present analyses showing how this tool supported their articulation and a summary of the ideas they viewed as central to their identity.

Introduction

Identity is a central concept in many learning theories, for instance, the funds of identity (FOI) framework proposed by Esteband-Guitart and Moll (2014). Funds of identity refer to the subset of their background knowledge that students find relevant to their own lives in their current context. While it is crucial that teachers understand their students' FOI to develop dignity-affirming instruction, teachers struggle to elicit this kind of information (Neri et al., 2019). In this study, we attempted to extend the theoretical notion of FOI in two ways, one practical and one theoretical. Practically, we show how network visualizations can help make identities - a key component of FOI work - visible in new and interesting ways. Theoretically, we expand the conception of a fund of identity as something that can be understood as shared or emergent. This allows us to lay the groundwork for theorizing the concept of collective funds of identity, a concept developed in collaboration with Dr. Rebecca Colina Neri.

A network visualization is a graph composed of 'nodes' which are connected to each other via lines, called edges (see Figure 1 for an example). They are often used to understand complex datasets where the relation between entities is important - for instance, a social network like Twitter. Net.Create is an online tool designed to create network visualizations (Craig, 2017; Craig et al, 2021). It supports simultaneous editing by many users, making it ideal for in-classroom use. Other analyses (Zhou et al., 2023) have shown how Net.Create can mediate students' understanding in classroom activities; the present analysis focuses on how these interactions support identity exploration.

Figure 1
An anonymized section of the identity network visualization made by participants in the class. The labeled circles are nodes, the lines between them are edges. Full graph: http://theraptlab.org/projects/netcreate_examples



Methods and design

The research team designed and led a six-day unit on networks and data literacy in a combined 5th- and 6th-grade classroom. The classroom was in a private school located in the midwestern United States. 11 students self-identified as female or girls, and 11 identified as male or boys between the ages of 10 and 12. Most students self-identified as White or American, 1 identified as 'Latina', 1 as 'Mexican', and 1 as 'Mixed'; English was the primary language spoken at home by all participants. From this intervention, the team collected video recordings (both classroom interactions and post-activity debriefs), physical artifacts, and digital networks created by students.

Each day, students participated in several activities designed to engage them with the concepts of network science, such as centrality, gravity, or betweenness (Hammer & Berland, 2014). Some of these activities used the Net.Create software while others used physical materials such as yarn to represent edges; most were playful. In addition to the other activities, students worked in pairs using the Net.Create software to iteratively construct a network visualization of their likes, interests, and connections. The categories (node types) in this network were based on the categories used in the FoI Literature (Esteban-Guitart & Moll, 2014). While individual students were only supposed to add and connect themselves to things that they personally liked, the eventual effect was something that showed collective as well as individual interests. For instance, students were able to see which people and things were more central to the classroom network - pet ownership was very central, something that several students claimed to not have been aware of before the activity.

Findings

Our analysis indicates that students, generally, articulated a greater number of network science concepts after engaging in network visualization activities (Zhou et al, 2023). Importantly for the present analysis, the identity network created by the students shows some of the key interests that students have and are comfortable sharing in their classroom such as interests in cats, drawing, and a wide range of foods. When asked in the post-interviews and during the implementation whether they felt the identity network 'represented' them *as a class*, students almost universally agreed (8 of 9 groups), leading us to infer that these entities are representative of actual interests. However, when asked if they felt the network represented them as an individual they were less positive.

Using interaction analysis of post-implementation interviews, paired with an analysis of the network artifacts, we also found that students felt like they learned a lot about their collective identity and how it may be represented through the network visualization activities. Much of this was specific facts, e.g., a lot of people in the class like cats or listening to music, but several students went further indicating that the network increased their sense of belonging. One student stated "I never knew how connected we all were…[or that] I had so many connections to people I don't even talk to" while another claimed that the amount of overlap in the classroom connection made them realize "if we just talked to each other more we'd be friends". When asked if the network helped them learn anything about themselves, one student said they "found out stuff I didn't think I was into", but then when they saw those things in the network they realized that not only did they like those things, others in their class also did.

Conclusions and significance

Eliciting identity in a way that is useful to an instructor is difficult (Neri et al., 2019). The use of network visualization software offers a promising classroom-based approach to eliciting students' individual and collective funds of identity in a manner that has the potential to support greater asset-based instructional work by teachers, though additional work is needed to better document how this representation both does and does not reflect learners' ideas and identities.

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Fostering Subjective Understandings: Exploring the Role of Place and Transdisciplinarity in a US Teacher Education Program

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Abstract: Education in the United States is often siloed by discipline, making transdisciplinary teaching and learning supporting social justice challenging. Drawing from a multi-year collaboration centering place, dominant narratives, and mapping in an elementary teacher education program in the mid-Atlantic region, we examine prospective teachers' justice-oriented inquiries posed across varied settings. We find that place-based pedagogies, collaborative cross-discipline teaching, and a question posing focus fostered transdisciplinary sensemaking, but also note limitations promoting further study.

Introduction

Within STEM education, there is an ongoing siloing of disciplines from Kindergarten through higher education, resulting in prospective educators often having limited opportunities to consider broader historical socio-political dimensions that shape disciplinary teaching and learning (Sengupta-Irving & McKinney de Royston, 2020). Takeuchi et al. (2020) argue that a *critical transdisciplinary* approach is essential to disrupting disciplinary hegemonies, to making possible forms greater than the sum of the disciplines centering equity and justice. We report on years 1 and 2 of a multi-year design-based research project that supported prospective teachers in experiencing and designing for transdisciplinary learning, building on our collective work as professors teaching Science, Social Studies, and Mathematics Methods, respectively, in an elementary teacher education program.

Theoretical framework

We draw on the work of Sylvia Wynter (1995), a Jamaican transdisciplinary scholar in U.S. Black Studies. Her essay *1492: A new world view*, uses *subjective understanding*, to offer an alternative perspective on Columbus. Subjective understanding refers to how sub-goals are a necessary part of the path to the ultimate goal. Applying this to Columbus, Wynter examines the many disciplinary frameworks (theology, social discourse, science, geography, politics) that made Columbus, the resultant narratives, and all the tragic consequences possible, that is, a subjective understanding of Columbus. This understanding of disciplinary learning and social justice aligns with Takeuchi et al.'s (2020) conceptualization of *critical transdisciplinarity*, which entails "interrupt[ing] disciplinary hegemonies to … lead to the emergence of new concepts, representations, and applications, that ideally should also re-center voices from the margins" (pg. 218).

In our collaborative methods classes, transdisciplinary learning and teaching took on three elements: 1) our own collaborative teaching as a model for our students, 2) using a variety of disciplines to answer larger questions about how injustices are made possible, not simply weaving together disciplines, and 3) centering historical and current narratives in local places as visible constructs that can be deconstructed and reconstructed by teachers and students.

Methods

Drawing on Soja, we understand "spaces as simultaneously sites of injustice and emancipation" (pg. 27), becoming particular places through "a simultaneity of stories-so-far" (Massey, 2005, pg. 5). We conjectured that a constructed and contested place would be generative for supporting prospective teachers in moving beyond *what is* towards *how it came to be*, in turn making visible dominant narratives across a range of phenomena and disciplines. To that end, we designed a three-class sequence as part of the methods courses, centering activities around a revered Colonial Site adjacent to the university campus and several public schools.

In the first class, prospective teachers were supported in considering the complexities of place for teaching and learning. In the second class at the Colonial Site, prospective teachers had extended time to explore their emergent questions and identify primary sources at the Colonial Site. Prospective teachers worked in pairs, spending 45 minutes freely walking around the grounds and recording emergent questions that intersected with science, math, and social studies disciplines. In the third class back in the campus classrooms, prospective teachers added their questions and images to a collaborative ArcGIS map, a participatory Geospatial Information System (GIS) mapping tool, enabling the sharing of questions, specific locations, and related media in their lesson plan designs. Prospective teachers then worked in groups of 3 or 4 to imagine transdisciplinary lesson designs anchored around questions that might surface dominant and nondominant narratives (e.g. whiteness, erasure of Black and Indigenous voices) through a transdisciplinary approach.

Participants and data sources

Participants included two cohorts of prospective elementary teachers, comprising 43 Masters (MA) and Bachelors (BA) students in total. Data sources include researchers' field notes for each class session, video recordings (e.g. GoPro video outside, whole group video), and digital/paper artifacts (e.g., brainstorming place from Day 1, pairs' questions and source note sheets from Day 2, collaborative question mapping using ARCGIS maps and poster lesson plans from Day 3).

Analytic methods

In this analysis we ask: Which subjective understandings became visible and which remained hidden in this transdisciplinary learning and teaching sequence? Using thematic analysis (Saldaña, 2016), we focused on prospective teachers' questions emerging across the three class sessions. We coded artifacts and video in two waves, focusing on (a) what disciplines were leveraged in questions and (b) if or how questions attended to the construction of the Colonial Site, demonstrating subjective understandings.

Results

Prospective teachers incorporated all three disciplines in their lesson plan questions centering social studies due to the nature of the site. Notably, prospective teachers generally generated math questions and activities by calculating costs or measurements, not engaging with socio-political or historical inquires (Gutstein, 2012). As an example, one pair developed an overarching question of "How communities interact with gardens?" For social studies, the pair emphasized social and economic inequities by asking "Who benefits from the garden? Who owns the garden?" They also included the question "Who works in the garden?" to attend to the reality of enslavement. With regards to science, the same group focused on how humans and more-than-humans shape the environment and each other by asking "How do gardens change the natural landscape? How do humans and animals interact or affect the gardens and one another?" The pair also posed mathematical questions, focusing on measuring the size of the garden and other spatial arrangements removed from historical, social or political inquiries.

In terms of the visibility and invisibility of subjective understandings emergent in prospective teachers' questions and lesson design plans, we found that every group developed lesson plan question ideas on Day 3 that acknowledged the presence of socio-economic and historical inequities, drawing together several disciplines. Yet rarely did their questions move deeper into *why* and *how* they came to be, that is, the subjective understanding that Wynter details in *1492*. Across the multiple groups that fully or partially attended to subjective understandings, we observed that the theme of change and continuity over time facilitated an initial responsiveness not only to the constructedness of the Colonial Site, but to how knowledge in science, history, and as disciplines are also simultaneously constructed and deconstructed.

Conclusion and contributions

We join scholars and educators attending to the complexities and possibilities of supporting *critical transdisciplinary* teaching and learning, with a focus on equity and place in teacher education. We offer empirical evidence of how such transdisciplinary sensemaking might emerge within a closed time period, centered around a contested place and involving cross-disciplinary faculty collaborations, with key areas identified for further support in future iterations.

Endnotes

(1) All authors share first authorship, contributing equally to the project and the proceeding.

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#Antiracist: White Teacher Agency and Learning on Twitter

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Abstract: This study draws on interviews with three White teachers to answer the question: How do White teachers agentically pursue their own antiracist learning and development through their use of Twitter? My analysis shows how participants use Twitter to interrogate their own whiteness, hold themselves accountable, and find support for vulnerability and discomfort—creating rich opportunities for transformative antiracist learning.

Introduction

Many teachers rely on resources found outside of schools and even outside of their local communities to supplement their professional development, especially where controversial topics such as race, racism, and antiracism are concerned. In this paper, I highlight teachers' agency in self-directing their antiracist learning and development on Twitter, guided by the question: How do White teachers agentically pursue their own antiracist learning and development through their use of Twitter? The three study participants described rich possibilities to build supportive race-conscious learning communities beyond what is available within the confines of school- and community-based learning spaces.

Prior research and theoretical framework

Using Whiteness Studies (Leonardo, 2009), and sociocultural learning theories (Vygotsky, 1978), this study views White racial identity development as a process of unlearning (Tatum, 1992) supported by participation in social activities that challenge to previously held ideologies (Leonardo & Manning, 2017). Following these frameworks, antiracist learning requires trusting and supportive relationships that hold teachers accountable to their antiracist development as well as humanizing support and guidance in which White teachers are situated as valued members of an antiracist community as they navigate the vulnerability of unlearning (Leonardo, 2009; Leonardo & Manning, 2017; Picower, 2021). Prior research suggests that White teachers often resist the necessary and uncomfortable work that antiracism requires (Picower, 2009). Other studies emphasize the success of specific programs and in-person communities that not all teachers have access to, and in which teachers have little responsibility or agency for directing themselves (Picower, 2021). Without discounting the literature describing White resistance to antiracist learning, this study investigates teachers' agency in seeking support to develop their understanding of and commitment to antiracism. There is growing recognition that teachers are agentic sense-makers who make meaningful decisions impacting their own development (e.g. Anderson, 2010; Louie, 2017). Social media may be a particularly valuable resource for teachers pursuing antiracist learning and development, as they may use online platforms to self-direct their own learning and build supportive communities (Carpenter & Krutka, 2014). The present study offers new insights into the possibilities of sites like Twitter for supporting White teachers' self-directed antiracist learning.

Methods

This analysis focuses on three participants, Mark, Erica, and Pam (pseudonyms), that all self-identified as committed to antiracist education and agreed that Twitter influences their antiracist development. These three participants also participated in "Accomplices" (a pseudonym), a private Twitter group of White educators, which became a central interest of my analysis. Interviews were conducted and recorded via Zoom in Spring 2021. Using a form of stimulated recall interviews (SRI; Dempsey, 2010), I prompted participants to provide detailed descriptions of their experience on Twitter by situating that experience in their recent activity. Following SRI protocol, I used participant observation to gain knowledge of participants' behavior to inform the questions that I asked. Although excluded from my analysis, these observations provided a sense of how participants typically used Twitter. Interviews focused on how participants made decisions about who they perceived as guides and sources of support for their antiracist learning. To analyze the interview data, I used open coding to identify common themes first focusing on the tools and activities that participants described (e.g., following, likes, hashtags) and the people that they named as influential to their development. Informed by the literature, further analyses focused on how participants made decisions about whom they perceived as guides and whom they turned to for support. I also looked for indications of how these decisions were made with a consciousness of the racial dynamics of Twitter-based relationships and how this consciousness influenced how they used Twitter.

Findings and implications

Three themes emerged from my analysis: 1) participants valued Twitter as a space to find new sources of guidance that could offer resources for making sense of antiracist teaching and that challenged their previous ideologies; 2) beyond only engaging with other users as sources of guidance, participants also developed personal relationships with users that supported their growth by holding them accountable and offering a space to share vulnerabilities; and 3) each participant described the ways they confronted their own racial biases and white socialization as a result of their engagement with networks of teachers on Twitter.

In making decisions about whom they perceived as guides and chose to follow, each participant named race as a key factor. Specifically, Black women were named as important sources of knowledge along with other White teachers who functioned as role models for their antiracist development. Although they did not always interact with these guides in ways the guides noticed, the guides were nonetheless meaningful resources to participants. Furthermore, participants made critical decisions about who would best support their development based on the content of the user's Tweets and their reputation within antiracist Twitter circles. Eventually, each participant became a member of a private DM group, Accomplices, for White teachers committed to antiracism. The community they built through Accomplices provided a space to work through their discomfort and hold each other accountable without expecting people of Color to do so. Critical to their online relationships was a sense of accountability and trust that developed over time and shared values that allowed them to express vulnerabilities and challenge one another.

Through access to guidance and the communities that they became a part of, participants described their Twitter activities as helping them become more conscious of systemic inequities and the ways that they themselves have been socialized by whiteness. This was especially true for one participant (Erica) who described having limited interest in her own antiracist development prior to encountering discussions of antiracist education on Twitter. This points to the unique ways that platforms like Twitter can make unexpected resources for learning visible to teachers. They also named ways that their conversations on Twitter inspired them to incorporate lessons that examined racial biases (Mark); explicitly address implications of recent events of racist violence (Pam) and help their students (preservice teachers) to find resources and communities of support that would encourage their antiracist development (Erica). While conscious of their positionality and aware that they always have more to learn, each participant expressed that Twitter helped them to feel a sense of empowerment to challenge racist systems in their daily lives.

These findings demonstrate the possibilities for White teachers to actively pursue antiracist (un)learning in transformative ways. Rather than avoid discomfort, the teachers in this study frequently sought out discomfort and built relationships with people who would hold them accountable to their antiracist development. Furthermore, this study describes teachers' agentic use of technological resources to access new sources of guidance and support and suggests that sites like Twitter may provide opportunities for White teachers to participate in new social activities that help reveal the ways that they have been socialized by whiteness. More research is needed to investigate the themes described in this study such as the role of White teachers in acting as antiracist guides for other White teachers and how such learning is taken up in practice. By examining teacher learning in informal and self-directed spaces, we can better understand the types of activities that both support teachers' development and invite their active participation. Additionally, by examining the increasing use of technology and social media as a resource for expanding opportunities to engage in antiracist learning, we can learn more about future possibilities for teachers to build the kinds of national and cross-racial coalitions that are necessary to dislodge the foothold of white supremacy in education.

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A Pilot Study of Chinese Academic Motherhood, Strategic-Decision-Making, and Course Design

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Abstract: Academic motherhood remains an area to be explored more deeply in China. This pilot study of online course (re)design during the COVID-19 pandemic is timely given shifts in China's Family Planning Policy. The Learning Design Components framework guided interview analysis of two mothers' strategic decision-making in (re)designing university courses. While their motherhood experiences during campus closures were challenging, their vicarious observations of their children's teachers' online pedagogy supported new strategies their adoption to empower undergraduates.

Introduction

Studies into Chinese academic mothers emerged after the late 1970s alongside policy reforms. Historically, female academics in China have had different career profiles and access. Before 1949, they were subject to compulsory termination upon marriage. While this improved with the creation of the People's Republic of China and the Cultural Revolution, access to qualifications for career advancements remained limited, as reflected in minimal research outputs (Tang & Horta, 2021). Ward & Wolf-Wendel (2004) indicated that a sense of accomplishment, self-esteem, respect, flexible schedules, improved efficiency and autonomy, and even being a better mother for some were positive aspects of academic motherhood. However, they also idenfied gender inequity, heavy workload, time shortage, and sometimes even guilt of not being a 'good mother' because of juggling work and life as challenges. Chinese academic mothers' work-life conflicts have their own specific characteristics, especially given their social context and China's family policy changes from one child (1980) to two children (2016) to three children (2021) per family. Research into Chinese academic motthers' course design experiences for online teaching and returning to campus during the COVID-19 pandemic will bring new insights into their academic lives. By investigating Chinese academic mothers' home-teaching and child-rearing experiences, this study aims to address the issues of school-society disconnect in a networked society (Tabak et al., 2019).

Conceptual framework

During the global pandemic and campus closures, academics adapted to emergency remote teaching, acquiring the expertise to (re)design courses and teach online from their homes. Rapanta et al.'s (2021) Learning Design Components (LDC) framework reflects the centrality of strategic decision-making for successful online course design and conceptually guides this research. Specifically, strategic judgments are influenced by institutional decision-making and long-term planning (macro-level professionalisation), cognitive apprenticeship (meso-level empowerment), and pedagogical and instructional approaches (micro-level flexibility). Meso-level empowerment scaffolds teacher expertise through co-design and coordination across formal and informal communities of practice, with the final design and its implementation reflecting the teacher's strategic decisions. The guiding question adopted in this pilot study is: *How does being an "academic mother" influence Chinese university educators' strategic decision-making in their course (re)design processes during the COVID-19 pandemic?*

Methodology

From the respondents of an ongoing online survey, two academic mothers from Liaoning Province, China were selected for case analysis based on their teaching discipline (English) and child profiles (Tracy - one 15 year old high school son; Rachel - two sons (15 year old middle school; 8 year old primary school). Tracy is a newly promoted professor and course coordinator, while Rachel is a lecturer and course team member. The differences in academic rank and child profiles indicate differences in workloads and priorities; however, both have courses of a similar size that required a shift to fully online delivery. Both joined in-depth, open-ended audio-recorded interviews (~30 min each) which were conducted in Mandarin via WeChat™ and translated into English. Thematic analysis of interview transcripts focuses on the student empowerment dimension of the LDC framework to explore the strategic judgements of both course designers (Braun & Clarke, 2006).

Results

Academic mothers and their child(ren) in this project all reported experiencing online and/or hybrid teaching during COVID-19 campus closures in China. Overall, both Tracy and Rachel's reflections illustrate the mutual effects of their dual identities of "mother" and "course designer". They indicated burdens of "workload," "lack of rest, and research productivity"; however, both dedicated time and space to course (re)design as they valued the quality of their online teaching during the pandemic. For example, Tracy equipped her course with an online "quiz" for formative testing of students' speaking. Specifically, academic motherhood during home lockdowns provided opportunities for them to observe "from the other side of the screen" and both cases reflected that this enhanced their empathy, encouraging them to create supportive classroom environments, a key facet of LDC empowerment. The emic, almost ethnographic observation of Tracy's son's home zoom classes provided an insight into "behind-the-scenes" activities facilitating new understanding and approaches:

> We can't see what students are like behind the screen in online classes. But if I observe my child in his online class, I will know his role as a student and how he interacts with teachers. It inspires me to motivate, interact, and be thoughtful with my students. (*Tracy, Nov 2022*)

Similarly, Rachel gained insights into students' home learning from her son's experience and found that it supported her interactions with her students and motivated her students' autonomy in the class:

> My son would lie to his teacher when he sneaked away by repeating "hi" to indicate a bad network. When my student did the same in my hybrid class, I would jokingly say, rather than being angry, "I can't ask him questions due to a bad network". (*Rachel, Nov 2022*).

Discussion & conclusion

Pilot analysis of these two cases indicates some positive outcomes from academic mothers teaching online from home during campus closures in China. Although the additional workload was acknowledged, both chose to prioritize their teaching over work-life balance and research productivity. As academic mothers teaching working online for the first time, they were able to adopt, adapt, and explore new strategies to empower students for synchronous online classes. From an LDC perspective, their observations of their children's classes and engagement in learning online at home scaffolded their learning and enhanced their adaptive expertise. While many university systems sought to support teachers formally, their "spontaneous", informal learning by observation supported their online (re)designs and provided a new dimension to their professional development in a networked society (Tabak et al., 2019). In both cases, they viewed this professionalisation as a rewarding aspect of academic motherhood. Their flexibility and creativity reflect Darling-Hammond and Bransford's (2005) notion of teachers' "innovation expertise" with creative solutions to online teaching challenges. Their decisions to appropriate the teaching practices of their children's online teachers and to support student empowerment by adopting more empathetic approaches led to transformations in their practice. Despite the challenges of caring for children whilst teaching online, they felt their motherhood experience positively influenced their strategic decision-making as teachers and course designers.

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Unsettling Socio-Emotional Learning:
Perspectives From Working With Resettled Refugee Youth

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Abstract: The COVID-19 pandemic ushered in significant shifts in how youth experience both in-school and out-of-school learning. One of the most notable changes was in where and how group interactions took place. This paper argues that in the transition from in-person to virtual programming, socio-emotional learning (SEL) requires additional planning and intention. We explore how facilitators and refugee youth negotiate SEL in a virtual summer program. Our findings reveal authentic SEL when facilitators use an ethic of care through technological troubleshooting. We also present nuances that youth offered to SEL, which trouble uniform depictions of what SEL might mean. From this, we share implications for further SEL work and intergenerational learning supports that extend beyond the challenges posed by a global crisis.

Introduction

Resettled refugee youth face significant challenges acclimating to a new society, including language barriers, unfamiliar social norms, values, belief systems, practices, institutional environments, and unwelcoming contexts of reception (Bennouna et al., 2021). The COVID-19 pandemic exacerbated the challenges that refugee youth face. Attending to, and supporting, socio-emotional Learning (SEL) skills serve as a powerful tool to support acclimation, sense of belonging, and continued learning in a new place (d'Abreu et al., 2019). This poster shares facilitative moves in a segment from a virtual summer program that centered Socio-emotional Learning for refugee, immigrant, and asylum seeking youth (grades K-12). We utilize discourse analysis to explore facilitator and children interactions as they read a book "Pete the Cat and His Magic Sunglasses". We highlight findings that demonstrate how facilitators can embody and implement authentic SEL and moments when youth expanded what counts as SEL.

Background

SEL is widely described as "the process through which children and adults understand and manage emotions, set and achieve positive goals, feel and show empathy for others, establish and maintain positive relationships, and make responsible decisions" (CASEL, undated). The layered traumas, grief, uncertainties, and isolation due to the COVID-19 pandemic, in the midst of increased racialized violence, has amplified calls for re-imagining teaching and learning that centers care and socio-emotional development (de Royston et al., 2020; Bang, 2020; Bang et al., 2021). Despite the promises of SEL to support students' learning and center relations of care, SEL curriculum often follows rigid scripts, which has negative consequences for the health and wellness of students of color (Camangian & Cariaga, 2021; Simmons, 2019; Simmons, 2020). Authentic SEL responds to students' cultural contexts, affirms those contexts, and addresses traumas. Facilitators need training that supports them with modeling and embodying SEL through an ethic of care.

Contexts, participants, and data

Researchers and participants

Participants are from a research practice partnership (Coburn & Penuel, 2016) started in 2017 with Refugees Around the World (RAW), a nonprofit refugee organization located in a large midwestern city. For the past several years, the research team has partnered with RAW to support after school and summer programming for local youth. Additionally, the research team takes on the responsibility of training summer interns for their work with the youth. An intern, Jamie, and the youth program coordinator, Myra, co-facilitated a session with five kindergarten-aged children. Jamie read aloud a book "Pete the Cat and His Magic Sunglasses" with an animated video to accompany the reading.

All participants use she/her pronouns and pseudonyms are used for participants and the organization. Jamie was not formally a teacher and was in a masters program for social work. Myra had led youth programming at RAW for one and a half years and has a background in trauma-informed and culturally-responsive pedagogies. The researchers were second and third-year Learning Sciences graduate students.

Methodological framework

Using discourse analysis (Gee, 2004; Rogers, 2011) we examine the interactions between facilitators and kids as they read and discuss the book "Pete the Cat and His Magic Sunglasses". Two vignettes highlight contrasting forms of 1) supporting youth as they struggled with the logistics of participating virtually, and 2) not fully acknowledging emotional sensemaking from youth that diverged from the learning material and facilitator's expectations.

Findings

Two findings demonstrate how facilitators and kids engaged with SEL. In the first finding, we notice moves enacted within the constraints of the virtual platform to model and embody SEL within an ethic of care. In the second finding, we share tensions around cultural framings that surfaced during a discussion of the book.

Discussion

The book and discussion serve as the primary artifact that Jamie used to implement her sensemaking around SEL with the kids. The discussion surfaced negotiations and tensions around cultural framings and assumptions tied to SEL goals in this session. In the second case, we see Myra's interventions to troubleshoot microphones as a move to value each kid's participation and part of a larger effort to lower the barrier to participation. Beyond a set of skills that can be developed, SEL is an embodiment of empathetic response and attending to oneself and others. Zoom required a level of slowed down attention from Myra and other facilitators, which reflected their goals of a SEL rich summer experience.

Implications

Existing scholarship argues that intergenerational, home contexts might offer a space and relationships to engage in authentic socio-emotional learning.

Conclusion

We see glimpses of possibilities for enacting authentic SEL that engages students, facilitators, and family members in embodying SEL skills beyond scripts. Future training for facilitators needs to articulate the dominant cultural framings of SEL that perpetuate ideas of SEL as scripts, and support sensemaking toward SEL rooted in relationships that attend to the layered contexts for youth.

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Supporting Culturally Relevant Computer Science: Evaluating Lesson Plans With a Research-Practitioner Partnership Rubric

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Abstract: This poster explores how teachers in a research-practitioner partnership utilize a rubric to evaluate lesson plans in terms of their integration of culturally relevant computer science. Results include that teachers felt able to include opportunities for cultural competence but indicate that additional support is necessary to include opportunities for cultural critique and conceptions of knowledge. The poster will highlight additional supports that teachers may need to develop culturally relevant computer science lesson plans.

Introduction and background

State and national frameworks in the United States (e.g., K-12 Computer Science Framework, 2016) task teachers to offer opportunities for equitable access to computer science (CS) to their students (Madkins et al., 2019). To promote equitable CS, we support teachers to integrate culturally relevant computer science education (CRCSE) through a research-practitioner partnership (RPP; Chiu et al., 2022). We broadly define CRCSE as a pedagogical strategy for teachers to leverage students' cultural identities and resources within the contexts of classrooms (e.g., Madkins, 2019), drawing on concepts of academic success, cultural competence, and sociopolitical consciousness (e.g., Ladson-Billings, 1995).

Elementary teachers may need support to develop CRCSE lessons, because they may not have a background in CS, may have limited experience with CS pedagogical practices, or may need support to draw upon their students' cultural assets within CS (e.g., Morales-Chicas et al., 2019; Yadav et al., 2021). RPPs can support elementary teachers to equitably teach CS within their culturally diverse classrooms by providing ongoing professional development (PD) tailored to fit the specific needs of their teachers through strong practitioner involvement. For example, PD through RPPs can help teachers to increase their confidence in teaching with CS (Rich et al., 2021) and empower teachers with the agency to develop tools for their own classrooms (e.g., Christian et al., 2021).

Yet few studies have explored how RPPs can support elementary teachers to build knowledge of CS practices, concepts, and pedagogical strategies (Henrick et al., 2019), particularly culturally relevant CS. The purpose of this work is to support elementary teachers to develop and implement culturally relevant curricular materials that integrate CS into core content areas. Specifically, this study explores how teachers utilize an RPP-developed rubric to evaluate their lesson plans to (1) support culturally relevant CS lesson development and (2) privilege the voice of teachers in considering the areas in which they find successes and the areas in which they indicate that additional support is needed. We explore the research question: To what extent do teachers evaluate their own integrated CS lesson plans as reflecting culturally relevant pedagogical strategies?

Methods

This study uses an embedded, single case study methodology (Yin, 2018) to consider artifacts from a five-day, summer PD workshop conducted by an RPP for elementary teachers. The purpose of this workshop was to help 3rd-5th grade teachers outside of the RPP develop culturally relevant lesson plans that integrate CS. Workshop participants included eight teachers, five teacher-leaders from the RPP, three researchers, and two non-profit leaders. Prior to the workshop, the RPP collaborated to create the lesson plan rubric. The rubric operationalized cultural relevance through cultural competence (maintaining students' cultural integrity during teaching and learning processes), cultural critique (helping students recognize, understand, and critique current social inequities), conceptions of self and other (commitment to the belief that all students can achieve), social relations (enhance student-teacher and student-student relationships and collaborative learning opportunities), and conceptions of knowledge (scaffold learning using artifacts endemic to your students' racial and ethnic identities and local/global culture and history). The rubric also enabled teachers to select the extent to which their lesson plan offers these opportunities for cultural relevance (yes, no, maybe) as well as to explain their reasoning. In the PD, the eight teachers worked to create their own lesson plans with support from the teacher-leaders, researchers, and non-profit leaders. The eight teachers were then encouraged to self-evaluate their lesson plans using the RPP rubric. The poster includes these artifacts (i.e., lesson plans and rubrics) and information about PD activities. For analysis, lesson plans and rubrics were blinded. Five RPP researchers together analyzed the teachers' rubrics in aggregate to note themes in how teachers used the rubric, areas of cultural relevance in which teachers felt they were doing well, and what additional supports they may need.

Results

Findings reveal that five teachers (pseudonyms used below) were able to use the rubric developed by the RPP to evaluate their CS lesson plans for opportunities of cultural relevance. Four out of the five teachers felt successful in the area of providing opportunities for cultural competence. For example, Ms. Vittitow noted in her explanation of their lesson plan that she will, "Play a video that explains the history of the term *debug* - the video offers students background knowledge and shows the important role women have in technology." Ms. Vittitow also noted that students will, "Create their own division story problems. This allows students to draw from their own experiences and cultures to create practical problems." In these ways, Ms. Vittitow felt that she was able to offer cultural knowledge relevant to the students' identities and build upon students' background knowledge. However, none of the teachers felt that they addressed providing opportunities for cultural critique in their lesson plans, and they were mixed in whether their lesson plans provided conceptions of knowledge. For example, Ms. Sunshine noted that she would "provide a program for students to express their knowledge on how to build/create a graph" and students would "use their knowledge to create a bar graph." However, Ms. Sunshine did not feel that she demonstrated that knowledge is shared and constructed together or provided pathways to connect to students' identities, culture, and history.

Discussion

Findings demonstrate that teachers generally felt as if their integrated CS lesson plans provided opportunities for students to connect to their own experiences and cultures but did not provide as many opportunities for sociopolitical consciousness. This poster will invite a discussion about the extent to which these kinds of rubrics can be helpful by providing more detail about the teachers' lesson plans and rubric ratings. The poster will also contain future plans of the RPP to continue to support these teachers to plan and implement CRCSE lessons. Results contribute to understanding how RPPs can support teachers' learning of CRCSE lesson planning.

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Students’ Attitudes Towards Mathematics During Math Walks

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Abstract: Math walks are informal learning activities where students create mathematical meaning from their everyday surroundings. In this qualitative study, we observed 5th–8th-grade students (N = 52) across three urban informal learning sites (a community center, a zoo, and an aviation museum) as they created their own math walks exploring geometric concepts. In a post-survey questionnaire, students described their attitudes toward math using affective language motivated by three psychological factors: autonomy, competence, and relatedness. Implications for informal math learning are discussed.

Conceptual framework

Recent informal learning science literature (Guzey et al., 2016) maintained that situated learning has been used to broadly study students’ attitudes toward STEM (science, technology, engineering, and mathematics) as they participate in authentic learning activities (Brown et al., 1989). The construct of attitudes toward math has been extensively studied in formal schooling scenarios, revealing that students typically express their attitudes toward math using affective descriptive language (Chew et al., 2019; Russo & Minas, 2020). Those studies showed that students’ attitudes toward math can range from being “positive” to “ambivalent” to “negative” and usually vary in strength along that spectrum. But, how do students express their attitudes toward math in informal learning environments? Math walks, or informal learning activities where students walk around their communities and form math connections with the art, nature, etc. within their surroundings, are being used as a way to improve students’ attitudes towards mathematics (e.g., Wang et al., 2021). We used self-determination theory (Deci & Ryan, 2012) to examine how students expressed their attitudes toward mathematics based on three psychological factors that motivate behavior: autonomy, competence, and relatedness (Russo & Minas, 2020). As such, our research question was: How do students describe their attitudes toward mathematics after participating in and creating a series of math walks?

Methods

Over 3–4 sessions, we examined a diverse group of learners in grades 5–8 (N = 52) at three informal learning sites (a community center, a zoo, and an aviation museum) in a large urban city in the southwestern U.S.A. Across the sites, learners were mostly female (71%), Black (49%), and Hispanic/Latinx (27%). Grade level breakdown was 33% (5th grade), 37% (6th grade), 19% (7th grade), and 11% (8th grade). Students self-organized into groups of 3–4 paired with one researcher who video-recorded the group’s daily interactions. After they finished the math walk activities, they took a paper-based survey, which included two open-ended questions: (1) What did you like about your experience creating your math walk? and (2) What do you wish had gone differently? In isolating students’ attitudes toward math, we used thematic analysis (Braun & Clark, 2006) to contextualize students’ written feedback on their experiences and iteratively coded responses as either positive, ambivalent, or negative. Then, like Russo and Minas (2020), we categorized the statements into three themes representing the psychological motivators: autonomy (choice over how they approached the task), competence (feeling they have the necessary success skill), and relatedness (collaboration with their peers during the task).

Results

Students’ affective attitudes toward math walks

Analysis of the data revealed that affective attitudes (how they felt) toward mathematics after the math walk experience (see Table 1) were predominantly positive across all sites, with 69% (*n* = 27) of students reporting positive sentiments. Positivity language included phrases such as "I liked...," "I enjoyed...," or "It was fun...." For instance, a 5th-grade female community center participant expressed her satisfaction by saying, "What I liked about creating my own math walk is when I got to go and find an area that was math related." Students who expressed ambivalent or negative feelings were evenly split at 15.4% (*n* = 6). For example, a female 8th-grader at the aviation museum reported mixed feelings, saying, "It was okay. It really doesn't matter to me. It was boring sometimes, and then it wasn't boring." Meanwhile, a male 8th-grader at the zoo expressed a desire for "things being more related to math." We coded this as a negative feeling because a specific learning need was unmet. Unanswered questions were excluded from the analysis.

Table 1
Summary of Students' Affective Attitudes toward Mathematics during Math Walks

Positive	Ambivalent	Negative
27 (69.2%)	6 (15.4%)	6 (15.4%)

Psychological motivators for students' positive attitudes toward math

Next, we described the student attitudes and found that they primarily attributed positive attitudes due to their perceived ability to demonstrate *competency* in math (n = 23). For instance, one fourth-grader at the zoo wrote, "I liked finding similarities between math and animals." Other students used language that emphasized *relatedness* (n = 11) when expressing their attitudes toward math during the math walks at their sites. Two documented responses were:

> *"I like that we got to be in a group and express our ideas in math."* –4th-grade male zoo participant
>
> *"I also enjoyed how we worked in a group because groups make me feel more comfortable."* –5th-grade female student community center participant

Finally, eight students (n = 8) discussed the importance of *autonomy* when completing their math walks. "Being able to pick our stop was my favorite part," explained one 8th-grade male who attributed his positive attitude toward the math he was learning to his enjoyment of autonomy during the tasks.

Conclusion

Our analysis revealed that student-created math walks are promising tools for practitioners to gauge students' affective attitudes toward mathematics and the possible reasons behind those attitudes. Although most students expressed positive attitudes toward mathematics, some reported negative or ambivalent feelings. The impact of math walks on students' perceived competence requires further exploration to inform the development of math walk activities and theories of change for informal math learning. These preliminary findings are based on data collected in the first year of our five-year study. Future implications include students' transferability of positive attitudes towards mathematics developed in informal learning environments to formal learning environments (i.e., schools) and teachers' experimentation with math walks to improve students' attitudes toward mathematics.

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Issues in Infrastructuring OST STEM Learning for Selective College Admissions

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Abstract: We report findings from interviews with college admissions personnel (CAP) as part of a larger infrastructure project examining opportunities to enhance the value of out-of-school time (OST) STEM learning in the U.S. college application review and admissions process. Our findings report on how CAP employ holistic review practices with information on both formal and OST learning experiences in the context of STEM admissions to render admissions decisions.

Introduction: Expanding the college admissions infrastructure

Our focus in this study is to explore the dimensions of the existing infrastructure of college admissions and to better understand how the existing infrastructure affords *some* students admission to selective colleges and universities in the United States but not others. Following Star and Ruhleder (1996), and later Penuel (2018), we understand infrastructure to be primarily relational. As such, we study infrastructure by examining the materials, standards, and work practices that support coordinated and distributed work with diverse stakeholder groups: in this study, the context of holistic review in selective college admissions in U.S. colleges and universities. This study builds off previous work by Cederquist, Fishman and Teasley (2019) which explored the potential of digital credentials as an innovative college admissions data source. This study expands our understanding of how college admissions professionals (CAP) make holistic admissions decisions and the role information on out-of-school time (OST) learning plays in selective admissions with a focus on access to STEM programs in post-secondary education. Through this work we are developing a platform (a kind of mastery-based record of OST learning) in partnership with the Mastery Transcript Consortium (MTC), OST program providers, and OST students and their families, to document the learning occurring at these sites. Our findings point to the potential benefits and challenges of incorporating mastery-based transcripts of OST learning into the college admissions process and unique challenges to inclusiveness presented by STEM admissions standards and practices.

Methods and participants

This is a qualitative study of how CAP conduct holistic review and the information they use to understand readiness for learning at their institution. We recruited 12 participants using snowball sampling methods: all have first-hand experience reviewing college application materials and making holistic admissions decisions in real admissions scenarios. The participants represent a range of institution types: private liberal arts colleges (n=4) and both public and private research universities (n=8). The institutions also represent a range of selective (n=8) and open (n=4) institutions (selective meaning a 60% admission rate or lower). Our sample size limits the generalizability of our findings, but our objective in this study has been to surface issues for future inquiry.

Conversations with participants followed a semi-structured interview protocol and addressed the following topics: 1) participant roles and responsibilities, 2) how CAP identify promising applicants in undergraduate admissions, 3) how information on formal and informal (OST) learning is used in holistic review, and 4) how STEM readiness standards influence holistic review. Data collection consisted of audio and video recordings of interviews and digital transcripts autogenerated by the video-conferencing platform. We prepared data for analysis by cross-referencing audio recordings with written transcripts to correct transcription errors. Data cleaning coincided with creating content logs for each interview. Content logs allowed us to document our initial reflections on each interview. We inductively coded both content logs and transcripts in an iterative fashion to develop emergent themes into a codebook that will guide future rounds of inquiry and design work.

Findings and discussion

CAP review files for evidence of academic and nonacademic fit. A judgment of academic fit is made from verifiable curricular information reported by the applicant's secondary school: academic transcripts and standardized test scores. CAP use school profiles and personal knowledge of specific schools to contextualize academic rigor. Nonacademic fit is understood through information submitted by an applicant or someone in their network: personal essays and letters of recommendation. When discussing OST learning, CAP often referenced lists of "extracurricular" activities produced by the Common App, a platform that allows students to scale the submission of applications through a common portal, an affordance CAP believe has further complicated review: i.e., as application submission increases, quality decreases. Finally, some admissions systems allow students to submit their own supplemental information: e.g., research reports or creative writing.

Time and application volume are common factors that interact within holistic review. Standardized academic transcripts afford quick analysis and comparison between applicants. When applicants attend the same school, comparison is quite straightforward. When transcripts vary in format, curricula, and reporting metrics, comparison becomes more difficult. The opacity of grades further complicates understanding what students know: i.e., what is the difference between an A and an A- in terms of effort? Limited time also means CAP usually do not review supplemental student work. In addition to not having time, CAP believed they do not have the content knowledge to make informed judgements on the quality of the work. Nonetheless, student work was often described as a strong signal of student passion, interest, and character.

Trust in data sources and concerns of equity influence how CAP understand nonacademic fit. Because essays, extracurricular lists, and reference letters are the responsibility of the applicant, CAP view this information as less reliable than academic information as students have control on what to include, exclude, and how to frame achievement. Extracurricular lists are read to understand the motivation behind interests: alignment of engagement across activities is significant here. CAP believe a successful essay communicates an applicant's authenticity. This could be understood as engagement driven by intrinsic motivation, an understanding of self, or a commitment to others beyond oneself. CAP also acknowledge how inequitable access to resources that can improve college applications impacts the quality of student-submitted information.

We found that two factors primarily complicate STEM admissions: 1) a perception of STEM curricula as rigid and hierarchical pathways, and 2) competition for limited seats drives up admissions standards. When standards rise, the question becomes who merits admission most. This is difficult to answer, but it is encouraging that some CAP believe readiness for STEM can be understood through multiple dimensions, those both academic and nonacademic. Still, there is an understandable reluctance to admit students who do not meet minimum academic requirements. CAP acknowledged potential equity issues with emphasizing academic information in STEM admissions but note that a student's background information, essays, and letters of recommendation (when genuine) provide alternative sources of information on an applicant's potential for success. The objective then is to determine why the student did not meet academic standards and if they could still do the work. Evidence comes from school profiles, examples of managing personal responsibilities, evidence of engaging in group work, or evidence of a broader impact the student might have on the institution's community. Ultimately, when academic information is not *the* determining factor, but rather a floor that must be reached, holistic review is a matter of determining how each student *distinguishes themselves* as opposed to how each diverges from the academic norm.

Conclusion and future work

The next phase of research will include the development of a prototype mastery-based transcript. Design research work on the prototype will include human-centered design studies with CAP that mimic the holistic review process. Our goal in this design work is to understand issues of usability while being sensitive to the values underlying holistic review. Our findings suggest a focus on features that support sensemaking of student work and contextualizing extracurricular activities is needed, as these issues align with two features of mastery-based transcripts: the ability to embed and curate student work and the ability to capture work pursued outside formal classrooms.

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Schoolyard SITES: School-community Partnership to Learn about Teaching Locally-Relevant Citizen Science

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Abstract: Schoolyard SITES is a community partnership STEM teacher professional development program and research study at University of New Hampshire. The program partners elementary teachers with UNH Extension science volunteers to bring locally-relevant citizen science projects to K-5 students. Our research study examines the community-based partnership PD model and its impact on school teachers' self-efficacy and their success in engaging students in the NGSS science practices through citizen science projects.

Introduction

Currently K-12 science instruction is changing in the United States. As described in the *Framework* (National Research Council [NRC], 2012) and outlined in the *Next Generation Science Standards* (NGSS Lead States, 2013), the national K-12 science education recommendations emphasize active learning that engages students in the science practices while learning disciplinary content. Furthermore, a fundamental principle of the *NGSS* is that K-12 students engage in science learning that is relevant to their everyday lives, hence demanding real-world, problem-based learning (NRC, 2012). Given this new vision of K-12 science education, teachers' approach to instruction is expected to significantly change. Therefore, there is an increasing demand, nationally and in New Hampshire, for professional development (PD) that builds both K-5 teachers' science content knowledge and their ability to integrate the science practices into the classroom (Osborne, 2014).

Schoolyard SITES (Schoolyard Science Investigations by Teachers, Extension Volunteers, and Students) is a community partnership STEM teacher PD program and research study at University of New Hampshire (UNH). The program partners elementary teachers with UNH Extension science volunteers to bring locally-relevant citizen science projects to their students. We designed Schoolyard SITES to address identified needs of elementary school teachers, for PD in *NGSS*. It also capitalizes on emerging trends in citizen science programs and their associated learning outcomes (National Academies of Sciences, Engineering, & Medicine, 2018).

The study focused on the following research questions: 1. What collaborative components do teachers and volunteers focus on while working on a successful interdisciplinary collaboration? 2. What are the changes that are observed in elementary school teachers' self-efficacy teaching science and ability to integrate NGSS science practices through a locally-relevant citizen science project?

Schoolyard SITES model & activities

The Schoolyard SITES professional development model is a 3-pronged collaboration among elementary teachers, Extension science volunteers, and professional development/citizen science professionals. This 3-way collaboration is central to building both content knowledge and teacher self-efficacy. The teachers, volunteers, and professional development specialists create a synergy of skills, expertise, and content knowledge. The Schoolyard SITES PD workshop series emphasizes a collaborative learning approach that supports the development of a partnership between teachers and project volunteers. The PD framework is structured such that elementary teachers share their knowledge of instructional planning and pedagogy, while at the same time the volunteer shares their knowledge of specific, local life or Earth science topics and their passion for the scientific enterprise. Participants learn together as a team, and gain experience with scientific investigations and content that they will use later in their classrooms. With support from the volunteer, teachers design and teach a citizen science curriculum for their students that is relevant to the school district's curriculum and elementary school site.

Methods

We used a mixed-method research approach that incorporated pre- and post surveys and interviews plus document analysis of curriculum units produced as a result of the teacher-volunteer partnership. The online surveys and interviews (face-to-face) were administered before the first workshop and after participants taught the curriculum project in the elementary classrooms. The survey and interview instruments addressed volunteers' and teachers' process of collaboration, teachers' self-efficacy teaching science and integration of the eight NGSS science practices. The pre post surveys included the reliable and validated Science Teaching Efficacy Belief Instrument (STEBI-A)(Riggs & Enochs, 1990). Document analysis of collaboratively designed curriculum units were conducted to assess the extent to which the eight NGSS practices were represented in the projects.

Findings & analysis

Teacher-volunteer partnership

After going through the collaborative process, the teachers (100%, n=12) reported that they continue to feel that collaborating with community members is an important endeavor. All volunteers (100%, n=7) reported in their pre-surveys that collaborating with community members was an important endeavor and in the post survey most of the volunteers (86%, n=6) reported that they continue to feel that collaborating with teachers is an important activity, while one (14%, n=1) was unsure. Overall, the teachers were able to give more nuanced or very detailed explanations for each of the collaborative components after completing the Schoolyard SITES program. For example, we found that most teachers (n=11) in their pre survey suggested that listening is important part of a collaborative process but did not provide details. In the post survey most teachers (n=12) were able to illustrate with at least one example how listening is an important part of the collaborative process.

Teacher self-efficacy

The average self-efficacy score for the teachers before the Schoolyard SITES program was 50.8. Following the program, the average self-efficacy score for the teachers was 54. The change in self-efficacy for individuals differed. Some individuals demonstrated a larger change in efficacy than others. This variability among the 12 teachers attributed to the 'borderline' difference between the average pre (50.8) and post (54) scores (t-Critical two-tail = 2.20, $p = 0.06$, n=12) for the cohort collectively. In general, however, the majority of teachers (75%) demonstrated an increase in self-efficacy.

Integration of NGSS practices

All participating teachers (n=12) reported moderate or very improved integration of NGSS science practices after the Schoolyard SITES program. The top NGSS science practices reported were students' carrying out investigations, analyzing and interpreting data, constructing explanations, and engaging in scientific argumentation. The curriculums designed by the teacher-volunteer teams included the eight NGSS science practices. The practices of asking questions (SEP1), planning and carrying out investigations (SEP3) and data analysis (SEP4) were featured in all of the team's written curriculum units. In addition, scientific argumentation (SEP7) and communication (SEP8) were also integrated into most of the units.

Discussion

The Schoolyard SITES model emphasizes a pathway for how citizen scientist volunteers and teachers can build a sustainable partnership so as to engage elementary students in citizen science and authentic science practices. The study sheds light on how collaborative behaviors (e.g., listening, compromise) play a role in the partnership. We observe that all teachers and community volunteers understand that school-community partnerships are important, and our findings suggest that teachers increase self-efficacy and improve their integration of NGSS practices in the classroom after participating in the Schoolyard SITES community-based partnership PD model.

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The Power of Example? Lessons Learned About Equity and Inclusion Through COVID-19 Teacher Education Courses

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Abstract: The shift to remote teaching during COVID-19 raised awareness of inequities built into traditional teacher education, as well as limitations to the inclusiveness of teacher educators' accepted practices. Findings from student (n=170) and instructor (n=30) questionnaires are presented from a mixed-methods study that explores how the pandemic experience affected teacher educators' equitable teaching practices, and the impact of their modeling on the future instructional priorities of their in-service and pre-service students.

Introduction

Teacher educators must always be concerned both for their students' learning, and their students' own future teaching. Moreover, teacher educators not only teach through the material they cover, but also through the modelling they provide (Moore & Bell, 2019). The shift to remote teaching during COVID-19 raised awareness of inequities built into traditional teacher education, and limitations to the inclusiveness of teacher educators' prior accepted practices. Snapshots of students' homes and lives, realizations about what tools and conditions for learning were(n't) at students' disposal, and insights about assumptions baked into traditional program structures all fostered new awareness of barriers to equitable participation and learning in teacher education. Many of these equity issues were not actually new during COVID-19, only more visible. Long-standing inequities related to race, gender, socio-economic status, diverse learning needs and mental health challenges were well-documented before the pandemic (e.g., Linden, Boyes, & Stuart, 2021); but the necessity to re-design courses to accommodate COVID-19 protocols provided an opportunity for teacher educators to rethink traditional assumptions and practices, some of which had treated such inequities as normal and acceptable.

Many faculties of education in Canada have made commitments to pursue equity and inclusion in their programs and practices, and have made some progress meeting them. However, it was uncertain to what extent such progress could or would be maintained under the limitations of remote teaching conditions. Our study generated data about the equitable and inclusive practices that teacher educators at one Canadian faculty of education implemented during emergency COVID-19 remote teaching, and the insights their pre-service and in-service students took away from this modeling for their own teaching practice.

Methods

This data comes from a multiple-case study of teacher educators' design choices intended to address challenges of equity and inclusion. We took a sequential mixed-methods approach, using instructor questionnaires to inform case selection. Student questionnaires were not linked to specific courses or instructors, but were used to provide a general backdrop for the instructor data. Both questionnaires were administered in Fall 2021 and included a combination of selected-response and open-ended items. Questions focused on innovations that respondents deemed successful, that is, their "best" pandemic learning or teaching experience. The student questionnaire (n=268, 11% of enrolled students enrolled in summer 2021) captured the challenges students faced, their opinions regarding strategies their instructors used to support them, and the lessons they learned from those strategies for their own future teaching. The instructor questionnaire (n=30, 22% of instructors in summer 2021) captured how instructors ascertained what challenges students faced, the strategies they used to respond to them, and their opinions about which of these strategies were most effective. Descriptive statistics, such as frequency counts, percentages and means are provided for some of the selected response items. We also present responses to an open-ended question posed to students: "If you already teach or plan to teach, in what ways has your experience as a student in this course influenced your thinking about your own flexible and equitable practices as a teacher?" Responses from current teachers seeking graduate degrees and intending (pre-service) teachers (n=170) were coded by the first two authors into 12 categories related to three themes (student needs and voice; flexibility and designing for difference; communication and organization). Percent agreement across all coding categories was 95%. Finally, the first two authors coded teacher educators' responses to the question, "What teaching strategies that you typically use to promote learning and/or equitable participation in this class were hampered by pandemic conditions?" in five categories with 94% agreement. Consensus discussions were held to finalize all coding.

Teacher educators' adaptations

The most common challenges teacher educators noted among their students were non-school commitments, (e.g., childcare, work, 92%), general worries or stressors (e.g., crowded conditions or isolation, 91%), and mental health concerns (83%). Instructors' awareness of students' mental health needs and complex life circumstances drove greater flexibility in the form of reduced synchronous class time (88%) or better access to alternatives to that class time (e.g., pre-recorded or live-recorded lectures, 54%), more flexible deadlines (77%), reduction or elimination of late penalties (62%), more choice around how students demonstrated their learning (54%), and more opportunities to revise work (58%). Such adaptations mirrored those at other institutions (e.g., Goin Kono & Taylor, 2021; Johnson, Veletsianos, & Seaman, 2020). Our teacher educators also demonstrated care by regularly checking in with their students (81%). However, teacher educators found these approaches insufficient to address the social challenges of pandemic teaching and learning. In the open-ended responses, two-thirds of teacher educators described difficulty with one or more of the following: fostering productive group work (40%), circulating among groups (20%), fostering community or connection with students (27%), facilitating discussions (20%) and "reading the room" (17%), all of which could potentially hamper equitable participation for students. Nevertheless, most students from marginalized and equity-seeking groups (87%) or those who were uncertain of their writing, reading and presenting (67%) felt their learning experiences in their "best" pandemic class were *not* affected by such status. Thus, despite struggling with the affordances of the remote teaching format, instructors appeared to have been successful in creating space for diverse students to participate comfortably.

Current and intending teachers' learning from those adaptations

When asked how their experience as learners would affect their future teaching, most students either did not answer (35%) or provided short, general statements (51%), e.g., "Importance of flexibility and understanding." A few (28%) provided more detailed plans, such as, "Having varied assessments where students can display their learning. Flexible deadlines and connecting with students who may not participate as much. Having different forms to participate in class to manage anxieties."

A commitment to flexibility and/or designing for difference was most common (41%). Some students simply indicated they would be flexible (26%), such as, "Being flexible and comfortable with change." Others would give students choice in assignments or assessments (9%) or explicitly design for difference (14%), such as, "Should I become a teacher, I plan to put an emphasis on inclusivity and working with the UDL guidelines, as well as guided instruction." Very few intended to make learning materials available in multiple forms (3%).

About a quarter of students (24%) mentioned increased awareness of or attention to students' needs and voices. Some (18%) indicated more awareness of students' needs than before. A few noted the importance of being kind, patient and open-minded (9%), the need to be aware of the mental and physical demands of the learning context (6%), to listen and attend to students (8%) and to give them voice (4%). On rare occasions students expressed more nuanced insights such as, "It has made me realize that my students may struggle without speaking up, and as an instructor, it is important that I look out for signs of non-verbal struggle such as a sudden change of grades. Otherwise, it can create a vicious cycle where the student begins to fail, is too depressed or unwell to mention or care about it, and goes on and on."

Besides two students who indicated a desire to incorporate Indigenous perspectives and/or pedagogies in their teaching, none explicitly mentioned ways in which they might attend to the needs of marginalized or equity-seeking groups; though general statements regarding opportunities for all student voices to be heard or to engage in inclusive practices may be based on such concerns.

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Promoting Students' Productive Vocabulary Growth and Knowledge Advancement Through Knowledge Building

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Abstract: This knowledge building study was conducted in an English-as-Foreign-Language context and examined both students' productive vocabulary growth and collective knowledge advancement. Analysis of the lexical frequency profiles indicated students used greater number of sophisticated, academic and domain words across time. Inquiry threads analysis also suggested a higher level of knowledge advancement over time. This study has implications on how to design learning environments to facilitate language learning and idea improvement.

Introduction

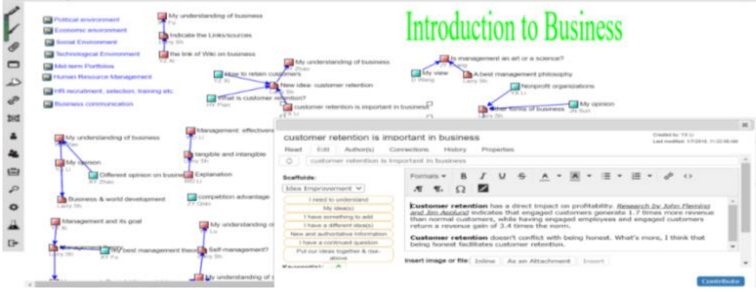
Very few knowledge building studies have focused on vocabulary growth in the process of collaborative inquiry. The one exploring this area was conducted in an English-speaking country (environment) and included Grade 3 kids as the participants (Sun, Zhang, & Scardamalia, 2010). This study is conducted in a university in Chinese mainland, where English is used as a medium of instruction (EMI) for delivering content subject, and a dual goal of developing both students' content knowledge and English language proficiency is expected to achieve.

Knowledge building is a social process through which learners work collaboratively and continuously towards idea improvement. To support the process, a networked technological platform, Knowledge Forum (KF) is used and students can compose ideas and build on, annotate, or rise above their early understandings. Through progressive and productive discourse moves, an idea or concept gets nurtured, enriched, revised or refined. In the second language acquisition or foreign language learning field, a content and language integrated learning (CLIL) approach is increasingly employed in recent years. The CLIL approach emphasizes both content knowledge and language acquisition; and more importantly, language is acquired or learnt through negotiation of meaning. This pedagogical approach is acting concordantly with the knowledge building model in that meaningful interactions of ideas are fundamental to learning, not matter it is language learning or subject knowledge learning. This study is conducted in an English-as-foreign-language context, and addresses two RQs: (1) How is the students' productive vocabulary developed in the knowledge building process? (2) What characterizes students' collective knowledge advancement; is it connected to student' vocabulary growth?

Research design

The participants were 30 Year-1 students (M=6, F=25) majored in English for International Business. In an 18-week length of a course entitled *Introduction to Business*, students were engaged in collaborative inquiry about business concepts in class and continued their discussion in KF after class (see Fig.1). Students were encouraged to write KF notes in English and try to use business domain words they learnt in and outside class.

Figure 1
KF View and An Open KF Note



Customer retention has a direct impact on profitability. Research by John Fleming and Jim Asplund indicates that engaged customers generate 1.7 times more revenue than normal customers, while having engaged employees and engaged customers return a revenue gain of 3.4 times the norm.

Customer retention doesn't conflict with being honest. What's more, I think that being honest facilitates customer retention.

The data of the study included all KF notes and analyses followed two major strands. One is productive vocabulary growth which is measured by "Lexical Frequency Profiles" (Laufer and Nation,1995). The measure provides an analysis of the percentages of word families at various frequency levels in a piece of written work, e.g., the first 1000 and the second 1000 frequent word families, and Academic Word List. In addition, a Business Domain Word List is also developed for this study to understand students' mastery of subject specific words. The second strand is to identify students' conceptual understanding and knowledge advancement via inquiry thread analysis (Lei and Chan, 2018). An inquiry thread was categorized low-, middle-, and high-level of knowledge advancement (LKA, MKA and HKA). A LKA thread is often short, consisting of students' quick or instinctive ideas about a business topic without referencing to authoritative sources of information; a MKA thread draws a pool of students' ideas, yet repetitions occur frequently and showing a lack of community awareness; a HKA thread demonstrates a question-explanation intertwined process, showing students' identifying and addressing knowledge gaps, negotiating meanings, and formulating more sophisticated views on business concepts.

Findings

Development of students' productive vocabulary use

The students composed a total of 746 KF notes (M=24.9 and SD=6.14) over 18 weeks. To examine the development of students' vocabulary growth, the dataset was divided into Phase 1 (from Week 1 to Week 9) and Phase 2 (Week 10 to Week 18). Using software including RANGE and SPSS, the study showed a comparison of lexical frequency profiles based on counts of word types in Phase 1 and Phase 2(Table 1).

Table 1

Comparison of Lexical Frequency Profiles Based on Counts of Word Types in Phase 1 and Phase 2

	Phase 1Mean (SD)	Phase 2Mean (SD)	T-test
First 1,000 words	73.69% (4.93%)	66.44% (4.69%)	T=7.75; p<0.001
Second 1,000 words	7.14% (2.00%)	8.24% (1.93%)	T=2.05; p<0.05
Academic words	11.48% (3.65%)	14.10% (3.38%)	T=3.34; p<0.01
Not in the list	7.70% (3.83%)	11.21% (3.88%)	T=5.23:p<0.001
Domain words	8.59% (1.55%)	10.44% (2.00%)	T=4.53, p<0.001

Students' collective knowledge advancement

Inquiry threads generally reflect the developmental trajectories of an idea or a business concept; how it gets shared, evaluated, enriched, revised or refined through the efforts of a learning community is a process of collective knowledge advancement. After assortment, a total of 29 inquiry threads emerged from the data. We then further classified the threads into Phase 1 (n=16) and Phase 2 (n=13) threads. In line with the coding scheme mentioned in the research design section, we coded all the threads into low-, middle-, and high-level of knowledge advancement which is shown in Table 2 as follows.

Table 2

Distribution of Low, Middle and High Level Knowledge Advancement Threads in Phase 1 and Phase 2

	Phase 1 (No. and %)	Phase 2 (No. and %)
L-level KA	9 (56.35%)	3 (23.1%)
M-level KA	4 (25.00%)	3 (23.1%)
H-level KA	3 (18.75%)	7 (53.8%)
Total (No. and %)	16 (100%)	13 (100%)

Conclusion

This study indicated students were able to use greater number of sophisticated, academic and business specific words as they were more engaged in knowledge building process across time. As well, student' collective knowledge advancement experienced a developmental trajectory, moving from a relatively low level to a high level.

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“Using the Master’s Tools” to Integrate Play With Kindergarten Mathematics: Creative Insubordination Through Playful Resistance

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Abstract: In this study, we focused on the challenges that kindergarten teachers discussed related to curriculum, lack of teacher autonomy, and administrative control. We explored teachers' resistance using the lens of creative insubordination (Gutiérrez, 2016) to answer these questions: 1) What challenges do kindergarten teachers discuss about implementing playful math in kindergarten? and 2) How do teachers discuss navigating implementation challenges? We found that teachers used playful resistance as a way to enact “Using the Master’s Tools,” an approach to Creative Insubordination outlined by Gutiérrez (2016). This study corroborates and extends prior work on creative insubordination by focusing on early childhood mathematics and exploring teachers’ strategies to employ playful resistance.

Purpose

This study responds to the widely discussed concern about ‘kindergarten as the new first grade’ (Bassok, Latham, & Rerom, 2016) by positioning kindergarten teachers as professionals with agency to make choices in their classrooms. In this study of early childhood (EC) teachers’ playful resistance, we highlight teachers’ agency as they invoke ‘the master’s tools’ to make developmentally appropriate changes within existing structures, in particular, disrupting a system that is eliminating children’s opportunity to play. Analysis of a weeklong professional development (PD) with four kindergarten teachers revealed what they identified as barriers to curricular interruption and initial steps they imagine in thinking ahead to implementing play in their classrooms. We analyzed teachers’ resistance using a lens of creative insubordination by exploring the strategies teachers imagined to resist and overcome challenges to bringing in play posed by their perceptions of the curriculum, school administration, and district and state testing and evaluation mandates; and to answer the questions:

1. What challenges do kindergarten teachers discuss about implementing playful math in kindergarten?
2. How do teachers discuss navigating implementation challenges?

Framework

Acts of resistance or ‘creative insubordination’ are the ways professionals interrupt rules to provide better services and conditions (Grando & Lopes, 2020, p. 621). Gutiérrez (2016) outlines an approach to resisting the systems operating against teachers using six strategies for being creatively insubordinate: press for explanation, counter with evidence, use the master’s tools, seek allies, turn a rational issue into a moral one, and fly under the radar. Gutiérrez (2016) proposes that these approaches are a stand against the status quo in efforts to change schools to match the best interests of the students. These strategies provided a lens for us to examine how teachers imagined paths of resistance. In our study, we found the teachers enacted on approach in particular, ‘using the master's tools’ to align with the rules and goals while bending the rules to meet the needs of students. Although, using the master's tools is an ineffective strategy to dismantle oppressive powers (Lorde, 1984), we found it effective way to work within the system. We offer the phrase “playful resistance” to capture how teachers used the masters tools to resist constraints (e.g., enforced pacing, administrative control, limited teacher autonomy) by bringing play into mathematics.

Methods

As part of a four-year longitudinal research project to investigate play in early mathematics, we facilitated a week-long PD with four kindergarten teachers designed to support EC teachers to incorporate play into their math classrooms. All discussions and activities during the PD were video and audio recorded. In individual interviews during the PD teachers were asked to describe their teaching experience, philosophical views about play and current teaching environment. All interviews were audio recorded. Using descriptive codes, we analyzed observation notes, video recordings, and audio recordings from the teacher’s interviews to understand how teachers talked about navigating challenges to enacting math curriculum by using the masters’ tools.

Findings

Throughout the PD, teachers discussed various challenges with bringing play into their classrooms including: issues with curriculum, state-wide assessment portfolios/pop-up observations, disjointed communication with administration, lack of autonomy, fears of reprimands, and views of play and academics as separate. Some of these challenges stem from an era of accountability, standardized testing, and an emphasis on academics over play in practice and research (Author 2; Schoenfeld, 2002). The larger social climate can frame play and academics in tension and perpetuate teachers' beliefs and practices that deemphasize play. All these challenges set the larger context of the school, administration, and classroom. However, the analysis for this study focused on the challenges teachers discussed related to the curriculum, lack of teacher autonomy, and administrative control as these were the most prominent in our discussions with the teachers in this study.

In Table 1, we provide a summary of vignettes that illustrate how teachers proposed to navigate the challenges. We found that the teachers had explicit ways of describing and planning for creative insubordination to bring play into mathematics instruction, specifically related to using the master's tools (Gutiérrez, 2016).

Table 1
Summary Vignettes

Navigating the Tension Between Play and Academics	Navigating Limited Time and Autonomy with Playful Resistance
This vignette highlights how the teachers discussed the tension between their mathematics curriculum and play and envisioned navigating this challenge with playful resistance by bringing in games to differentiate mathematics instruction and supplement the official curriculum. In this example, the teachers employed playful resistance as they followed the rules of using the curriculum materials while bending them by imagining how to differentiate activities with games.	This vignette highlights how teachers discussed navigating tensions they faced related to limited time and teacher autonomy for curriculum and scheduling. The teachers in-the-moment decisions without permission to teach with less fidelity to the curriculum and schedule illustrates how they employed playful resistance to administrative control as they discussed interpreting "problem-solving time" as a space to bring in a playful lesson. The teachers used the master's tools by following the dictated school schedule, yet, through their interpretation of "problem-solving time," they created a plan for playful resistance.

Conclusion and implications

We found that the teachers used playful resistance as a way to enact using the master's tools. While the teachers discussed other ways they could resist neoliberal practices (e.g., flying under the radar), we found that explicit connections to play were related to the approach of using the master's tools. Theoretically, this study corroborates and extends prior work on creative insubordination by focusing on early childhood and exploring how teachers invoke strategies to develop playful resistance. From a practical perspective, we see an opportunity to rethink future PD with these (and other) teachers that supports them to develop strategies for creative insubordination. We envision using this data in conjunction with readings from Gutiérrez so they can explore how they came up with their own strategies and how they might develop others. We then would have them practice using strategies in order to defend and support the decisions they make for their classrooms.

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Post-Humanist Perspective for Investigating Learning With Representations in Biochemistry

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Abstract: Research on external representations in biochemistry education has primarily focused on student interpretation of their assumed correct meanings. This orientation is related to the philosophical assumptions of representationalism, metaphysical individualism, and humanism. Engaging with feminist critique of science, this study aims to problematize these philosophical assumptions in research on learning with representations in biochemistry. We propose agential variation theory as a framework that create a new space for exploring the semiotic potential of different representations.

Introduction and background

Since molecular structures and events are not directly visible, biochemists rely on external representations such as diagrams, animations, three-dimensional (3D) models, etc. to explain biochemical phenomenon. In biochemistry teaching and learning, visualization and spatial reasoning have been identified as essential skills for students. The importance of visualization and external representation in biochemistry teaching and learning has directed research efforts towards the development of new external representations for biochemistry classroom instruction.

Treating the referentiality of external representations as a transparent and direct link between sign and meaning, existing research on learning with representations in the context of biochemistry education mainly focus on measuring individual student performance and student preference, with little attention towards how the meanings of external representation are experienced by students. Without critically examining how the experienced meanings of representations emerge, new forms of external representations are often treated as new signs referring to existing biochemistry concepts rather than as a dynamic transformation of the learning environment in which students experience the meaning of biochemistry concepts.

In recent years, augmented reality (AR) technology has received increasing attention in biochemistry educational research. AR technology affords the experience of a computer-generated 3D representation superimposed on top of the real world. Blurring the boundary between representation and reality, AR technology prompts researchers to reflect on the relationship between representation, meaning, knowledge, and reality. This study critically reflects on the implicit philosophical assumptions that underpin normative research on learning with representations, and explore possibilities for research informed by feminist, post-humanist perspectives on science, technology, and education.

Implicit philosophical assumptions in research on representations

Three philosophical assumptions, namely representationalism, metaphysical individualism, and humanism, work together to hold the normative worldview and paradigm of research on learning with representations in place. These philosophical assumptions are commonly associated with classical ontology, which entails a physical reality underpinned by objectively real, counterfactually definite, uniquely spatiotemporally defined, local, dynamical entities with determinately valued properties. Research that operationalizes this ontology seeks to create accurate and authentic representations through measuring the determinately valued properties of bounded entities.

Representationalism

Representationalism is the view that scientific models are best understood as representations of reality. Representationalism separates words (epistemology) from things (ontology) and produces the question of mediation between the two realms that made knowledge possible. Barad criticized this dualist notion for trapping epistemology between two facing mirrors of scientific realism and social constructivism where it “gets bounced back and forth, but nothing more is seen” (Barad, 2007, p. 803). If we commit to the assumption that cognition involves a separated cognitive subject representing the Other, the study of cognition itself would require another degree of separation, i.e., meta-cognition. Yet another degree of separation, i.e., meta-meta-cognition, would then be needed to investigate meta-cognition and gain insight on the processes through which the cognitive subject reflects on its own cognition. Studying cognition under the assumption of representationalism is akin to placing two mirrors against each other. Researchers become trapped in between two reflective surfaces, bouncing back and forth.

Metaphysical individualism

The metaphysics of individually determinate entities with inherent properties is another assumption on which many research practices are hinged. Research on learning with representations commonly puts the individual student at the center of attention. Assuming individual students are determinately bounded entities entails characteristics that can differentiate and describe individuals. However, scholars from a range of disciplines such as neurophysiology, anthropology, physics, feminism, and disability studies have called into question the self-evidentiary nature of bodily boundaries (Haraway, 1985). What it means for a body to be labeled (e.g., expert or novice) is always in a state of becoming with surrounding entities, and these labels cannot be seen as individual characteristics that can be measured to describe some facts about students as bounded entities.

Humanism

Another assumption that is closely related to representationalism and metaphysical individualism is humanism, which assumes a separated position of the human subjectivity to reflect on nonhuman nature at a distance, and attributes agency to only the human side of this separation. With the separation between human and nonhuman taken for granted, current research on learning with representation often focuses on conceptual understanding and identity in mutually exclusive research practice, with learning outcomes often reduced to measurable competencies and identities compartmentalized as different "human factors" in an impersonal process of cognition. The separation of humans as exceptions from the nonhuman nature ironically worked to dehumanize the human subject in cognition.

Agential variation theory

We propose agential variation theory to build a post-humanist account of learning that seeks to do without the assumptions of representationalism, metaphysical individualism, and humanism. Agential variation theory does not assume determinately bounded, pre-existing learning subject and object of learning. Rather, knowledge is thought of as sedimented out of the intra-activities of learning that differentially make learner subjectivity and the object of learning bounded and intelligible to each other. Students are not already bounded individuals entering a pre-existing, fully structured learning environment to engage with material that are external to them. Instead, learning is the always already ongoing (re)configuration of the separation between the learning subject and the learning object. What makes knowledge possible is not our ability to observe from afar but the opposite: we are always already entangled with what we wish to learn, and as the separation between the learning subject and the object of learning continuously (re)configures as an effect of different practices, the subject learns and forgets.

Methodology consideration

It is important to articulate new methodological language and labels along with theoretical perspective. We introduce Haraway's notion of String Figure, or SF as a metaphor to articulate an approach to qualitative inquiry that contest the philosophical assumptions discussed above.

Characterized as "a game of cat's cradle… of giving and receiving patterns…of relaying connections that matter", String Figure was first proposed by Donna Haraway as a methodology for forging partial connections through situated knowledge and local specificities (Haraway, 2016). Instead of retreating to the distant and secure position of an enlightened outsider, the researcher is tracing the ongoing (re)configuration of material and cultural practices as part of the world. Knowing as part of the world requires being accountable for our own involvement in (re)enacting normative boundaries. In this study, String Figure is explored as an approach for understanding learning as a process of giving and receiving patterns to craft conditions for external representations to become meaningful. SF frames the introduction of new forms of external representations (e.g., AR representation) as part of an ongoing transformation of the material and cultural practices of biochemistry education.

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Exploring Student Approaches to Science Knowledge Representation With Immersive VR Drawing

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Abstract: Drawing has been shown to be a productive tool in promoting learners to reflect on their knowledge. This pilot investigation seeks to identify the potential affordances of drawing representations of science concepts within a fully immersive virtual reality (VR) drawing environment. Drawing in VR provides new possibilities for exploring spatial arrangement and scale that have the potential to innovate the knowledge representation process. Taking a qualitative approach, this work documents the processes of seven participants as they engaged in drawing sessions constructing a representation of their existing knowledge around the lunar phases. Analysis of the recorded sessions allowed for the identification of a series of VR affordances leveraged by participants, as well as patterns of representation construction that can inform the development of future VR drawing software and activity designs.

Introduction

Drawing as a representation of a learner's progress in science has received increased attention over the last decade (Ainsworth & Scheiter, 2021). As part of this renewed focus, recent attempts have been made to break down the theoretical basis more explicitly for drawing's advantages in learning and create explanatory models for how drawing influences the science learning process (Wu & Rau, 2019). While previous research has found similar benefits to learning from multimedia when compared to the construction of drawings (Schmidgall et al., 2019), a common challenge in astronomy education is the majority of graphical representations found in authoritative sources (often by necessity) have concessions made in the accuracy and scale of the visual-spatial representations presented (Galano et al., 2018; Taylor & Grundstrom, 2011). While there is growing literature around the value of virtual reality as a medium for science learning (Jensen & Konradsen, 2018), the use of virtual reality for more generative applications (such as drawing or 3D modeling) has been largely relegated to fields such as engineering, architecture, and fine arts. The goal of this study is to bring the theoretical advantages of an immersive VR drawing interface into an application of science knowledge representation to explore how the tool is taken up by a learner as they explain their knowledge around the cause of the lunar phases.

Materials & methods

Environment design

The VR drawing platform "Tilt Brush" was utilized for this initial exploration of the potential affordances of VR drawing (tiltbrush.com). Tilt Brush was designed with a focus on general artistic expression via sketching in VR. At its core, Tilt Brush allows users to place drawn strokes anywhere around themselves in 3D space as well as manipulate those strokes to reposition them, change their size or rescale the entire drawing environment.

Participants and study design

The data discussed here was collected from the undergraduate research-participant pool of a midwestern university. While in-person data collection was not possible due to COVID mitigation steps at the time of data collection, an attempt was made to preserve as much as possible the interactions between a drawer and facilitator as the participant engaged in a prompted exploration of their knowledge around the lunar phases.

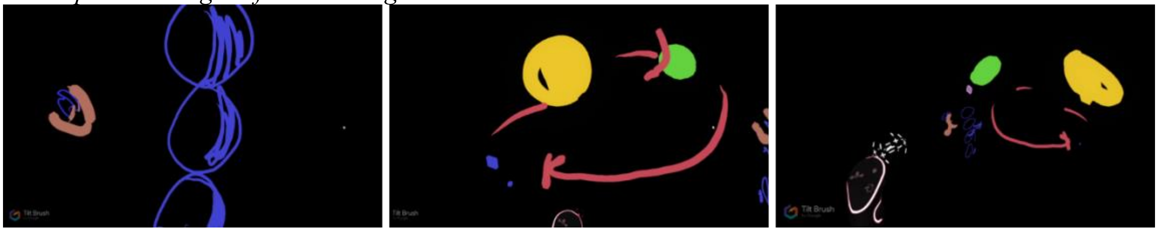
Each session was audio recorded and screen captured from the perspective of the VR user. Participants were first introduced to the VR equipment and Tilt Brush software. Participants were asked to explain the mechanism behind the change in lunar phases while drawing and thinking out loud. The facilitator remained on Zoom with the participant to address any VR technical questions. In addition, the facilitator provided conceptual support or clarifications only after prompting the participant to first attempt to reflect and address their question based on their own knowledge. In total, seven sessions were conducted, with four female and three male participants. The age range of all participants was 19-22, and of the seven, only three had previous experience with VR (two with some, and one a frequent VR user).

Results and discussion

To begin a high-level analysis of the kinds of approaches and potential affordances of the VR drawing system, session recordings were reviewed wholistically in order to generate a collection of observed actions and processes around the construction of a lunar phases knowledge representation. After the initial prompt, participants took multiple approaches to initiate the construction of their lunar phases knowledge representation. A majority of the participants engaged in a process of first creating 2-dimensional sketches within the drawing environment (ex: rings to represent the Sun, Earth, or Moon), often as acts of recall of prior knowledge and "textbook figure" representations of the lunar phases (see left of Figure 1 for example). Participant 2 exemplifies a particularly unique process captured in sequence in Figure 1. Participant 2 first began their session by drawing the progression of the lunar phases stacked vertically in 2D (Figure 2 left). After acknowledging their uncertainty around the mechanism that might produce this progression of phases, they abandon their 2D representation and begin to generate a 3D arrangement of the Earth, Moon, and Sun (Figure 1 center). Here they again express uncertainty about the spatial relationship between the Earth, Sun, and Moon, and as they manipulate their drawing by rotating themselves around it, they realize that their spatialized sketch was only interpretable from the single point of construction (work seated at arm's length) (Figure 1 right). Participant 2 then begins to move and manipulate the elements to align them so that the orbits sketched are no longer dependent on a single perspective.

Figure 1

Participant 2's stages of VR drawing construction.



Conclusion

Overall, given the limitations of the drawing sessions to accommodate non-contact protocols, all drawers were able to engage and leverage some of the affordances provided by the drawing environment to explore their conceptions around the lunar phases. The facilitator's support around the availability of specific VR functions was critical in many instances to their uptake and use by the participants. While the novelty of VR and the Tilt Brush drawing environment to many of the participants is certainly a factor, another limitation may be inherent in the design of Tilt Brush as a sketch-based artistic platform. While it provides all of the necessary tools to engage in the exploration of science ideas via VR drawing, some functions (such as selecting and moving drawn elements) are placed behind multiple menu interfaces. This makes their use "as needed" more cumbersome and also makes these capabilities less visible. These findings have already prompted the creation of a custom streamlined drawing environment for future studies that minimizes interface interactions for critical spatial affordances of VR allowing users to draw, manipulate, resize, and move within their drawings via button and controller motion interactions.

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Investigating Students’ Immersion in Relation to Cultural Heritage Learning in a Virtual Reality Environment

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Abstract: This case study analyzed an IVR activity to understand (a) whether immersion reflects a subjective psychological process towards presence and flow or whether these states reflect objective properties of VR, as well as (b) the relation of immersion to learning. Data were collected with questionnaires, post-VR-activity interviews, and screen-recordings of the activity of two higher education students. Our findings supported a subjective nature of immersion as well as a positive relation to students’ learning.

Introduction and theoretical framework

Recently, there is an increasing interest in using Immersive Virtual Reality (IVR) in K-16 education. However, empirical studies have often resulted in contradictory findings when comparing the learning effectiveness of IVR to traditional instruction with low-immersion media (Hamilton, 2021). One main explanation provided so far, is that IVR environments may induce a sense of presence and flow but that they may also detract students from the learning process. We argue that this explanation is not sufficient, and that presence and flow is not a given in IVR, as immersion is an individual and subjective psychological process. Similarly, Agrawal et al. (2020) note an ongoing debate on whether immersion reflects a subjective psychological process or whether it is simply an objective concept reflecting the technical affordances of VR. This work examines this issue by focusing on two higher education students, who participated in a case study structured around an IVR for cultural heritage learning to ask: (a) What was the nature of experienced immersion for each student?, (b) What were the main factors affecting the students’ experienced immersion?, and (c) What was the relation between immersion and learning?

Methodology

Learning intervention

An IVR learning environment was designed to support learning about a cultural heritage site (an early Christian Byzantine church), dated to 5th century A.D. in Cyprus. The IVR environment employs an inquiry-based learning scenario according to which students assume the role of historians who investigate the dating of a church ceiling mosaic through the collection of evidence.

Participants

As a case study approach, we recruited two higher education students who were communication studies juniors at a public university. Susan was 21 years-old while Tom was 23 years-old (both names are pseudonyms). Both students voluntarily participated in this case study. The students had no prior experience with VR environments.

Data collection and analysis

Screen-recording of the VR learning experience: Each student used a head mounted VR display to experience the environment through a single-user mode. As the user’s navigation of the VR environment was projected to an external screen, we were able to screen record the VR experience from a third-person’s point of view. These data were analyzed descriptively, in order to understand each student’s learning performance and experience.

Immersion and conceptual gains questionnaires: Upon completing the VR activity, each student responded to the Virtual Reality Immersion (VRI) questionnaire which was an adapted version of the Augmented Reality Immersion (ARI) questionnaire (Kyza & Georgiou, 2017). The VRI comprises of the Total Immersion scale, which has two subscales: Flow (3 items) and Presence (4 items). All items were evaluated on a Likert-scale from 1-7. In addition, a conceptual understanding test was administered to assess students’ learning about the concepts related to the topics of the VR investigation. The conceptual understanding test included eight multiple-choice items and four open-ended questions, and had a maximum score of 10. The data collected with the immersion and conceptual gains questionnaires were analyzed to create a quantitative indicator for experienced immersion as well as a quantitative indicator for learning for each student, which provided a numeric estimation of students' total immersion and conceptual understanding.

Post-activity interviews: Each student participated in an individual, thirty-minute, semi-structured interview after the intervention. Students were prompted to discuss their feelings of presence and flow, as well as the factors which had positively or negatively affected these feelings. Interviews were qualitatively analyzed using the Critical Incidents Technique (Flanagan, 1954). With this approach we sought to identify and contrast specific incidents which could be conceived as factors shaping students' immersion and learning.

Findings

Learning performance

When examining the students' learning performance, we find that both visited the learning stations within the fixed duration of thirty minutes, and that they viewed all the available multimedia resources. However, only Susan successfully completed the inquiry-based mission and specified the correct era of the wall mosaic. Susan's investigation lasted 28:17 minutes, while Tom's investigation lasted 24:10 minutes; the additional time in Susan's case was invested on the inquiry-based exploration of the church.

Quantitative indicators of learning and immersion

The examination of students' immersion indicators showed that Susan achieved higher levels of immersion, especially in terms of presence. More specifically, Tom's sense of presence was relatively low, while Susan experienced a higher sense of presence. Likewise, the examination of students' learning indicators showed that Susan achieved higher learning gains than Tom, especially in terms of conceptual knowledge.

Qualitative accounts of experienced immersion

Tom's interview suggested that while the VR environment captured his interest, there were three main barriers which negatively affected his sense of presence: (a) usability issues related to his navigation in space, (b) the multimedia learning resources which were perceived as "distractors" compromising the fluid progress of the game play, and (c) the limited sense of embodiment due to the lack of full-body interaction. On the other hand, Susan reported that the VR environment not only captured but also maintained her interest, resulting in a high sense of presence. We identified three main factors which positively affected her sense of presence: (a) the overcoming of usability issues, (b) the multimedia learning resources which served as "focal" points due to their audio-visual properties, and (c) a sense of embodiment due to the realism/authenticity of the environment.

Conclusions and implications

This work contributes empirical substantiation to the subjective nature of immersion as well as to its positive relation to the learning process. The findings are aligned with prior studies which support the claim that immersion is a subjective human experience, which may be mediated by learner characteristics (Georgiou & Kyza, 2017, 2018). For instance, differences in learning styles between the two students could provide a plausible explanation regarding their different perceptions of the VR environment. Likewise, it might be that students' digital skills may explain the persistence or overcoming of usability issues. Put simply, learner characteristics and personality traits may define students' immersion and subsequent learning. Our future work will explore these issues more systematically, given that this case study is part of a broader research effort that includes 50 additional students. Our next steps will focus on the analysis of the collected data for the extraction of more generalizable findings.

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GROOVA: A Data Visualization Tool for Elementary School Students Co-Designed by Teachers and Researchers

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Abstract: This paper describes a Research-Practice Partnership in which a data visualization tool, called Groova, was co-designed. The curricula and tool are conceptualized as boundary objects which served to increase the partners collective knowledge on ways to improve students' data science learning. Findings included teachers' beliefs that the tool was developmentally appropriate for elementary students, the tool would encourage student learning, and that their design ideas and voices were heard.

Introduction

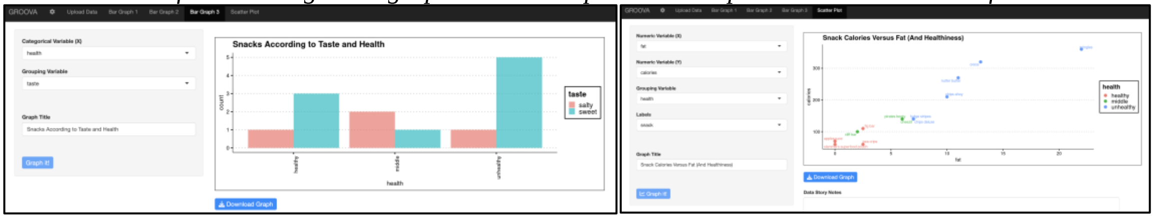
Data science skills and practices assist people of all ages in making informed decisions to better understand risks for individuals and broader larger society (National Science and Technology Council, 2018). For middle-school students, data literacies include *data storytelling*, the presentation of data and statistics coupled with visual and narrative elements to communicate to a broad audience the results and implications of data analyses (Wilkerson et al., 2021). One approach to engage elementary-school teachers in data science is through a research-practice partnership (RPP). In an RPP model, the intended outcomes are jointly determined and cycles of continuous improvement are supported by agreed upon rules, roles, routines and strategies (Coburn & Penuel, 2016). Farrell and colleagues' (2022) RPP conceptual framework outlines mutual learning between researchers and practitioners that involve *shifts in collective knowledge* by interacting with *boundary objects*. Examples of boundary objects in RPPs include co-designing curricula, assessments, or educational tools. In this paper, we describe how researchers and teachers co-designed a data visualization tool for students which served as a boundary object in this RPP.

Methods

Context and participants

This study is a preliminary analysis of GROOVA and is part of a larger RPP project in which researchers and elementary school teachers co-designed and implemented data science curricular units. In year 1 of this project, 7 researchers and 9 teachers participated in summer co-design sessions and implemented 4 data science units. In year 2, the same 7 researchers, 7 educators from year 1, and an additional 9 educators participated in summer co-design sessions and implemented 6 data science units. In year 1, teachers voiced difficulties with using TUVA, the data visualization tool (Arastoopour Irgens et al., 2023). Motivated by their partner teachers' experiences, one researcher developed GROOVA using R Shiny

Figure 1
GROOVA Interface showing a bar graph and scatter plot with sample data about nutrition facts.



Categorical Variable (X): health
Grouping Variable: taste
Graph Title: Snacks According to Taste and Health

Numeric Variable (X): fat
Numeric Variable (Y): calories
Grouping Variable: health
Labels: snack
Graph Title: Snack Calories Versus Fat (And Healthiness)

In this part of a larger descriptive case study, we collected field notes from teacher and researcher summer meetings, teacher's daily journal entries, and transcribed interviews from teacher focus groups. We coded all three data sources and then weaved the codes into three themes (Terry et al., 2017) that described teacher's perceptions and reactions to the data visualization tool that researchers presented at the summer meeting.

Findings

Better usability and more developmentally appropriate than other tools

When the researchers presented GROOVA to the teachers, the teachers' reactions were mainly about the increased usability of the tool compared to TUVA. When teachers explored the tool, they stated that GROOVA was "quicker, easier, and more efficient [than TUVA]" and had "less distractions." One teacher wrote in their journal, "Groova was super friendly and cool… It is very **user friendly** and **accessible for students and teachers**." In their interview, one teacher noted that GROOVA had options for increasing. She stated,

> "Last year… I got to see TUVA and I was like 'whoa, this is rough!' Like even me as an adult and a teacher, I was kind of like, "ummm…I don't really get it."… With GROOVA, they can step their way into, you know, you might have some kids that with that basic bar graph they need to stop right there, and just live in that basic bar graph. But you know your higher kids might use that scatterplot, that might click for them, so I think that's great, that there's options."

An effective learning tool

In addition to being user-friendly and developmentally appropriate, teachers also commented on GROOVA as an effective tool for graphing and telling data stories. For example, one teacher wrote in their journal, "Groova is a fabulous tool! I can see this being a wonderful way for students to create their data tables that **enable them to feel successful and reduce student stress.**" Another teacher wrote, "Groova looks cleaner and **better for students to understand**. If students understand the information better, he/she can explain a data story." This teacher connected the ease of usability of the tool to improved predicted learning outcomes.

Teacher's design ideas: "It's what we want too"

During the summer meeting, teachers were given a demonstration of GROOVA using sample data and then access to test GROOVA with a sample dataset. Then, researchers asked teachers to identify features that they wanted to add to the tool. One teacher explained in their interview that they had "buy-in" for using GROOVA because the researchers were listening to their needs and implementing their requests into the tool. She said,

> "We had a chance to share our ideas and what we felt like Gol [the researcher] needed to add to GROOVA… We said that graphs didn't have titles. So that's when, Gol [the researcher] went back and said, 'Well, I can add it where they can put their very *own* titles,' and because it was so important for them to be able to create their own titles based on the data, she was able to add that. **So, I feel like the buy-in is that it's what we want, you know, it's what we want, too**."

Conclusion and next steps

In this study, GROOVA served as a boundary object for mediating activity and knowledge between teachers and researchers (Farrell et al., 2022). This boundary object emerged from the RPP participants' shared goal (Coburn & Penuel, 2016). Future analyses will include observations of GROOVA in teachers' curricular units, discussions with teachers about improving the design, and discussions with students about their experiences.

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Intelligent Tutors, Cultural Blind Spots: Implications of Underrepresentation in Adaptive Learning Research

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Abstract: As intelligent tutoring systems (ITS) continue to mature and spread to lower- and middle-income countries (LMICs), it is becoming clear that basing such tools around models of learning overwhelmingly studied in Western countries has left severe blind spots that need to be addressed. This paper aims to raise awareness of the disconnect between the collectivist value systems espoused by many cultures and the Western individualistic mentality of ITS developers and researchers, along with some implications.

Introduction

Artificial intelligence in education (AIED) is an area of research in which the latest technological advances and the learning sciences meet. While this field encompasses multiple goals, one long-standing vision has focused on personalized learning through software that can adapt to the needs of individual students. This paradigm has dominated the design of intelligent tutoring systems (ITS) in the United States and other western, educated, industrialized, rich, and democratic (WEIRD; Henrich et al., 2010) countries. Not surprisingly, lower- and middle-income countries (LMICs) have yet to see much of the payoff from all the research these tools have sparked.

While the current imbalance in representation is not exclusive to academia, it stems largely from AIED research being predominantly undertaken in WEIRD countries. Several meta-analyses have highlighted this issue among published research in AIED and ITS journals and conference proceedings (Blanchard, 2012; Nye, 2015; Roll & Wylie, 2016). This underrepresentation in LMICs can be partly attributed to obvious barriers to AIED adoption, such as hardware access or electrical and internet reliability, but less tangible realities, such as cultural differences, may prove to be more formidable obstacles in the long run. Yet it is difficult to know what these challenging barriers will look like without investing adequately in research within LMIC contexts. In this paper, I aim to raise awareness of some of the practical implications of our current cultural and social blind spots.

Cultural behavioral differences

Much AIED research has focused on using data to capture student behaviors. However, studies in psychology have found that an overreliance on WEIRD populations for research can lead to an overemphasis on psychological constructs and behaviors that are not representative of the general global population (Henrich et al., 2010). One of the significant behavioral differences that researchers have identified across cultural contexts is that of student collaboration (Nye, 2015; Ogan et al., 2015; Ogan & Walker, 2012). These studies have found that students in many LMICs often collaborate extensively while using ITS. This appears to be the case regardless of socioeconomic status, urbanicity, or experience level with ITS (Ogan et al., 2015; Ogan & Walker, 2012). In these contexts, students have been observed providing help to classmates through oral communication or in some cases physically taking control of another student's computer. Practices such as these deviate significantly from the way ITS and other adaptive learning systems are typically designed to be used in WEIRD classrooms.

Implications for research and practice

While increased collaboration is generally considered positive in the learning sciences, this behavior does not align with the intended individualistic practice espoused by much ITS work. The learner models commonly developed in WEIRD countries may not reliably transfer to these different cultures, in part because they function under an assumption of a one-to-one student-to-device ratio, which is the foundation of the personalized learning paradigm at the center of much AIED work. Suggested solutions to this problem have included modifications to the algorithms used for knowledge tracing, which create and update the learner models used by ITS (Ogan & Walker, 2012), though it is difficult to see this as anything more than a band-aid solution. Some promising work has instead been aimed at designing ITS that enable students to share hardware while still being able to use their own input devices—an approach that has the added benefit of lowering hardware costs (Nye, 2015). Still, the majority of research continues to work towards a vision of one-to-one, machine-to-human tutoring.

All of this suggests that the heavy emphasis that AIED research has placed on personalized learning may come in conflict with the more collaborative pedagogies espoused by some cultures (Ogan et al., 2015). There may be a disconnect between collectivist value systems in some cultures and the Western individualistic mentality of AIED developers and researchers. Of course, I'm not claiming here that such values are the shared cultural heritage of all peoples in LMICs—a statement that would be reductionist at best. Instead, I am pointing out that it is problematic to assume that educational tools will always be used as intended.

Despite the difficulty of adequately addressing such a fundamental difference in how ITS are used in different contexts, the good news is that there does seem to be a growing interest on the topic. Roll & Wylie (2016) found that a much larger proportion of IJAIED papers from 2014 featured learner collaboration than a decade earlier, with not a single paper featuring it two decades earlier. To the best of my knowledge, such a systematic review has not been done in the ensuing years. It is important to continue identifying the trajectory of this research as a form of accountability and because awareness of LMIC underrepresentation in ITS research is the first important step towards mitigating the issue. Suggestions on where to go from here include hosting more conferences such as AIED outside of WEIRD countries—which may help researchers in these contexts become engaged in the community—as well as a call for researchers to more consistently describe the relevant contextual factors of their samples (Nye, 2015). The latter suggestion has the added benefit of helping to address some of the algorithmic biases that knowledge tracing and learner behavior models often carry (Paquette et al., 2020)—another issue that may be negatively affecting underrepresented populations such as those in LMICs. However, truly addressing the blind spots highlighted in this paper may ultimately require entirely reimagining what personalized learning will mean in an ever-more-interconnected, information-overloaded world.

Conclusion

This paper has highlighted one of the key implications (and subsequent challenges) of work that aims to expand adaptive learning to populations in LMICs. However, there remain fundamental questions to ask that this paper has not touched on. For starters, it has not called into question the very premise that expanding AIED access to LMICs is desirable. As is true of any large-scale implementation of a new technology, such an effort will undoubtedly bring with it both predictable and unpredictable unintended consequences. One such issue is the potential for neocolonialist outcomes that supplant traditional local practices and paradigms.

One of the principal driving forces behind AIED is the desire to reduce inequalities in education by making learning more personalized to individual students and their needs. Adaptive learning systems present the opportunity to make an especially positive impact in LMICs due to common shortages in these areas of qualified teachers (Zualkernan et al., 2013) and other resources such as textbooks (Nye, 2015). Yet the only way to work toward an equitable future on this front is to carefully reflect on the problems that may be introduced and possible ways to mitigate them. This is precisely what this paper has attempted to do, though only as an entry point into the conversation.

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Role of Learners' Agency in Facilitating Effects of Simulation-Based Learning in Higher Education: A Meta-Analysis

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Abstract: This meta-analysis includes 217 empirical studies and investigates the effectiveness of facilitating learners' agency as a strategy to adapt and individualize instructional support to learners' prior knowledge. We conclude that (1) facilitating learners' agency might have different effects on learners with different levels of prior knowledge; (2) allowing learners to control simulation flow enhances effects of simulations.

Introduction

Empirical research provides supportive evidence on the effectiveness of learning with simulations in different domains of higher education (e.g. Cook, 2014, Theelen et al., 2019). Student-centered approaches and adapting instructional support to the competence level and needs of learners enhances knowledge and skills (e.g. Bernard et al., 2019). We assume that facilitating learners' agency (i.e. control) over the flow of own learning is beneficial for developing a whole range of skills in higher education. However, there is a lack in systematic knowledge about designing effective instructional support within simulations in higher education, and in particular allowing support to be adapted based on learners' needs or characteristics.

Theoretical background and research questions

This meta-analysis is grounded in the research on the effectiveness of simulation-based learning in fostering the development of complex skills in different domains (e.g. Chernikova et al, 2020). We adopt the idea of adaptability as one of defining elements of scaffolding (e.g. van de Pol et al., 2010) and emphasize that by adapting the scaffolding, the effects on learning outcomes can be significantly increased (e.g. Belland et al. 2017). To capture adaptability of learning environments we rely on the framework by Plass & Pawar (2020).

As the empirical evidence considering effects of facilitating learners' agency by adapting instructional support is mixed, we expect to collect meta-analytic evidence to clarify those. On the one hand, learners' agency and control over own learning is associated with increased motivation and learning gains (e.g., Al Moteri, 2019). On the other hand, the meta-analysis by Belland et al. (2017) showed better effects for the external decision-making authority (i.e. decisions made by instructors or systems).

The following research questions were addressed in the paper.

RQ1: What strategies aimed at facilitating learners' agency are used in primary studies of simulation-based learning environments in higher education?

RQ2: To what extent can facilitating learners' agency enhance effects of simulation-based learning on learning gains in learners with higher and lower levels of prior knowledge in higher education?

Methods and results

A state of the art meta-analysis procedure (Schmidt & Hunter, 2014) was used. The analysis is based on extending the collection of primary studies in a meta-analysis by Chernikova et al. (2020) by 74 further studies (total N=217) and is focusing on facilitating learners' agency within simulation-based learning environments.

All primary studies were double coded by one of the authors and a student assistant with interrater agreement above .92. The level of prior knowledge was coded as "high" if the simulation context was familiar to the learners on conceptual and procedural levels as mentioned by the authors of primary studies and as "low" if the simulation context was unfamiliar (e.g. new topics). Strategies, which aimed at allowing participants to control learning situation, were coded at the next step. If learners were in control, strategy was coded as "by learner", if decisions were made by instructor or system; strategies were coded as "by instructor/system".

Average effect of simulations on learning was found to be g=.95, SE =.06. This effect was used as reference point for estimating effectiveness of each strategy for adapting instructional support.

The following strategies facilitating learners' agency (RQ1) were found in primary studies: (1) giving participants control over time/amount of support (used in 20 studies); (2) giving participants control over solution steps in simulation (i.e., deciding on activity/task order), identified in 37 studies.

In regard to RQ2 giving participants control over solution steps in simulation was beneficial for all learners, independent from levels of their prior knowledge. Giving participants control over time/amount of support they get had some positive tendency for learners with high level of prior knowledge, but not low level.

Table 1
Effects of facilitating learners' agency

	High prior knowledge Hedge's g (*SE*); *N*		Low prior knowledge Hedge's g (*SE*); *N*
1. Control over scaffolding			
By learner	1.15 (0.32); *N*=10	*	0.51 (0.14); *N*=8
By system/instructor	0.99 (0.10); *N*=61		0.82 (0.13); *N*=62
2. Control over task order			
By learner	1.19 (0.19); *N*=18		0.86 (0.20); *N*=19
By system/instructor	1.00 (0.09); N=52		0.75 (0.13); *N*=58

Discussion

This meta-analysis focuses on simulation-based learning environments in higher education and strategies that can be used within these learning environment to facilitate learners' agency or in other words enhance learners' control over the flow of simulation and own learning.

The findings of the current meta-analysis go in line with the effects reported in a range of more traditional learning environments (see Belland et al., 2017), confirming the claim that learners with lower levels of prior knowledge might have problems with identifying their need for help. Interestingly, the effect is different when learners are given the opportunity to decide on the task/solution steps order. This strategy has similar effects for both levels of prior knowledge; and its implementation is associated with higher effects of simulations on learning outcomes.

A couple of limitations need to be considered: (1) the categorization of strategies to adapt instructional support is relatively coarse-grained and may be confounded with some implicit instructional support used in primary studies; (2) this research only addresses objective measures of learning outcomes, but not attitudes, or motivation, which might be also affected within simulation-based learning environments.

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Positivist and Constructivist Orientation Impact on Supervisors' Conceptions of Video Use in Teacher Professionalization

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Abstract: This research aims at getting insight in the supervisors' conception in the use of video to bridge learning of students and the professionalization of teachers. Therefore, we interviewed supervisors why and how video technologies are being used or not in the process of enhancing their professional practices and collaborative learning with the student teachers. The main finding is that supervisors' knowledge orientation probably has an impact on how they perceive the use of video in their teacher professionalization practice. In fact, both groups (positivist *vs.* constructivist) are using video but the first group is prioritizing more objective ways to use video technologies and the latter group focuses more on using video in constructive ways to support the learning process.

Introduction

The Covid-19 pandemic prompted a transformative shift in education nearly two years ago. Teachers deserve commendation for their commendable efforts in ensuring the continuity of education, despite challenges in discipline and motivation arising from the absence of social interactions with peers and teachers. This transition compelled teachers to step out of their comfort zones, often marked by resistance rooted in social, psychological, and professional factors (Savina, 2019). While some teachers embraced the positive possibilities of online learning and sought to enhance their e-didactics, many still struggle to systematically integrate videos into their teaching practices, hindering productive and contemporary learning experiences. Insufficient understanding of how videos can support collaborative learning in teaching contributes to ineffective outcomes, limited engagement, and missed opportunities for technology-enhanced learning.

Our research constitutes the initial phase of a doctoral research project conducted in Évora, Portugal, and aims to investigate the influence of the supervisors' conceptions of knowledge, whether objectivist or constructivist (Fosnot, 1996; Perkins, 1999; Darling-Hammond, 2000), on their reported professional practices and their use of video technologies to facilitate collaborative learning between themselves and their student teachers.

Method

The research employed an exploratory approach, employing semi-structured interviews (in-person [5] and online [6]) with teacher-supervisors. Various analysis methods, including manual NVivo analysis, natural language topic analysis, semantic network analysis, and SPSS (M)anova procedure on KBDex were utilized to examine and interpret the supervisors' reported practices and perspectives. The study involved 11 supervisors from six universities and higher education institutions (HEIs) in Portugal.

Analysis

The analysis employed NVivo to analyze the supervisors' visions of knowledge (positivist or constructivist) as the initial step. The fourth part of the semi-structured interviews was specifically utilized for this purpose. To ensure reliability, three researchers received clear instructions to differentiate between positivist (P) and constructivist (C) visions in the supervisors' discourse. They independently analyzed the interview text corresponding to Part D and provided feedback. Inter-rater agreement was measured using Fleiss' Kappa test, resulting in a high agreement level of 0.876 among the three researchers (Table 1). In the second step, a list of stop words was used to prepare the text for topic analysis. Through topic modeling, the most frequent words from the semi-structured interviews were extracted and combined with a comprehensive word list. This process identified seven noteworthy categories for further analysis. Lastly, KBDex, in conjunction with the previous analysis results, was employed to examine semantic network differences between supervisors with positivist and constructivist knowledge perspectives across the identified categories.

Table 1

Inter-rater level of agreement (Fleiss' Kappa)

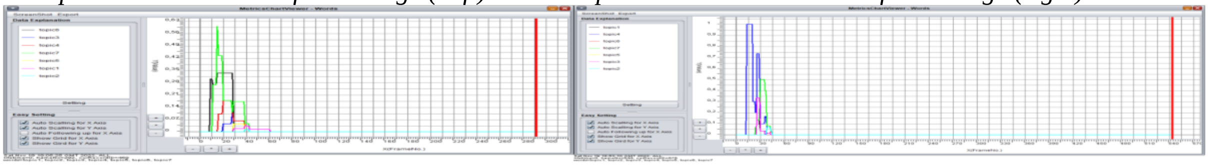
	Kappa	Asymptotic Standard Error	Z	P Value	Lower 95% Asymptotic Cl Bound	Upper 95% Asymptotic Cl Bound
Overall	0,876	0,174	5,032	0,000	0,535	1,217

Findings

The qualitative analysis revealed that there were five supervisors (Group A) with a positivist orientation and six supervisors (Group B) with a constructivist orientation in their perspectives on teaching and learning (Figure 1). Excerpts from the interviews showcased the supervisors' viewpoints on knowledge. Those with a positivist vision described knowledge as a set of research-based assumptions that inform a professional area, while those with a constructivist vision emphasized the incorporation of information into existing knowledge through transformative mental and bodily processes. The topic analysis identified seven categories, supported by frequent words, such as supervision process, video, collaboration, and reflection. A Manova analysis indicated a significant difference between the two groups, with constructivist-oriented supervisors showing stronger scores on the conceptualization of "Video-Teaching-Supervision."

Figure 1

Group A - Positivist view of knowledge (left) and Group B - Constructivist view of knowledge (right)



Discussion and conclusion

Because of the exploratory character of the study we intend to give continuity and update in the future. Looking at the 'Video-Teaching-Supervision' dimension throughout the complete interview data, it is clear that the constructivist-oriented supervisors differ from the positivist oriented by more attention to video and the supervision process, the role of the teacher in the learning process, collaboration supervisor-student-teacher/teacher in practice and training, internship and the supervisor. To summarize, video is being used by supervisors from both groups although they seem to be doing it in a different way and with slightly different goals. For instance, ones prioritizing more practical skills versus others giving attention to the development of reflection skills; more objective ways to use video technologies versus more constructive ways to use videos to support the learning process. Based on the variance analysis it can be concluded that the two groups of supervisors conception of video use is characterized by different foci. Sample size of 11 teacher supervisors may limit the generalizability of the findings. Additionally, the subjective nature of the interview responses and potential interviewer bias could influence the results.

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Teachers’ Beliefs and Practices of Technology Integration: A Case Study of Kerala (India) Teachers From an Ecological Perspective

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Abstract: Research on teachers’ beliefs and practices of technology integration suggests that contextual factors be given sufficient attention, in addition to cognitive and affective factors. The present study used an ecological perspective to understand how contextual factors situated at three ecosystem scales affect the enactment of teachers’ beliefs and practices of technology integration. We present findings from a multiple-case study of three middle and high school science teachers in Kerala, India.

Introduction

The significance of teachers’ beliefs in classroom practices of technology integration has been established by prior research. While most researchers agree that teachers’ beliefs and practices of technology integration form and change through a dynamic interplay of cognitive, affective and contextual factors, existing studies are predominantly focused more on the individual characteristics of teachers, and are inadequate to account for the complex interactions happening between teachers and the ecosystem of the school (Nadelson et al., 2018) and this creates a crucial gap. In the present study, we use an ecological perspective to address the research question: ‘How do contextual factors contribute to the enactment of teachers’ beliefs and practices of technology integration?’

Theoretical framework

The present study operationalizes teachers’ beliefs about technology integration as related, but independent components of pedagogical beliefs about teaching and learning, self-efficacy beliefs for using technology and beliefs about the value of the use of technology (Park & Ertmer, 2007).

Throughout the study, we used an ecological perspective from research gap identification to findings and interpretation. We have adopted the learning ecosystem conceptual framework proposed by Hecht & Crowley (2020). In the present study, we consider the ecosystems of teachers at three scales i.e. regional, school and classroom ecosystems. We consider the ecosystem as a constellation of inter-twined and entangled elements such as teachers, students, parents, school administrators, teacher educators, community, technology, etc., and their dynamic relationships that we can find within and across the school and out-of-school places. Another aspect is the ecotone, which is a zone of transition between two ecosystems, where one set of environmental conditions merges into another (Ryberg, et al., 2021).

Educational context

The present study is conducted in the rural area of the Thrissur district of Kerala in southwest India, which is known for its high literacy rate. Kerala has implemented various innovative programs to support teaching and learning through technology such as VICTERS (Versatile ICT Enabled Resource for Students) and Samagra eResource Portal. Kerala is exceptional in terms of the degree of society’s participation in public education, particularly at the local level, in the form of various civic collaborations with schools and teachers. All teachers in the selected schools are qualified with minimum BA/BSc and BEd degrees and state eligibility tests (SET). Teachers received induction training on the use of ICT through a platform called KITE's Open Online Learning (KOOL). The majority of parents are daily wage workers and from fishermen communities. However, some parents are also educated and involved in teaching, business, politics, banking, etc. People in this area speak the language of Malayalam.

Method

The present study used a multi-case study research design to develop an in-depth analysis of each teacher. We define our case as a middle or high school science teacher in the state of Kerala, India, who utilizes technology for the teaching and learning process. The goal here is the theoretical replication of similar or contrasting findings we get from each case. A broader study designed for 14 middle and high school science teachers from different types of schools (government and government-aided private) in the Thrissur district of Kerala is ongoing. For the present study, we used a maximum heterogeneity sampling strategy (Patton, 2015), to purposefully select three teachers from the 14 teachers. Data were collected through semi-structured interviews with individual teachers and observation of teachers' continuing professional development (CPD) programs.

The audio-recorded interviews were transcribed into Malayalam text and then translated into English for further analysis. We first identified the instances of transactions reported by the teachers. These include but are not limited to dynamic interactions of teachers with students, families, teacher educators, administrators and the material elements they engage with such as technology. Within those transactions, we classified them as transactions within and across the ecosystems at three scales. Transactions which involved or led to teachers' beliefs and/or practice of technology integration were considered for further analysis. We examined teacher statements which directly or indirectly related to one of the three beliefs (i.e. pedagogical beliefs about teaching and learning, self-efficacy beliefs for using technology and beliefs about the value of the use of technology).

Findings and discussion

This study conducted among middle and high school teachers in the state of Kerala, India has shown different patterns of transactions within and across ecosystems at *the classroom, school and regional scales*. At the classroom scale, we have identified that *immediate feedback, family background of students, availability of resources, the need of students, adaptability of technology, nature of learning content and ability of students* are the contextual factors that affect teachers' technology practices. However, contextual factors such as the family background of students and the availability of resources do not influence teachers' beliefs about technology integration. At the school ecosystem scale, *sharing success stories by colleagues, monitoring and auditing of teacher practice by the head teacher, availability of resources, and administrative decisions or policies* are found to be the contextual factors that affect teachers' technology practice. However, only the contextual factor 'sharing success stories by colleagues' is capable of influencing teachers' beliefs about technology integration. In the regional ecosystem scale, *policies or guidelines, parents' involvement in children's education, and pressure from the teachers' families* are found to be the contextual factors affecting teachers' technology practice.

The study found that contextual factors situated at the regional and school ecosystem scale have equal potential to influence teachers' technology practice at the classroom ecosystem scale. This finding reiterates the observations of Hecht & Crowley (2020), who argued that ecosystems exist at both micro and macro scales in nested, but nonhierarchical, structures. However, we found that contextual factors have diverse effects on teachers' beliefs about technology integration. Not all contextual factors are capable of influencing teachers' beliefs, for example, the contextual factors situated at the regional ecosystem scale did not influence teachers' beliefs about technology integration. At the same time, we also noticed some contradictions in teachers' reported technology practice and their beliefs about technology integration. The contextual factors situated at the regional scale such as monitoring/auditing, availability of resources, and administrative decisions/policy are capable of forcing teachers to use technology in a teacher-centred manner, even if they hold student-centred beliefs. Another important observation is that the *community of practice of teachers* functioned as ecotones and augmented the influence of contextual factors acting across the ecosystems scales and facilitated productive changes both in the beliefs and practices of teachers. For example, the teacher professional development programs provided by the teacher educators at the regional scale are facilitated by continuous and constant support provided by the community of practice of teachers through both physical and virtual teacher subject groups (ecotones). The discussions and sharing of innovative ideas and success stories in these teacher groups made a positive influence on teachers' technology practice and affected their beliefs about technology at the classroom scale. Even if the contextual factors at the regional and school scale could not affect teachers' beliefs about technology integration positively, the community of practice of teachers (ecotones) facilitated this process and made possible productive changes both in the beliefs and practice of teachers.

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Examining Demonstrations of Presence in a Multimodal Art Exhibit Created by Latina/x Youth

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Abstract: Museums have longstanding issues with reproducing colonial narratives of marginalized communities and/or erasing their perspectives altogether. In response, visitors of color may feel that museums are "not for them." Our team developed a multilingual after-school program aimed at increasing representation of Latina/x youth in museums through co-creation of an art exhibit. We used thematic analysis to examine visitors' written responses to the exhibit and identify how the exhibit allowed the artists to demonstrate presence.

Introduction

Museums have problematic histories regarding the representation of objects, artifacts, and artworks from communities of color. Museums tend to represent colonial perspectives due to a largely homogenous workforce and an unwillingness to broach uncomfortable topics (Dewhurst & Hendrick, 2017; Feinstein & Meshoulam, 2014; Hooper-Greenhill, 2000; Martinez, 2020; Seitz, 2012). In response, visitors of color may find that exhibits diminish and/or erase their perspectives (Martinez, 2020). As an example, mainstream museums may lack multi-layered representation of Latinx artists or fail to accurately contextualize Latinx works (Acevedo & Madara, 2015; Zamora, 2007), thus recreating feelings of exclusion and irrelevance.

In response, we began a multi-year project aimed at supporting the inclusion, representation, and relevance of museums to Latinx youth through co-design of art exhibits. We leveraged community partnerships to develop a multilingual after-school program that scaffolded participants' design of a multimedia exhibit about identity, community, and culture. In turn, we hoped that museum visitors would relate to and reflect on the girls' experiences via a "Response Wall." To examine how the exhibit impacted visitors, we used thematic analysis (Braun & Clarke, 2006) to investigate visitors' responses on the wall: *what themes emerged in visitors' responses to the exhibit, and how did these responses bear witness to the artists' presence in the museum?* This paper illustrates how youth-driven designs can increase museums' capacity to serve marginalized groups as artists and visitors while using a practitioner-friendly approach to analyzing visitor impacts.

Methods

This project was developed with the input of multiple partners, including Latina/x middle-school girls; school staff; a university art museum in the U.S. Midwest; and a nonprofit organization that encourages career exploration for young women. From Sept. – Dec. 2021, up to 10 girls joined 10 after-school sessions, with five girls attending most sessions. Participants identified as Latina/x young women and spoke English, Spanish, and/or Indigenous Guatemalan languages (Q'anjob'al and K'iche'). During the program, the girls engaged with activities that examined their identities, communities, and conflicts in middle-school life. They created a community map of important locations in their daily lives; a "snack-off" video of creative dishes; a music playlist; framed drawings of important words in their lives; and an artists' statement that blended English and Spanish to describe the exhibit intentions. The exhibit was displayed at the university art museum from April - July 2022 with free admission. A digital archive is available at https://catdoti.github.io/latina-community-voices/.

This study draws from a larger data corpus documenting the program. We focused on visitors' responses to the exhibit based on 204 written and/or drawn sticky notes on the Response Wall. The first two authors qualitatively analyzed all notes using thematic analysis (Braun & Clarke, 2006). We read all notes independently, then generated a tentative coding scheme. We met to sort notes and identify themes based on broad categories of notes being "related" or "unrelated" to the exhibit. We finalized all themes, codes, and interpretations when writing our report. The full coding scheme can be found here: http://bit.ly/3Ar3ZOf.

Findings

Visitors left 204 responses on the Response Wall, of which 83 (41%) were related to the exhibit and 121 (59%) were not (or could not be determined). We noted that 153 responses (75%) were written in English, 41 (20%) in Spanish, and 10 (5%) in other languages. We identified six themes within related responses (see Table 1), which include sub-codes not listed here due to space constraints; more detail will be included during the presentation. Five responses were left by the participants themselves after reading other visitors' responses.

Table 1
Emergent Themes in Visitors' Responses

Related to Exhibit	# Codes	Unrelated to Exhibit	# Codes
General exhibit feedback	24	General addition of presence	93
Specific exhibit feedback	19	Provocative statements	18
Feelings of inclusion	12	Languages other than English/Spanish	10
Other Latinx representation	15		
Responses from participants	5		
Responses about the museum	11		

Discussion & conclusion

This project aimed to increase representation of Latina/x youth in museums, and we see the visitors' responses as evidence of progress toward this goal. Related responses indicated that visitors had largely positive experiences with the exhibit, with some alluding to shared identities (e.g., "Feels like home") or directly stating them (e.g., "I'm Puerto Riceña pero I relate con muchas cosas que los estudiantes están diciendo"). Other notes thanked participants for sharing pieces of their identity, highlighting how the exhibit created space for Latina/x cultures (e.g., "I feel so proud to be Latina when I see others embracing our beautiful cultura") and languages, with at least 20% of responses including Spanish. Some praised the inclusion of Latinx perspectives (e.g., "Gracias por crear una exhibición para representación y darnos una voz") while others attempted to co-participate through basic phrases (e.g., "Me gusta tu cultura"), both of which legitimize Spanish in a "mainstream" American art museum.

This initial analysis discusses one element of a multi-year project and thus has several limitations. First, the Response Wall was anonymous, and we lack demographic information about respondents. Second, we cannot assume that the artists' perspectives encompass the varied identities, cultures, and lived experiences of all Latina/x youth. Last, participants did not analyze responses with us. As we continue this project, we intend to integrate our participants into analytical and interpretive research of this project's impacts.

While the exhibit co-design process served as a participatory experience for its artists, it also invited visitors to participate via the Response Wall. Visitors' contributions of responses as sticky notes not only allowed artists and visitors to interact, but also provided tangible artifacts that acknowledged the artists' efforts and presence, further building on the exhibit. Some visitors used this space to encourage, relate, appreciate, and offer feedback, and some took it as an opportunity to express their own identities through creation of images, text, and other personal markers. For all notes, regardless of relevance, adding to the Response Wall was a way to document presence and witness the artists' creations. When the artists visited the exhibit shortly before deinstallation, they left a message of their own: "We loved all the love you guys gave us."

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Play-Inspired Organic Differentiation in Early Math

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Abstract: As part of a larger project to explore the possibilities for children to learn mathematics in play, we examined how opening up a pattern block activity provided space for children to differentiate their interactions. The limiting nature of the original task would have stopped children from demonstrating what they could do and might explore. Using Bishop's (1988) fundamental mathematical activities as our codes, analyzed video of eight children engaging in pattern block play revealed how they organically differentiated, pushing learning opportunities beyond the scope of the original lesson.

Situating the problem

Revising a lesson to invite children to play with mathematics and take agency provides them with opportunities to demonstrate mathematical understanding beyond what the lesson goals require. In a spatial reasoning activity modified to be more playful, we found that children's varied engagement that derives from a child's agency, rather than a different activity put forth by the teacher, is what we call 'organic differentiation'. This engagement can range from children participating in ways that align with the expected goals for the task (e.g., placing the pattern blocks on the puzzle) to a demonstration of pushing their participation beyond expectations in a challenging or new way (e.g., using pattern blocks to create a new design). Organic differentiation may allow children agency to approach activities in ways that align with their own experience, interests and expertise. As part of a larger study of designing classrooms that support children's mathematics learning with play, we explored the questions:

1. How do playful pattern block activities support children's engagement in mathematics?
2. How do open-ended play-based activities provide opportunities for organic differentiation?

Conceptual framework

Vygotsky (1978) viewed human development as a socially-mediated process; informed by social experiences/ interactions (including play). When considering learning opportunities, the children operated in their zones of proximal development (ZPD); working in spaces they were familiar but also trying new things. As a lens to examine children's engagement with the mathematical activity, we drew on the work of Bishop (1988) who identified six fundamental activities of mathematics (counting, locating, measuring, designing, playing, and explaining) that he found to be universal and necessary for mathematics. These fundamental activities enable us to see what mathematics is around to be learned, what mathematics children are doing, and how to label those practices as such.

Methods

These data are from video recordings of two small groups of kindergarten children. Analysis focused on a guided play activity: pattern block puzzles where children were provided with a large box of pattern blocks and several templates to create shapes with the pattern blocks. From Bishop's (1999) six fundamental activities, we collectively identified "designing" and "locating" as the primary practices children engaged in. Using video analysis software, we coded each video multiple times, focusing on individual children each time. Descriptive codes that characterize the ways children participated in locating and designing guided the narratives we wrote for each child. We then compared narratives and codes and discussed children's engagement across groups.

Findings

Our analysis shows that the children engaged differently with the pattern blocks even when given similar instructions and materials for the guided play math center. We argue that these children's actions, the mathematical practices they engaged in, and their engagement supports our finding that this playful activity afforded the children the opportunities to self-differentiate in an organic way. To characterize the children's engagement, we identified four common patterns of play: the rotators, the aligners, the designers, and the duplicator. Although some children participated in practices that were used across the groups (e.g., rotating shapes), we identified these groups to showcase the primary ways the children engaged in mathematical practices.

The Rotators (n=2) would look at the puzzle, select the shapes, and then rotate and slide them to fit together. They participated in the math practice of locating as they actively rotated and slid shapes to fit within the puzzle. The different ways the children did this (in the air or on the paper) and the different goals of rotating (to match the shape or to determine the fit within the puzzle), highlight, even within this group, the ways the children differentiated their engagement with the mathematical practice of locating to be successful with this activity. The Aligners (n=3) made sure each shape fit perfectly on the pattern block puzzles or in line with the other shapes. A key characteristic of this group was their attention to the final product which required that pieces were precisely placed. Making sure that each shape fit perfectly within the pattern-block puzzle, the children would look at the puzzle and then find that shape in the box and place it directly on top of the puzzle in the exact placement. They attended to precision in the placement of each shape by touching it on either side with both hands in order to slowly and more accurately adjust it to fit the puzzle. The Creators (n=2) did not follow the pattern puzzle instead, upon recalling that the teacher had told them, “we are making shapes out of other shapes”, decided to create their own. In their designs, the children attended to symmetry and created patterns using tessellations and symmetrical patterns. The Duplicator (n=1), unlike all other children who either stayed on the pattern block template or completely deviated from it, used the pattern block template as a guide and completed his puzzle off of the paper itself. To do so, he first sorted all of his shapes and then using the snake pattern block puzzle as a reference duplicated the puzzle on the desktop next to it. During this process he continued to use rotating and sliding to ensure that the correct sides of each side aligned with one another.

Discussion, conclusion, and implications

Play can afford children opportunities to organically differentiate their engagement with mathematical activities. While differentiation is often thought of as a way that teachers can create various access points for children during lessons (Goddard & Kim, 2018), we saw organic differentiation through the ways the children naturally engaged with the materials differently and participated in different mathematical practices. The children used the same materials, but the ways they engaged were very different. The findings are are purposefully presented, not to suggest linear learning trajectories, but to highlight the complexity and fluidity of children’s engagement during playful activities when they have the autonomy to engage with materials.

The findings have implications for teaching. Playful activities where children can engage with materials with autonomy can be spaces where children can naturally challenge themselves to push their learning further. Rather than providing constrained tasks with explicit standards in mind, by opening up an activity we found that children went well beyond the intended mathematical goal. Rather than a teacher having to intentionally give each child a different task, the autonomy the children experienced contributed to the children differentiating how they engaged while still staying on task. Teachers can increase students' autonomy by providing spaces for organic differentiation.

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Tools Dictate the Divide: Entrenched Gendered Practices in the Making of Kinetic Sculptures

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Abstract: One of the promises of STEAM-based education is to ameliorate existing gender disparities regarding access to STEM fields. We analyze youth making kinetic sculptures as a novel STEAM-based approach to infusing historically gendered practices into the study of robotics. We found the distribution of labor was based on gender normative practices. This study highlights how STEAM-based education requires an examination of our tools and materials and how they reinscribe existing practices along traditional gendered lines.

Introduction

The potential of STEAM to transform education depends on how it tackles evident gender disparities regarding access to (and invitations to participate in) fields such as science, technology, engineering, and mathematics (STEM). In particular, activities related to electronics engineering and robotics have a particularly male-centered culture that needs to be changed in order to make learning spaces welcoming and nurturing to many gender identities, particularly female youth (Peppler, 2013). Prior work has explored the emergence of new ways of exploring STEM, starting at the tool level, where the introduction of the LilyPad Arduino in a classroom setting produced similar disruptions of gendered participation around electronics and coding as seen in the broader Maker Movement (Buechley & Mako-Hill, 2010). By examining children's use of a wider array of materials during the construction of kinetic sculptures (sculptures in which movement is a paramount element), we aim to identify tacitly accepted practices rooted in gendered stories of materials, examining children's use of artistic media and an Arduino-based robotic kit while learning coding, robotics, electronics, and sculpture making. The questions that guide our study are: (1) What are the practices in making a robotic kinetic sculpture? (2) How do gendered patterns affect the division of labor in a mixed-gender triad while designing and building a kinetic sculpture?

Methods

In the spring of 2022, data were collected during a workshop in a combined 5th and 6th grade class at a charter school in Orange County, California. From a total of over 15 hours for four student groups, we analyzed 75 minutes of video and audio recordings focused on one student trio, a sample composed of two girls and one boy, which served the purpose of identifying how youth divided labor with respect to gender in a group composed with majority girls. Our analysis focuses on the final hour of a kinetic sculpture workshop as students worked to piece their final sculptures together. The excerpt contains complex manipulation of materials with key moments of negotiation in the division of labor, while still being representative of the overall project labor division. We drew from Buchholz et al.'s (2014) methodology, coding *instances* in the video data, and determined the practices that took place. Each time one of the three youth exhibited a mediated action, it was coded and categorized as arts, electronics, or coding practice, using sub-codes within each of these categories. Two authors coded the video data to identify practices and count the frequency of these practices' appearances. We also registered duration (measured in seconds) for each category and subcategories of practices and coded 15 minutes of data; inter-rater reliability of the coding scheme was calculated by Cohen's kappa with k=.82. This coding process led us to determine the frequency and duration of each practice.

Findings

After coding the frequency and duration of each practice, three major groupings for the practices emerged: *Arts Practices*, *Electronic and Robotics Practices*, *and Computing Practices*. Our findings align with notions of art perceived as predominantly feminine, with girls engaging in art practices with more frequency and duration (70%) than their male counterparts (30%). Overall, the boy in the studied trio engaged 85% of the time spent with electronic and robotics practices, with girls collectively at 15%, reflecting a heavily male indexing of historically masculine-perceived practices (Buechley et al., 2010). Of the total time spent coding, the studied boy engaged 66% of the time in the coding activities, and the two girls altogether engaged in coding 33%. Nevertheless, girls held the computer (without coding) for more time (59%) than the boy (41%), which suggests that the computing activities themselves have a gendered division of labor that is worthy of further study. We observed that students from this trio had a very clear division of labor, which largely fell along gendered lines.

Table 1

Percentages of labor division in key practices by gender

Description of Practice	Percentage of Time Girls Engaged in Practices	Percentage of Time Boy Engaged in Practices
Arts (Including touching/hold art materials, balancing materials, drawing, planning the design, selecting and applying color/texture, building/manipulating/cutting materials)	**70%**	30%
Electronic and Robotics (Including touching/holding the Arduino Kit, connecting/disconnecting cables, manipulating/troubleshooting the potentiometer, manipulating/troubleshooting the servo motor)	15%	**85%**
Computing (Including coding/troubleshooting code; touching/holding the computer)	33%	**66%**
Totals	**47%**	**53%**

Figure 1

Kinetic sculpture made by the studied trio: "A bowl that spins and has symbols."

Discussion

Our findings reinforce previous research on how STEAM activities and group practices that integrate the arts into STEM provide opportunities for broader participation in STEM education (Mejias et al., 2019; Peppler, 2013). This is evident in the way girls were engaged and spent more time in artistic practices during the kinetic sculpture project, as well as in the way the boy dominated electronics and robotics elements of the project. Interestingly, the arrangement of a trio of two girls and one boy did not favor girls' use of electronic and robotics, nor computing materials; gendered scripts of materials and practices seemed to have prevailed, with the two girls dominating artistic practices and the boy leading STEM practices. This study highlights how simply high-quality STEAM-based education alone is not enough to eradicate existing gender divides in STEM fields. To truly transform STEM education, it requires a closer examination of our tools and materials and how they implicitly reinscribe existing practices along traditional gendered lines.

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Peer Feedback: Exploring What Hurts and What Helps

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Abstract: The role of peer feedback in project-based learning is poorly understood in computer science education. Therefore, the current study analyzed 238 student reflections in a design-based computer science course. While lack of experience and poor teamwork presented peer-feedback-related challenges, students' learning experiences benefited from feedback processes that were perceived as interesting and entailed perspective-taking. The relevance of learning theories is also discussed. These findings may inform approaches to future assignments as well as general approaches to peer assessment within project-based learning in computer science.

Introduction

One of the fastest growing education programs, computer science, has enjoyed the successful use of project-based learning (PjBL). Therein, students engage in social learning which benefits artifact construction and students' ability to apply real-world knowledge. Peer assessment consists of students evaluating the performance or achievement of their peers. Ideally, this process should be well-suited to collaborative learning environments such as those afforded by PjBL curricula. However, there exists little research on the use of peer assessment in a PjBL computer science setting. The current study addressed this gap by exploring college students' peer assessment experiences within a PjBL computer science course. Specifically, this study explored what students perceived as working well in the peer assessment process and what they struggled with. This study also evaluated how these experiences aligned with learning theories. The overarching research questions included: *What did students discuss in terms of their struggles with the peer review process? What did they report worked well? How are the strengths and struggles connected with the learning theories?*

Method

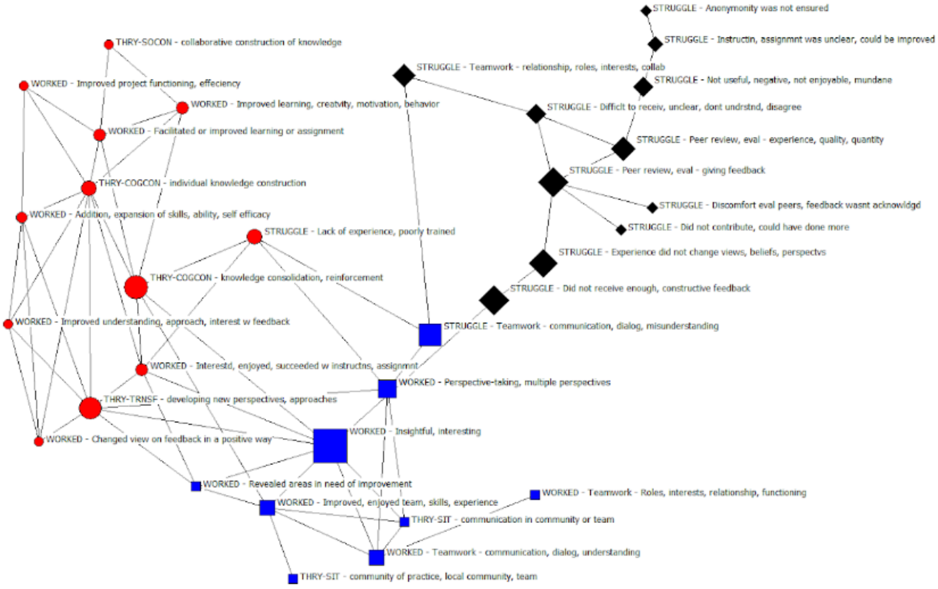
This study included 55 students in an undergraduate computer science course in the Spring of 2022. Students worked on 2-3-month-long, collaborative projects and completed written reflections of their experiences. This study is based on five learning theories including metacognition theory where learners reflect about their learning experience, cognitive constructivist theory where learners are engaged in individual knowledge construction (Piaget, 1956), social constructivist theory as the learners were also involved in collaborative learning through projects (Vygotsky, 1978), situated learning theory as the course included teamwork and communities of practice (Lave and Wenger, 1991) and transformative learning theory where learners develop new perspectives (Mezirow, 1997). We coded students' reflections at the sentence level in the MAXQDA Analytics Pro data analysis software. We used *a priori,* in vivo, and axial coding within categories, including what worked well, student struggles, and learning theories (Thornberg, 2012. We used MAXQDA software to create correlation matrices at the level of $p < .05$, $p < 0.01$, and $p < .001$ levels. We then imported the matrics into the UCINet network analysis software and the NetDraw social network visualization software (Borgatti, 2002) to create semantic network maps using the Girvan-Newman algorithm (Girvan & Newman, 2002). We used betweenness measures of centrality to identify leverage points to indicate the more important nodes in connecting to each other in a semantic map. The resulting network maps were used to identify design moves to improve the peer feedback process for subsequent courses.

Findings

A three-cluster semantic map was generated at $p<0.001$ level (Q=0.44, see Figure 1) using the categories of "student struggles", "aspects of peer feedback that worked well" and "learning theories". In the **red** cluster, the leverage point (biggest node) of the cognitive constructivist principle of *knowledge consolidation*, was connected to the struggle, *lack of experience*, and the "what worked" subcategory of *interested, enjoyed, or succeeded with instructions or assignment*. This indicates that knowledge consolidation may promote interest in the project and positive views towards feedback. To address lack of experience with feedback, future course iterations may benefit from emphasizing students' personal interests in and enjoyment with the feedback process. In the **black** cluster, student experiences consisted exclusively of struggles. These were related to experiences in the blue cluster. Thus, the leverage points of *giving feedback*, *experience did not change views, beliefs, or perspectives*, and *did not receive enough constructive feedback* may be addressed by emphasizing perspective-taking and insight or interest within the peer assessment process. In the **blue** cluster, the leverage point, *insightful or interesting*, was connected to the situational learning principle of *communication in a team* as well as *improved or enjoyed one's team, skills or experience* and *perspective-taking or exploring multiple perspectives.* Thus, the struggle of *teamwork miscommunication, dialog, or misunderstanding* could be addressed in future courses by emphasizing team communication and exploring multiple perspectives.

Figure 1

Semantic Network Analysis of Student Struggles, What Worked, and Theory (p<0.001)



Implications and conclusion

Results of the current study indicate that three learning theories, especially cognitive constructivism, and situational learning, were aligned with the students' perceived struggles and benefits. Results also indicate that a lack of experience and poor teamwork and communication produced challenges for students going through the peer assessment process. On the other hand, when peer assessment was perceived to improve skills, seemed insightful and interesting, and integrated perspective-taking, students reported benefits to their learning experience. While these insights will be used to shape subsequent feedback assignments, they may also inform general approaches to peer assessment within computer science courses that leverage project-based learning. For instance, when creating peer assessment criteria, including students as co-designers may ensure that assessment guidelines and prompts are interesting and insightful.

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Probing Mathematical Language in Concreteness Fading Vector Addition Learning

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Abstract: This study designed an intervention to teach middle schoolers vector addition in two conditions: concreteness fading (CF) and concreteness introduction (CI). All the participants had three learning tasks (in a different order) followed by a storytelling activity. We discovered the CF participants had consistent growth in using math language and were more confident when demonstrating their learning.

Introduction and theoretical framework

Current secondary-level vector addition learning and teaching rely heavily on symbols and abstract concepts, which fails to let students make sense of the notations and concepts (Karnam et al., 2020). In response to this issue, we propose that a concreteness fading intervention can be a potentially effective way to teach middle schoolers vector addition. Fyfe et al. (2014) propose *concreteness fading* (CF)– a three-stage instructional approach that enables students to use concrete learning materials that tie to their previous experiences, gradually decreases the level of concreteness of the learning materials, and eventually provides more abstract and generalizable learning materials. To evaluate mathematical learning, the use of mathematical language can be a good way because students' success in mathematics requires them to use proper mathematical language and vocabulary to communicate (Powell et al., 2019). Thus, our research question is *how mathematical vocabulary changes over the course of a concreteness fading intervention.*

Methods

This study recruited 14 8th graders from a charter school in a large Midwestern city in the U.S. who had no previous knowledge about the topic. We designed a four-stage CF intervention to teach vector addition. This study had two different conditions: *concreteness fading* (CF) and *concreteness introduction* (CI). Each condition included three learning stages (see Table 1) and an extra stage (*Constructionist Problem Design*, Stage 4: CPD) to allow the participants to demonstrate their learning from the intervention (CF task order-EP, ID, AR, CPD; CI task order - AR, ID, EP, and CPD). Four two-hour study sessions were conducted from February to March 2022, which were videotaped and later transcribed. By examining the transcripts, the research team developed a math vocabulary dictionary with scores for each word. A math vocabulary score can reflect their use of language related to the topic of vector addition. We used the python package Pandas and Seaborn to analyze and visualize results.

Table 1
Learning Activities

Stage	Activity	Duration
Enactive Physicality (EP)	The participants played football passing on a tiled floor, using informal vector addition skills.	20 mins
Iconic Depiction (ID)	The participants played a short football passing simulation game.	20 mins
Abstract Representation (AR)	The participants worked on a worksheet on vector addition problems that uses formal math notation and symbols.	20 mins

Results and findings

Figure 1 shows a consistent arc of the participants' math vocabulary scores in the CF condition. In stages 1 (EP) and 2 (ID), their math vocabulary scores are relatively low; there is a spike in stage 3 (AR); then, in stage 4 (CPD), all their math vocabulary scores are greater than their scores in stage 1 and 2. Figure 2 (CI Condition) does not present as clear an arc.

Figure 1
Math Vocabulary Total Score (Σ) by Stage (Concreteness Fading, n=6, CF group)

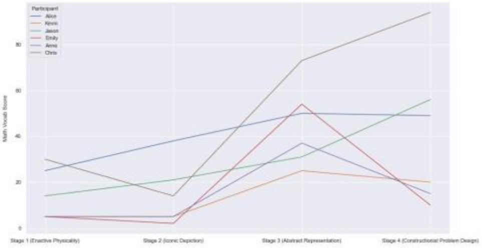
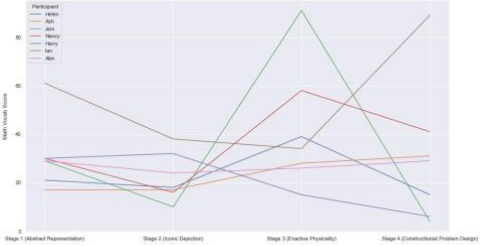


Figure 2
Math Vocabulary Total Score (Σ) by Stage (Concreteness Introduction, n=7, CI group)



The spike that the CF participants have in stage 3 (AR) suggests a change in the use of math vocabulary throughout the intervention. The CF participants seemed more comfortable with the use of math vocabulary in a similar but more abstract context. In contrast, the participants' math vocabulary use in the CI condition showed no clear trend. Those CF participants utilized their previous experience and informal vector addition knowledge to solve problems in stage 1(EP) and tested their knowledge and problem-solving strategies again in stage 2 (ID), during which they further developed their math vocabulary related to vector addition. Another finding is all the CF participants' math vocabulary scores in stage 4 (CPD) are higher than those in the first two stages. In stage 1 (EP), the participants needed to use their own language to figure out an approach to describe their positions on the tiles and the ball flying path, which activated the participants' previous math language to solve a new problem. Stage 2 (ID) provided a similar problem and some math symbols, in which the participants could connect their problem-solving experience in the previous stage with the possible encountered math vocabulary. Tackling similar questions with a progressive increase in math vocabulary may enable the participants to develop their own math vocabulary during the intervention.

As for the contribution of this paper, we provide a new lens to inspect learning in a CF intervention: by examining their mathematical vocabulary, we can quickly estimate their mathematical language change over the course of intervention. Thus, we believe mathematics educators should pay more attention to students' progressive development of mathematical vocabulary and language in class. However, this study also has limitations: this study's small sample size may harm the generalizability of the results. Also, this analysis cannot uncover whether their use of math vocabulary represents their understanding of vector addition. Though we see value in understanding their use of math vocabulary, exploring their understanding of vector addition requires a more nuanced investigation on their conversations.

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A Quest for Information—And Data Literacy: Can 6th Graders Make Informed Decisions?

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Abstract: Information- and data literacy, the ability to critically examine and evaluate information and arguments in relation to empirical evidence, is increasingly crucial in a world overflowing with data and information from a multitude of sources. Information- and data literacy in younger students being understudied, we investigate these skills in Swedish 6th graders to learn more about the educational challenges. Next, these findings will inform the development of a digital game for data literacy.

Background

Today digital information is easily produced and accessed without being properly reviewed. Thus, misinformation easily spreads and turns into ‘truth’. Many youths are caught up in a tangled mess of facts and opinions and hence need updated skills in how to orient this information (Mihailidis, 2018). The term information- and data literacy (IDL) includes being able to critically examine and evaluate information and arguments in relation to empirical evidence. In turn, the following kinds of abilities are involved: understanding tables, graphs, and diagrams and being able to translate such visual formats into verbal formats, and vice versa; understanding basic statistics and how data can be used to create a narrative; being able to distinguish when data is correctly and fairly used as opposed to when it is not (Vahey et al., 2012). This is also highlighted as one the most prominent challenges of our time and research shows that only about half of the world´s 15- to 16-year-olds understand the difference between facts and opinions (Agence Science-Presse, 2019).

Citizens who can make well-informed decisions for themselves regarding what they read or hear is, furthermore, essential to sustain the fundamental structures of a democratic society. In this, schooling and education have fundamental roles to play, equipping young people with knowledge and skills so that they, as they grow up, can meet their surroundings in a capable way (Biesta, 2017). In this, IDL provides a ticket for participating in society and making well-informed decisions, lowering the risk of being misled or deceived, as well as of one-self creating misunderstandings or spreading misinformation. However, previous research has shown that children as well as young adults struggle when it comes to these issues (Ku et al., 2019). IDL should hence be highlighted in school curricula. Yet, the topic is complex and relates to many subjects and tasks within the natural sciences as well as the social sciences. To be able to work with IDL in a tangible and preventive way we need to know, as a first step, what skills students of different ages actually have. What do they know? What is more and less challenging? Learning more about this is necessary to inform interventions to support both early and later developmental stages of IDL. This study aims at contributing to our knowledge on IDL skills among 6th grade students.

Method and procedure

We enrolled 104 students (54 boys and 50 girls) from three schools and five different classes to fill out a questionnaire, validated by five middle school teachers. The questions (11 in total) were categorized into four subcategories, suggested and agreed upon by the authors. Three questions addressed the subcategory of *representations* targeting the ability to interpret diagrams, such as matching tables with diagrams. Two questions addressed *proportionality* where the students were asked to for example, compare a news headline with a diagram.

Four questions targeted students’ knowledge about *scientific method* and asked questions about when science can be trusted. Finally, two questions asked whether a set of statements in combination with a picture or a diagram represented *facts vs opinions*. The questions were presented in random order and all questions but the two on facts vs opinions were multiple choice questions. When more than one answer could be correct, this was spelled out in the question. The questionnaire took about 15 minutes to complete.

Results and discussion

For the nine multiple choice questions, the number of response alternatives ranged between two to four. To receive a full score all alternatives had to be filled in correctly, that is if two alternatives out of four were correct these two had to be filled in and the two incorrect alternatives were not to be filled in. Questions that were left blank by the student were calculated as incorrect responses. Results were calculated both per question (see Table 1) and averaged over categories (see Figure 1).

Table 1

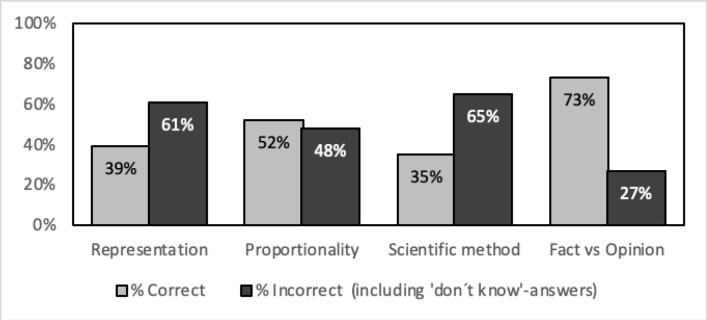
Table showing the number of subjects answering correct or incorrect per question.

	Representation					Proportionality				Scientific method						Fact vs Opinion			
	Q1	**Q6**	**Q7**	**Tot.**	**(%)**	**Q2**	**Q10**	**Tot.**	**(%)**	**Q5**	**Q8a**	**Q8b**	**Q9**	**Tot.**	**(%)**	**Q3**	**Q4**	**Tot.**	**(%)**
Correct answers	41	22	60	123	39%	54	54	108	52%	50	56	30	10	146	35%	70	82	152	73%
Incorrect answers	63	82	44	189	61%	50	50	100	48%	54	48	76	94	272	65%	34	22	56	27%

* 'No of subjects incorrect' includes 'don´t know'-answers

Figure 1

Histogram showing the distribution of precent correct and incorrect answers per category.



These results indicate that questions regarding representations and scientific methods are the hardest for this age group; not even 50% of the 6th graders knew the answers here. The questions on representations require abilities to correctly read and interpret diagrams and detecting misleading formats, such as a truncated diagram – important skills in order not to make misinformed judgements or decisions. The questions on scientific methods tap an understanding of what science is and is not. One questionnaire item addressed ‘false balance’ presenting a scenario with a TV debate featuring two scientists discussing on the same premises and as equals; one communicating what an overwhelming majority of all scientists in the area agree on – the other communicating the opposite.

The questions about proportionality and facts vs opinions seemed less challenging for the students (52% answered the proportionality questions and 73% answered fact vs opinion correctly). Possibly they are more familiar with these types of questions, for example evaluating a graph in relation to its heading. The two questions concerning proportionality, however, had only three alternatives to choose from (while most others had four) with only one alternative being correct, which may have made these questions easier for the students. The fact that facts vs opinions, were by far the easiest for the students to answer might not come as a surprise since these types of questions are commonly discussed in Swedish classrooms under the umbrella of source criticism.

A next step is to look at the questions in more detail and anlyze how and when different categories start to become more difficult. On a more general level, there is evidently room for improvement when it comes to different aspects of IDL and this results contributes to the understanding of youths’ information- and data literacy skills and where we have to put in extra effort. Starting 2023, we intend to develop a digital pedagogical game where students can learn and practice IDL. Before then, we need to investigate how students are best scaffolded.

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Sorting Out the Bad but Bringing in Filter Bubbles

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Abstract: Being information literate, i.e. being able to critically evaluate information and arguments in relation to empirical evidence, is extremely important. Our study combines learning science and drama to explore if 6th grade students can grasp certain aspects of information literacy, such as fake news and filter bubbles. By analyzing free-text responses we concluded that the students are aware of the problems with fake news but have a very vague and naïve view of filter bubbles.

Background

Living in a time often referred to as the information era, it is of utmost importance to educate our youths in how to critically examine and evaluate information and arguments in relation to empirical evidence, something that is often referred to as being information literate. The Association of College & Research Libraries (ACRL) summarizes this skill as having the ability to locate, evaluate and effectively use information needed. The fact that youths today are bombarded with information in all sorts of platforms and media does not automatically make them informed citizens, rather they need to learn how to use information effectively and we need to teach them about the dangers of trusting "fake news" as well as not trusting trusthworthy information.

Previous research has shown that children, as well as grown-ups, struggle when it comes to information literacy. For example, Breakstone et al., (2019) showed that high-school students have a hard time telling

the difference between news stories and advertisements, and that only 4% of them reflected upon why ties between a climate change website and the fossil fuel industry might decrease the websites credibility. Further on, Nygren and Guath (2019) showed that 88% of their participants had difficulties with distinguishing news from ads in digital newspapers. These results togheter with the fact that students often tend to overestimate their information literacy skills (Gross & Latham, 2012), the need to educate our youths in this topic can not be highlighted enough. Being information literate also includes the ability to be open to other views and opinions and being able to reconsider one´s own belief, something that has proven to be difficult (Flynn et al., 2017). The risk of not being open to other thoughts and discussions are that you might end up in a so called "digital echo chamer" where one only confirms one's already established thoughts and ideas and hence does not challenge possible misinformation.

This study is part of a larger project, aiming to map out 6th grade students' understanding and skills in information literacy , exploring if and how these skills best can be taught. In this study we combined learning science and performing arts and storytelling to inform the students about the subject. According to Willingham (ref, årtal) the art of storytelling in classrooms works because we seem to understand and remember stories better than pure lectures.

Method and procedure

In this study we worked together with a local theatre group that wrote a play (in collaboration with a researcher) on different aspects of information literacy. The same group also performed this play on site in classrooms. The performance was accompanied by a pedagogical follow up with discussions and interactions between actors and students. The researchers also met with the students who answered a free-text questionnaire with four questions (about fact resistence, false balance, burden of proof, and fake news/filter bubbles). 145 students (73 boys and 72 girls) from 3 schools in southern Sweden were enrolled in the study. In the experimental group (4 classes) the students saw the play before answering the free-text questions (in this study we only analyze the question about fake news/filter bubbles) while students belonging to the control group (3 classes) saw the play after answering the same questions.

Results and discussion

The students could choose to respond to two questions of their own liking. The most popular question to address was the one about fake news/filter bubbles, which was formulated as follows: "*Why could it be problematic that an app like for example TikTok choses what type of feeds you are shown?*". In sum, the majority of students (74% in the experimental group and 79% in the control group) responded to this question. Many students (33% in the control group and 48% in the experimental group) wrote about the potentional problems with falsely spreading fake news and commercials. *"TikTok can make us see bad things about a country that are not true, and then they may spread it further, and then you have spread a rumor that is not true, and TikTok can also show videos prohibited for children."* (Student, control group). *"Then we don't see what is real but we see what TikTok wants us to see and believ that this is true even if it isn't"* (Student, Experimental group).

However, very few (9% in both groups) discussed these issues further by bringing up the problem with getting filtered information that may narrow your view and understanding of different topics. "*If the app only selects what you like, you may not really get to take part in other news [...] You might not learn much if you only watch videos in the same genre all the time. The information you receive can also be false"* (Student, control group) *"Yes it can be problematic because if you like a video and only are fed such videos, then you wont learn about other things happening"* (Student, experimental group).

Many students (29% in the control group but only 13% in the experimental group) mentioned the risk of being exposed to "risky or bad" material. *"There could be bad things there, some accounts are creepy and dangerous. You can't trust everyone in that app"*. (Student, control group) *"You can be shown unsuitable things because it is an algorithm and it doesn't know what is good or bad"* (Student, experimental group)

Some of the students (17% in the control group and 13% in the experimental group) mentioned the fact that is is a good thing how filtering things can provent them from seeing scary or bad things. *"TikTok selects material according to our liked videos, for example if I like a video with a cute cat, then it appears on a so-called "for you"-page where things you have liked pop up in other videos such as other cute cat videos"* (Student, control group). *"I see no problem because they chose to show us what we like"* (Student, Experimental group)

The topic of fake news and risks with social media is something quite heavily discussed in Swedish schools. This together with the fact that most Swedish youths use TikTok themselves possibly makes them comfortable and confident to discuss this topic. Many students seem aware of the problem with fake news on social media, wich relates to source criticism, something that is part of the Swedish curricula. Even though this is reassuring, their knowledge and discussions about the actual filtering problem are quite shallow and naive. Some students discuss how the filtering may protect them from seeing inappropriate material but they don't see the problem with only receiving a narrow field of "nice" and "good" feeds in their flow (as for example seeing cute cats). The issue with only receiving information that aligns with your previous preferences and opinions is very rarely mentioned.

One might suspect that their replies stem from discussions in school, warnings from parents or other adults and their own habits of use. However, they seem to lack a wider outside perspective, understanding that algorithms in social media may create filter bubbles and how this could narrow their field of view. This could be due to lack of education, but also to our participants' young age. Filter bubbles is also a complex topic in general and many adults don't see the problem with the issue. This makes teaching about information literacy even more important and we cannot expect people to learn about this themselves.

It is also hard to know if students actually apply their knowledge about fake news/filter bubbles when interacting with an app like TikTok. For instance, do they reflect upon whether or not a post in their feed is actually true or not, and do they search for alternative perspectives to possibley contradict what they already believe? This would be interesting to investigate further as well as how keen they are to share information or posts that they suspect to be fake.

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Student Staff as Co-Designers in Higher Education

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Abstract: Student-centered learning initiatives in Higher Education rely on the participation of student staff to co-design and facilitate learning. Using an ethnographically inspired approach we investigate their involvement in the empirical setting of colloquium leaders facilitating sessions for first year law students at a Norwegian university. We identify challenges around tensions between individual's agency in designing and renewing teaching-learning and their structural environment. This provides practitioners with additional tools to understand, evaluate, and adapt their practice.

Introduction

Educational initiatives that have the goal of letting students learn from each other and develop more general academic competences are increasing. These initiatives rely on the participation of student staff (i.e. advanced Bachelor and Master students employed by the university) to facilitate student learning and co-creating and co-designing teaching-learning (Healey et al., 2016). Little research is done on how student staff contribute to the pedagogical initiatives at their educational units. We draw on Bovill et al. (2016) who discuss challenges emerging in co-creation and co-design processes, among them the navigation of institutional structures, practices and norms. Often co-creation initiatives start in individual classrooms, redefining norms and practices there. Expanding innovation across institutions requires the establishment of new practices, structures and norms on a higher level.

We put special focus on the student staff´s perceived structural embedding and individual agency using a sociocultural and practice-based approach (Wertsch, 1998). Agency we define as the "temporally constructed engagement by actors of different structural environments – the temporal-relational contexts of action" (Emirbayer & Mische, 1998). The structural environment is assumed to be dynamic and sustained by and changed through human agency. Emirbayer and Mische (1998) differentiate between iterational agency, thus routinely patterns, practical-evaluative agency in emergent situations and a projective element of agency, reconfiguring current structures. Rooted in this theoretical framing, we explore the dynamic between individual and structure in student staff practicing development work. Starting point are individual's perceptions of these structures and their experience of agency within them.

In this study we investigate student staff working as colloquium leaders (CL) for first year law students at a Norwegian university. CL are 3rd to 5th year law students facilitating colloquia. They apply to be CL and are employed by the university based on grades, motivation letter and an interview. Purpose of the colloquia is for the first years to support each other in solving cases and writing texts, to learn to collaborate and learn from collaboration. Within this theoretical embedding and empirical context, we ask: *What agency do CL perceive to have in co-designing colloquia for first year law student?*

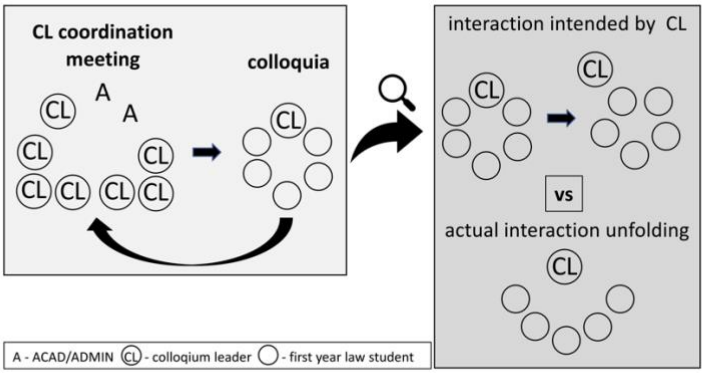
Methods

Using an ethnographically inspired approach our research comprises field observations of a colloquium and CL coordination meetings, a survey among 13 CL with 4 reflective questions addressing their colloquium work and role understanding, and follow-up interviews with 8 CL. The interview guide was developed based on a thematic analysis of the CL's survey replies. The interviews addressed CL's own expectations and experience with colloquia, their work during and surrounding colloquia and their development within it, the role of collaboration, safe spaces and student ownership within colloquium work and their role, responsibilities and embedding within the wider institution.

Preliminary findings

Figure 1 visualizes our preliminary findings. To the left is the timeline of activities for CL: CL participate, co-create and co-design in CL coordination meetings organized by student, administrative (ADMIN) and academic (ACAD) staff. It comprises of input from the organizers – ACAD, ADMIN and student staff and reflective discussions among CL. Then CL proceed with around six of their own 2-hour colloquia, of which they have full responsibility. Within and surrounding the colloquia, CL interact indirectly with ADMIN and ACAD through the provided structures. Further, CL also co-create and co-design with the participating first years in the colloquia and engage in individual design work surrounding these. This pattern is iterated once with a mid-semester CL coordination meeting. Within the two settings CLs' agency differs, also based on their role.

Figure 1
Activities colloquium leaders participate in and interaction patterns they experience.



CL1: "The educational offers by the faculty are mainly lectures and courses, of which the former is *completely passive* and the latter often does *not require active participation from all students*. [...] It is largely based on my experience that students *expect the CL to provide answer* and do not take into account their fellow students in the process. [...] Even if I do *not provide direct answers* or try to initiate a dialogue these often *stay CL focused* [...]."

The excerpt to the right, a survey response by one of the CL describes a recurringly reported pattern within colloquia, visualized in the center of Figure 1: CL intend an interaction pattern, in which they act as facilitators when and where necessary, and move to the background over time, aiming for participating first years to talk to each other. This is also suggested by the organizers in the CL coordination meeting. Instead, what CL report happens is that students mainly communicate with them, expecting input and answers, instead of with each other. This pattern resembles other teaching at the faculty as reported by the CL. Taking the structure-agency perspective, we note that organizers and CL aim to innovate, changing prevailing structures in students taking ownership of their learning and collaborating, by exerting their projective agency. However they are hindered by established institutional cultures of passive learning playing out in students using their iterational agency, an instance of the challenge described by Bovill et al. (2016). Institutionalized norms and practices already play a role here within individual innovative settings, not only when expanding beyond. And the responsibility of redefining these norms in this instance appears to lie with the CL. As the last sentence of CL1's excerpt shows, CL try to use their practical-evaluative agency to address the issue but perceive it difficult to solve.

Implications and questions for discussion

Empirically, we catch a first glimpse of the complexity of the co-design of teaching-learning that CL engage in and its challenges. Conceptually, these preliminary results provide starting points to investigate the interplay between structures and individual agency within changes to one's practice, the structural environment or one's professional development. Practitioners, student staff and those organizing their work can gain a deeper understanding of the tensions and challenges arising and the support student staff members need.

Based on this current state of our study we would like to open the following questions for discussion:

1. Where does co-design begin and end in terms of structural arrangements, who is meeting whom?
2. What differences in co-design work can be identified before and during colloquia and CL coordination meetings?

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Weaving in and out of School Experiences to Craft STEM Identities

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Abstract: Out-of-school time (OST) experiences suggest promise for providing historically marginalized youth with expanded notions of and avenues for becoming in STEM. Yet, OST are often isolated from school experiences and require youth to weave together disparate notions of STEM and positioning with respect to STEM. In this paper, we examine this process for young women of color in STEM as they leveraged identity resources across OST, family, and school during high school and into college.

Purpose

The work described in this paper was motivated by a concern with the persistent underrepresentation of large populations of youth (namely, females and youth of color) in fields of STEM and by the growing body of research that demonstrates the ways K-12 learning environments overwhelmingly reconstitute constrained notions of what it means to participate in and be "good at" STEM. For instance, being "scientific" is often reduced to achieving established answers in uniform ways (Calabrese Barton et al., 2012). Youth, for example, who can work to get the answer quickly and work independently, are more likely to be seen as "scientific" in school (Carlone et al, 2011). Such practices offer limited avenues for expressing and being recognized as a STEM-oriented person, while further marginalizing youth already underrepresented in STEM fields. Out-of-school time (OST) experiences suggest promise for providing youth with expanded notions of and avenues for becoming in STEM (Bell et al., 2009). Yet, these experiences are often isolated from or in conflict with STEM school experiences; and, as such, they require that youth *weave* together STEM identities across these spaces. In this paper, we analyze this weaving by examining the ways in which young women, underrepresented in STEM, leveraged available identity resources across these spaces to craft a STEM identity during high school and into college. Specifically, we asked: *(1) What identity resources are available to youth within and across the social spaces of their lives? (2) How are these resources woven by youth to author STEM identities?*

Conceptual Framework

We draw on Holland and colleagues' scholarship (Holland, et al., 1998), that emphasizes how identity is developed, performed, and contested in local practice and on critical feminist scholarship (Crenshaw, 1989) to consider how identity contestations intersect with broader patriarchal, racialized, and historicized structures. Using Holland et al.'s (1998) development of *figured worlds*, we view STEM as a "socially and culturally constructed realm of interpretation" (p. 52) that has particular actors, actions, and outcomes that are valued over others and has a collective understanding of appropriate actions. How youth talk about STEM, who is good at STEM and why, provides an indicator of their figured worlds of STEM. Further, as youth "author" STEM-oriented selves, they draw on figured worlds to do so (e.g., emphasizing involvement in research or "getting" math). When examining youth's identities in the context of their high school lives, we considered how participation was structured across STEM experiences, access to different forms of participation, and implications such practices had for youth's figured worlds of STEM and the kinds of identity work they engaged in (Holland & Lave, 2001).

Method

This paper draws on student interview, student survey, and parent interview data from a 5-year ethnography that focused on the identity work and college and career trajectories of youth from populations underrepresented in STEM (Allen & Eisenhart, 2017). The ways in which 9 young women authored STEM identities during high school and into college was analyzed using case study methodologies (Yin, 2013). All youth were from the same large city in the West; they were selected for the larger study because of their expressed interest in STEM (as identified by their school counselors) and successful academic record). Focal youth were selected through two primary criteria: (1) they maintained an interest in a STEM career throughout high school and (2) they expressed involvement in some form of out-of-school or extra-curricular that was STEM related. For this second category, "STEM related experiences" was defined broadly to include experiences such as a "career fair" to more involved, longer-term experiences, such as an engineering camp.

Youth were interviewed twice each year from 10th to 12th grade (fall and spring) and then surveyed once each year (in the fall) into their first two years post-secondary. Interviews focused on students' views of STEM, interests, planned majors, and experiences in STEM-related courses. Parent interviews focused on hopes and goals for their child, and their experiences with college and STEM. All interviews were recorded and transcribed. In the initial analysis, interviews were first coded for STEM learning experiences, views of STEM, views of self with regard to STEM, and OST STEM experiences. Next, data displays were created for each youth of (1) salient STEM experiences, organized by year; (2) their conceptions of STEM, their involvement in STEM, and their self-identifications as a "STEM person." For this new analysis, we deductively coded for moments of weaving and the interconnections between how youth participation in STEM activities and their forms of self-authoring.

Findings

OST STEM experiences played a critical role in disrupting dominant notions of STEM and providing identity resources for connecting with STEM disciplines. Furthermore, they supported young women in weaving together multiple identities. Naomi (African-American and culturally Jewish), for example, shared how she discovered engineering as a path that she "could do for the rest of her life" after participating in an engineering camp: "At first, I didn't want to go. I heard the camp was [for nerds]…I mean, I thought an engineer was some white guy with glasses and pants pulled up high." However, once Naomi met friends "like her," participated in robotic challenges, and experienced the "hands on" and social aspects of engineering, she came to see how her "social," "athlete" self and engineering could be interwoven.

Similarly, Shawna's (Vietnamese-American) OST experiences were particularly influential in her continuing to pursue a career in medicine. While she had always had an interest in science and the human body, she found courses she took through her high school and a local university's Pre-Collegiate program to be too devoid of "human interaction," and had come to the conclusion that most science careers would put her "in a lab all day." Shawna, however, valued "helping people" and connecting with others. Once she participated in a summer program that took her abroad to provide medical care to those lacking access to it, she came to see how her interests in science and her passion for helping others could be brought together. OST experiences became the social and material threads that these young women were able to leverage to reject and counter the times they were positioned unfavorably with respect to STEM in the social and discourse contexts of their schools.

Discussion and Conclusion

Our findings give further credence to the role that students' OST experiences have for expanding notions of STEM, self, and possible futures. They also speak to the ways that young women can weave together identities across the social spaces of their lives that are coherent with their multiple selves such as being caring, altruistic, social, and also scientific. The extent to which in school experiences can replicate or complement the identity resources available to youth remains to be seen, but at a minimum these findings motivate additional work regarding the designs of coherent ecosystems (Dierking et al., 2021) that support youth learning and participation in STEM that extend beyond the classroom.

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Stealth Assessment: A Systematic Review of the Literature

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Abstract: Stealth assessment is embedded within technology-rich environments, like games, to measure and support learning. In this paper, we discuss how stealth assessment is being used and where it may be headed. We identified 93 relevant studies consisting of 41 journal articles, 27 conference papers, 14 book chapters, 10 dissertations, and 1 book. These studies included participants ranging from third grade students to adults. We briefly discuss our findings in this paper.

Introduction

Stealth assessment (Shute, 2011) uses methods and technologies to collect and analyze learners' interaction data and make real-time inferences of learning based on the data. Digital learning environments employing stealth assessment can help researchers to accurately assess learners' competencies and adapt the learning environment to fit learners' needs (Shute & Rahimi, 2017). Such adaptivity is closely linked to learning, engagement, and motivation theories (e.g., Csikszentmihalyi, 1990; Deci & Ryan, 2012; Vygotsky, 1978). The backbone of stealth assessment is evidence-centered design (ECD; Mislevy et al., 2003) which provides the requisite models for the system. There are four core models: the Competency Model (CM) defines the set of knowledge and skills of interest, along with their sub-facets (unobservables) and their relationships to each other. When defining the competency model, researchers respond to the question of *what* to assess; the Evidence Model (EM) identifies appropriate indicators (observables) in the game that provide evidence for the CM variables via statistical linkages (i.e., the statistical model). When defining the EM, researchers answer the question of *how* to assess; and the Task Model (TM) involves the creation of various task types that can elicit the evidence needed for the evidence model. After more than a decade of research using this method to assess and support various competencies, across different learners and in various settings, in this in-progress study, reviewed how stealth assessment is being used and where it may be headed. We address the following research questions: (1) What are the publication trends and contexts of research that use stealth assessment? (2) What is the purpose of the stealth assessment research? (3) What types of validity are more common in stealth assessment studies?

Method

To address the research questions, we conducted a systematic review using the updated PRISMA (Page et al., 2021) method. To provide comprehensive coverage of the literature, two search phases were conducted: database and reference search. In the database search, the following search string was created: "stealth assessment" OR "game-based assessment" OR "embedded assessment" OR "evidence-based assessment" OR "computer-based assessment for learning" OR "evidence-centered design" AND ("game" OR "online-learning" OR virtual reality") OR "stealth assessment" AND ("game" OR "online-learning" OR virtual reality"). We searched through the following databases: Web of Science, Scopus, Emerald, Google Scholar, Taylor & Francis, EBSCOhost, IEEE, Elsevier, Springer, and Wiley Online Library. The inclusion criteria were as follows: 1) the studies should be published between 2004-2022; 2) the language of the publication should be in English; 3) stealth assessment should be the focus of the study; 4) the studies should target learning outcomes. Following the PRISMA guidelines, we included 32 studies for review. Finally, through hand searching within various papers' references and conducting additional targeted search (e.g., identifying studies from scholars who we knew were employing stealth assessment methods), we included an additional 61 studies for review, reaching our total number of studies to 93. To extract the data, we created a spreadsheet to collect and summarize focal features per study. At this stage, we entered the information of each included paper in separate columns. In this study, both qualitative and quantitative analyses were used. First, the basic features of our dataset provided a descriptive analysis of the papers. Second, a content analysis method was conducted to obtain an in-depth understanding of each included study to examine our research questions. Two researchers independently extracted the data from each study and met to resolve their disagreements in an iterative process.

Results

Addressing RQ1 (i.e., the publication trends of stealth assessment), we identified 93 studies (41 journal articles; 27 conference papers; 14 book chapters; 10 dissertations; 1 book). These studies included participants ranging from third grade students to adults. The competencies that were assessed in those studies (see a sample of studies in Table 1) included: (a) hard-to-measure competencies such as creativity (e.g., Shute & Rahimi, 2020), persistence, problem solving, computational thinking, risk taking, safety and emergency readiness; and (b) content knowledge and skill acquisition, such as mathematics, physics (e.g., Shute et al., 2020), genetics, geometry, reading and writing, and ratio and proportional reasoning. The studies included in this review came from various fields of study including computer science, educational technology, learning sciences, bioengineering, and applied mathematics. Moreover, 81 studies used or designed a game, while 11 studies used a simulation or an immersive learning environment to assess their competency of interest. Regarding RQ2 (i.e., the purpose of stealth assessments in each study), so far, we were able to categorize 60 studies into three categories: (a) validational studies (*n* = 42); (b) studies that used the stealth assessment estimates for purposes of providing adaptivity or feedback to students (*n* = 4); and studies that only discussed the design phase of a stealth assessment (*n* = 14). This result suggests that most of the current stealth assessment studies are validational. Finally, regarding RQ3 (i.e., the type of validity approaches in stealth assessment studies), from the 60 studies that we coded, most of the studies (*n* = 24) used a *convergent* validity approach (i.e., correlational analysis between the stealth assessment estimates and the external measures); 18 studies used other types of validation methods (i.e., predicting the posttest and classifying accuracy). The remaining studies did not specify any validational measures.

Discussion & conclusion

In this systematic review, we included 93 studies that have used stealth assessment to assess a competency within a digital environment, typically a game. Our findings indicate that studies that have used a stealth assessment methodology focused on a diverse set of competencies, included a range of target audiences, and came from multiple fields of studies. This finding shows that this methodology has been adopted and adapted by researchers in multiple contexts to assess and, in some cases, support learning. Although some studies included uses of the stealth assessment estimates in real time (e.g., for adaptation or providing personalized feedback to the learners), most of the studies are still at the validation stage where they describe the design of a stealth assessment for a particular competency using a validational approach (e.g., convergent validity) to indicate the accuracy of their assessment. After more than a decade of work in this area, it seems that stealth assessment can move to a new phase which is using the stealth assessment estimates to enhance learning (e.g., by adaptivity or personal feedback and support). Finally, our results indicate that most of the studies used a game as the vehicle in which to embed their stealth assessment. However, eleven studies used other learning environments. Despite the common understanding about stealth assessment, it is not only bound to games. We hope to see more studies that use this methodology in advanced, technology-rich learning environments in the future.

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Stressors in Online Exams - Same Same but Different?

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Abstract: In order to design optimal online exam environments that are conducive to learning and not too stressful for students, knowledge about potential stressors in these situations is important. In the present study, we investigated a newly developed instrument to assess stressors in online exams regarding its factor structure and its association with digital skills and performance. Analyses revealed an eight-factor structure, with the factor system failures being the most stressful for the students.

Introduction and related work

Exams are perceived as stressful by many students (Bradley et al., 2010), and stress can negatively impact one's performance (Hafeez et al., 2018). Online environments for learning and test-taking from home are becoming increasingly popular and can also impose technological, social, and emotional challenges for students (Loderer et al., 2020). Online exam environments are, obviously, different from traditional on-site exam environments at school or on campus, but to date only little is known about students' subjective experiences in online exam environments and about the stressors they might face in these new settings (Harley et al., 2021). Besides technical problems, social and emotional aspects of writing an online exam from home could also play a contributing role in the perception of stress (Schult & McIntosh, 2004). Other factors that might be stressful for the students include exam proctoring, prominent time indications on the computer screen, or external disturbances (e.g., noise from children playing outside). These differences and challenges can affect students' subjective experience of online exams and thus their perceived stress - and in the long run also their performance. Hence, knowledge about potential stressors is important for the design of optimal exam environments. In this study, we therefore investigated the factor structure of a newly developed instrument to capture these stressors arising in online exam environments.

Method

The present study took place in spring of 2022 and was part of a large multicentred project on the topic of e-assessment. The sample of the present study consisted of N = 367 students from different study programs (299 females, 56 males, 10 not specified, 2 various; M_{age} = 25.88, SD_{age} = 5.43) from the University of Applied Sciences and Art Northwestern Switzerland FHNW and the Bern University of Applied Sciences BFH. After concluding their individual online exams at the end of the spring semester in 2022, participants were asked via email to participate in an online survey that included multiple scales addressing their subjective experiences in online exams (e.g., stressors, emotions, appropriateness of exam format). Along with these scales, demographic data (i.e. age, gender) were collected. The stressors questionnaire was first developed in a previous study (Jeitziner et al., 2022), and it included scales for the context of online exams based on stressors that might occur in these settings. The participants reported on their level of stress (i.e., "*For each of the following statements, please indicate how stressful the situation is for you during an online exam.")* on a scale ranging from 1 – "not stressful at all" to 5 – "extremely stressful". In an exploratory factor analysis, a five-factor structure was found (i.e. System Failures, Social Pressure, Self-inflicted Noises, Time Indications and External Disturbances). For the present study, the 26 items scale was further developed, and additional items were included. The final questionnaire consisted of 31 items. Based on these new items, we expected an eight-factor structure consisting additionally of the factors Physiological Reactions, Proctoring and Difficulty. To test this hypothesized factor structure, we conducted a confirmatory factor analysis in R.

Results

The confirmatory factor analysis was calculated based on the described sample (N = 367). All of the items indicated no multivariate normality ($p < .001$). Moreover, since the Likert-like format of the questionnaire implied ordinal scaling of the data, we chose weighted least squares estimation instead of maximum likelihood. The hypothesized model indicated a good fit (TLI = .99; CFI = .99; RMSEA = .015). Therefore, we did not modify the model or conduct post-hoc analyses. In a next step, we descriptively investigated participants' perceived level of stress separate for each of the identified factors. *System failures* (e.g., "The internet shuts down") were the largest source of stress ($M = 4.33$, $SD = 0.77$), followed by the factor *difficulty* ($M = 3.90$, $SD = 0.80$) of the exam (e.g., "The exam is too difficult") and the factor *social pressure* ($M = 3.00$, $SD = 0.86$) (e.g., "The feeling of being behind compared to other students"). The factors *external disturbances* ($M = 2.35$, $SD = 0.92$; e.g., "Sounds of footsteps in the room"), *time indication* ($M = 2.31$, $SD = 0.84$; e.g., "A visible countdown clock on the screen"), *experience of physiological reactions* ($M = 2.24$, $SD = 0.92$; e.g., "feeling one's own heartbeat") and *experience of proctoring measures* ($M = 2.12$, $SD = 0.83$; e.g., "Feeling observed to avoid cheating") indicated medium levels of stress. The factor *self-inflicted noises* ($M = 1.39$, $SD = 0.60$; e.g., "Noise of own keyboard while typing") indicated low levels of stress.

Discussion

The goal of this study was to investigate potential stressors in online exams using confirmatory factor analysis and to provide insights on how stressful each of these stressors is perceived by students. We found that our hypothesized factor structure fitted the data, and we were able to break down the construct of stress in online exams written from home into eight different factors. In comparing the factors, we found that for our student sample, possible system failures and difficulty of the online exams were associated with the highest levels of stress. This implies that a lot of students fear that the infrastructure, soft- or hardware may cause problems, which concords with previous research on students' subjective experiences in digital educational environments (Bogdandy et al., 2020). Similar to on-site exams, difficulty seems to be a major stressor also in online exams. Unexpectedly, although proctoring has become increasingly important and much discussed recently - especially in the context of higher education due to the introduction of online exams from home during Covid-19 - it was not perceived as very stressful by the students. It should be noted, however, that although this factor was not perceived as a major stressor, it may indirectly cause stress through potential system failures (e.g., when using virtual machines or webcam monitoring as proctoring measures), which is why it is worth considering it in future studies.

This study, evidently, has certain limitations, which provide directions for future work. First, we examined potential stressors in online exams in a predominantly female sample, which implies that our results should be taken with caution and that future studies should consider a more heterogeneous sample. Second, we asked students to self-report their perceived levels of stress in their online exams. For a more complete measurement of exam related stress, future research should not rely only on self-reports, but should also consider other measures such as physiological measurement (e.g., electrodermal activity or heart rate variability; Roos et al., 2022).

In sum, the present study identified that some stressors in online exams are similar to those of on-site exams, but as described, there are also differences. These identified aspects could be helpful for the development and design of future online exam environments.

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Global MOOC Learners' COVID Narratives: Pandemic, Purpose, and Core Questions of the Human Experience

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Abstract: The ongoing COVID-19 pandemic caused many to reconsider their life's purpose and contributions. Massive open online courses provide an accessible avenue to explore knowledge safely at home. In this study, 70 learners from 28 nations on six continents were interviewed about their goals and the outcomes of their participation in MOOCs offered by a large US university. Learners shared deeply personal narratives of the ways open learning expanded a sense of possibility, redefined self-purpose, and offered flexible learning opportunities, demonstrating MOOCs' value beyond access, toward expansion of human capability.

Background

Massive open online courses (MOOCs) are a 21st-century development in distance education that expand institutional reach to a global scale (Baggaley, 2013; Diver & Martinez, 2015). Once expected to disrupt the postsecondary status quo, contemporary critiques now include profit, privacy, epistemic hegemony, and postcolonial influence by well-resourced universities (Laryea et al., 2021). Nonetheless, millions worldwide engage in MOOCs annually, with some studies indicating a more than tenfold enrollment gain due to the pandemic (Shah, 2021). We must understand both how learners use these courses and how the pandemic influenced their experiences. Part of a larger study of global learners MOOC experiences, this poster presents data demonstrating how MOOCs satisfied an emergent need for exploring one's goals and sense of purpose. Our inquiry was guided by the research question: How has the COVID-19 pandemic influenced MOOC learners' experiences and outcomes? The human capabilities framework (Sen, 2003) served as an instructive lens for this study. Originating in economics, the framework emphasizes well-being on three interrelated dimensions: functionings (i.e., goals we value), capabilities (i.e., skills and attributes empowering us to pursue goals), and agency (i.e., our ability to apply skills toward our goals). This framework allowed us to analyze whether and how MOOCs enabled expansion of one's goals, purpose, and capacity in the face of the pandemic.

Study design

Participants were recruited from the population of 130,000 learners in MOOCs offered by a United States university who answered a post-course survey. We used stratified random sampling to invite a narrower group of participants who mirrored the nationality proportions in the total learner population. 70 learners from 28 nations on six continents participated in this study. Qualitative inquiry with semi-structured interviews allowed participants to guide the conversation within established research-goal bounds. Data analysis included both deductive and inductive coding strategies, first identifying codes related to our research question and framework, then coding for findings identified in our engagement with the data. Codes were subsumed into themes in accordance with Deterding's and Waters's (2021) flexible coding method for large qualitative interview datasets.

Findings

We identified the following answer to our research question: the pandemic influenced learners' MOOC experiences and outcomes by enabling social contribution, redefining one's sense of purpose, and fostering exploration via flexible modularity. We include brief narrative fragments to illustrate the richly nuanced ways learners conceptualized their pandemic-related course experiences and outcomes. Notably, the experiences detailed were common among our global sample regardless of nationality, indicating the universality of both these core, humanistic needs and the applicability of the MOOC format in addressing them. Joseph (all names pseudonyms), a learner in Mexico in an introductory social work course shared:

> I've been working in the corporate world for over 20 years and I'm in that point of life where you are like, "well, what I'm doing, does it make sense? Do I envision myself doing this for another 20 years?" And the answer was no. I want to do something geared towards helping.

As Joseph used a MOOC to explore contribution, Jonna, a finance undergraduate in India, described the ways a MOOC helped her define a new sense of purpose during a time of pandemic-induced personal crisis:

> I was feeling purposeless at the time, unclear what I was doing with my life, because several family (members) had just died due to COVID, and I wasn't sure why I was living. Online means were all that was available at that time. It gave me a purpose. It helped me in interviews, in college. I use the word "purpose" in my interviews now. I didn't think I was that good in finance. But no, I see that as my purpose now.

The preceding outcomes were enabled in part by the MOOC format's flexible, modular content. Susan, a data scientist at the US Centers for Disease Control and Prevention, was part of a team using a MOOC to gain skills for the agency's pandemic response. She emphasized the importance of these modality characteristics:

> I wouldn't have progressed as fast if I hadn't completed that class. We're using data science skills to look at these longer-term outcomes and disparities around case rates, hospitalizations, vaccinations, testing, mortality, and trying to get a big-picture view. Now we're using surveillance data to tell the stories of health disparities and COVID in a comprehensive narrative. I probably could've gotten this content elsewhere, but not in this format, and the format really mattered. I could go in and watch a video for 15 minutes, then go do something else, then come back when I was able.

While open access is touted as the key benefit of the modality, a plurality of participants in our study named this sense of modularity and temporal agency as the prevailing factor in their successes. We encourage course designers, faculty, and providers to consider that it is not only MOOCs' openness that lends meaningful advancement to postsecondary accessibility, but also what learners encounter after enrolling in a course.

Discussion

Our study demonstrates the value of MOOCs in advancing not only specific skills and knowledge, but also satisfaction of core questions of the human experience, e.g., purpose and contribution. We build upon the work of Veletsianos et al. (2016) who offered a qualitative understanding of MOOC learners' experiences and called for further insights beyond quantitative datasets. Our study gathered one of the largest and most globally-representative collections of qualitative data on MOOC learning to-date. Its timing at the start of year three of an ongoing global pandemic allowed us to analyze the interplay between COVID-19 and open courses in real time. Given the role technologically mediated learning has played throughout the pandemic, we anticipate an expanded role for MOOCs in the coming years. The capabilities framework also lends significance to this study. Employing this lens, our study contributes to a growing understanding of how MOOCs can allow individuals around the world to advance their social participation, personal dignity and fulfillment, and quality of life. Beyond showing MOOCs expand access to postsecondary education, our study shifts the scholarly focus by demonstrating how these courses expand human capability for individual and collective benefit through satisfaction of core questions of the human experience, purpose and sense of contribution, each supported by the format's flexible modularity.

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Understanding Emotion-Cognition Interplay When Processing Feedback During the Standardized Patient Debrief Sessions

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Abstract: This study examined how medical and social work students perceive and process feedback during a post-simulation debrief session. A novel methodology was employed for multimodal sentiment analysis, which consists of gathering sentiments from videos (n=113) by fusing audio, visual, and textual data features. Results indicate that most students expressed positive or negative deactivating emotions when reflecting on their performance. Evaluating and looking for alternatives were the most frequent reflective behaviors with few occurrences of looking forward behaviors.

Introduction

Simulation-based training augmented with team-level feedback on communication skills during debriefings are widely used in medical schools to improve skills needed for highly reliable clinician-patient interaction. Feedback in post-simulation debriefing settings is defined as the transmission of information to individual team members or the team as a whole regarding actions, events, processes, or behaviors relative to task completion or teamwork. Feedback is widely acknowledged to be central both to motivation (by promoting team efforts) and to learning due to its informational value (Gabelica & Popov, 2020).

In this study, we explored the ways in which medical and social work students perceive and process information cues contained in feedback during Breaking Bad News (BBN) debrief sessions. Constructive uptake of feedback can be "obscured by emotional static" (Chanock, 2000, p. 95), where team members' emotions can hamper cognitive processing of feedback. This study makes two contributions. First, our multimodal sentiment analysis provides unique insights into the ways in which medical and social work students perceive and process information cues contained in feedback during debrief sessions. Feedback on crucial aspects of team interaction needs to be perceived and meaningfully processed to reach the expected benefits of improved communication. Second, we explored a multimodal system for automatic quantification and interpretation of an individual's response when receiving feedback based on verbal and nonverbal behavior markers during the debrief sessions, such as words (speech content), head and body movements, facial expressions, tone of voice, and turn-taking. Specifically, we leveraged machine learning to build a sentiment classifier to reliably predict in near-real time students' cognitive-emotional states when receiving feedback. Specifically, we explore two research questions:

1. How do medical and social work students self-reflect as well as perceive and process information cues contained in feedback during BBN debrief sessions?
2. Can we leverage machine learning to build a sentiment classifier, so we can reliably predict in near-real time students' cognitive-emotional states when receiving feedback?

Method

Our research team transcribed, analyzed, and annotated 113 standardized patient simulation videos. To understand how students perceived and processed their feedback, meaningful units of analysis (i.e., phrases, sentences or series of sentences), were hand-coded using two coding schemes to affective and cognitive dimensions of feedback perception: team reflection coding scheme, and the taxonomy of academic emotions Gabelica et al., 2014; Pekrun, 2006). To code emotions, we adapted the taxonomy of retrospective outcome emotions from Pekrun's (2006) using a combination of categorical (e.g., discrete categories such as anger, happiness), and dimensional (valence: positive or negative; activation: activating or deactivating) approaches to emotion measurement. Each student response was hence coded as: (1) positive activating, (2) negative activating, (3) positive deactivating, (4) negative deactivating. A team reflection coding scheme was adapted from Gabelica et al. (2014) to capture the degree to which team members engaged in three cognitive (reflective) behaviors: evaluating performance or strategies, looking for alternatives, and making decisions ("looking forward").

Results

We found that a large majority of students expressed either positive (e.g., relief) or negative (e.g., disappointment) deactivating emotions when reflecting on their performance (Table 1). We found that 'evaluating' and 'looking for alternatives' were the most frequent reflective behaviors with very few examples of looking ahead reflective behaviors (Table 2). Table 3 shows with what accuracy we can predict student' sentiment using each modality vs. multimodal model.

Table 1
Distribution of emotions across students based on Pekrun's (2006) taxonomy

Sentiment	Positive deactivating	Negative deactivating	Positive activating	Negative activating
Overall	75	344	30	18
Medical student	44	178	10	9
Social work student	31	166	20	9

Table 2
Distribution of reflexivity across students based on Gabelica et al. (2014) scheme

Reflexivity	Evaluating	Looking for alternatives	Making decisions (feed-forward)
Overall	232	202	14
Medical student	124	100	10
Social work student	108	102	4

Table 3
Performance of unimodal and multimodal classification models for negative and positive deactivating sentiments

	F1*-score for negative deactivating	F1-score for positive deactivating
Video features	0.49	0.41
Audio features	0.67	0.52
Text features	0.85	0.60
Combined features	0.88	0.71

*F1-score is from 0 to 9, 9 being the highest in terms of precision and recall.

Discussion and conclusion

In this study, we have identified and captured emotional and cognitive responses to team-level feedback during BBN debrief sessions using audio, visual and textual clues from video data. We have found that most of the expressed emotions were negative deactivating, and that students were mostly engaged in reflective behaviors related to their past team performance. Hence, they seemed to have missed an opportunity for 'feedforward', that is for leveraging insights about themselves for better team performance in the future. Necessary future research should address the extent to which negative deactivating emotions are related to low future-forward team reflection. This study is part of broader research with the objective of optimizing feedback delivery and reception to prepare future medical professionals to provide the best care possible to their patients.

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Vernacular Science and Community Mediation: Tracing the Invisible Fabric

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Abstract: There exists within many communities of interest in our society an invisible fabric of vernacular science activity. This fabric may play an important part in the reception, interpretation, and evaluation or filtering of the results of mainstream science. As illuminated in an ethnographic study, this fabric is seen to be both the result, and the enactment, of people's agency as participants in their world as experienced, and as thought about.

Introduction

How does a community of interest mediate the definition, transmission, use, and valuation of science in American culture? A theoretically rich account of science knowledge must take account of social/cultural context and the processes by which science is understood, constructed, and used in everyday settings — the 'vernacular' culture of science (Wagner, 2007). Vernacular science is constructed through conversation, and situated in specific *communities of interest* (Fischer, 2001) or *practice* (Lave and Wenger, 1991) with their specialized knowledge, practices, and discourse. Knowledge is produced through communication and interaction (including disagreement, e.g. Holland and Lave's (2009) "local contentious practice"). The community is an *agent* of education, as well as *context* for it: People engaged in their local communities are part of a “figured world”(Holland et al.,1998). Their knowing and doing, and their sense of themselves in those communities, is largely mediated by language, immersed in discourse processes. Discourse, gossip (Foster 2004), and discussion are *revealing* and *socially constitutive* activities (Bailey et al. 2014, Condor & Antaki 1997, Halliday 1990) that contribute to the development and transformation of social norms.

Data sources and analysis

I conducted ethnographic research in a rural community in New England which presents a rich diversity of active social networks. Data consisting of field notes from observations, community documents, and interviews (recorded and transcribed by permission) were coded in a concept-driven framework (Spencer et. al 2014) with respect to the following: a. The science central to the group's interest; b. The structures and sources of information and authority relevant to their science of interest; c. The processes, customs, or structures that support and frame the discussion or decision-making. As memos and research narratives were constructed, hypotheses were tested against the whole body of data, and member-checked with participants.

Findings

1. The science is often tacit, isolated, and/or atheoretical — but not necessarily unsystematic. The science of central interest to the participants in these communities is often not recognized as science: Child nutrition or vaccination is not science, it's health or parenting. The botany and ecology of gardeners is not thought of in those terms, as a member of a local garden club said: . *We don't usually do anything scientific...Well, actually I guess we do, but it's just not called that.* The science relevant to each community was not related to formal disciplinary knowledge, so consistency with established theory was not an important criterion, while richness of claims was convincing. Thus, if an authority figure makes a claim, there is no external motivation or leverage for critique.

2. A person gains ***authority*** *within the community's discourse primarily through* ***authenticity****.* People were able to identify specific persons within their community whose authority served as a warrant for claims made: *In most cases, you give more credence to what those active farmers are experiencing and understanding about whatever it is, certain varieties of grass, certain land management practices, health issues with animals. Those are very powerful.* An authority with a well-articulated alternative worldview, who performs authenticity, often is appealing because the search for and use of scientific knowledge in a community of interest is connected with members' articulation of identity. The person just quoted had been disillusioned while a student at a major military academy. From field notes: *9/11, the wars in Iraq and Afghanistan shook his confidence in established authorities...It seemed important to seek information that could help him make up his own mind.*

3. Diversity of opinions is valued, but conflict is avoided. In all cases, controversy over science is seen as secondary to the core purpose of the group , and so while differences of opinion are known to exist, many are not discussed or critiqued, in order to preserve the comity of the group whose focus is not the establishment of knowledge. Silence is constructed (Drayton, 2023). As a parent said about the prevalence of "alternative medicine" in the school community, *[My husband and I] lie...The kids are fully vaccinated. We're not going to suffer through,* *we're not going to try to wait out strep. I'm getting the drugs for it, the antibiotics, but I'm definitely not going to say that out loud.*

Discussion and significance

This preliminary work suggests that robust vernacular science cultures are present and active in many communities of interest, and are not to be understood simply by deficit models (where the deficit may lie in the learner, the science teacher, or the scientists). Such science is of daily use for matters of direct relevance, with informal authority structures and methods of transmission. Its atheoretical nature, and isolation from mainstream disciplinary knowledge, reflects a difference in core function from mainstream science, whose aim is to render a coherent and verified accounting for natural phenomena. Vernacular science engages with real phenomena, but its purposes include community solidarity and personal identity, as well as providing the basis for growing expertise in a particular area of practice. A fuller account of the varieties of vernacular science current in a communnity may well provide important insight into barriers to the credibility and uptake of mainstream science as conveyed in schools or the media.

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Knowledge in New Pieces: Exploring Modern Youth's Intuitive Knowledge

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Abstract: Youth's worlds are increasingly large, connected, and inextricably digital and analog. The intuitive knowledge that youth develop in navigating and constructing these worlds may similarly evolve in ways that could inform formal education. We present initial findings of a broader research program that studies what and how youth know about complex systems from their daily experience with them. Findings could guide the design of educational activities and curricula that leverage such knowledge in preparing youth for contemporary life.

Motivation and background

Youth's exposure to complex systems, natural phenomena, and forms of social interaction has increased dramatically. Some systems are technological; networked, internet-enabled, real-time processing devices are an inextricable part of youth's reality, making the gathering, processing, and flow of data as real a consideration as why the seasons change. Other systems arise in discourse; conversations about resource use, climate change, global economics, and systemic inequity and algorithmic bias, to name a few examples, are "in the air" more so now than ever. Youth inhabit and explore increasingly large, detailed, complex, and interconnected worlds.

This project is inspired by Knowledge in Pieces (KiP, diSessa, 1993) and its account of the diversity and contextuality of intuitive knowledge. KiP's *phenomenological primitives (p-prims)* capture small bits of intuitive knowledge about how things work (diSessa, 1993) (e.g., "forces act in balance," and "multiplication makes numbers bigger") that constitute the building blocks of sense making. This pilot is a first step in studying the novel, overlooked intuitive knowledge "pieces" - that is, the **knowledge in new pieces** (KiNP) - generated by youth's modern, techno-social lives. We are guided by the following research question: *what do youth know about complex systems based on their everyday, out-of-school exposure to such topics?*

This work could inform curriculum design and education in a few ways. diSessa's work tells us that learners do not simply "forget" typically unproductive p-prims (Smith III et al., 1994); they may be unaware that they regularly use a p-prim, and a given p-prim may remain productive in certain contexts. KiP also describes how, as learners' conceptual understanding matures, it develops into *coordination classes* (diSessa & Sherin, 1998) that highlight concept-relevant features and inform more consistent reasoning. We also base this work on research of how people think with and about technology (e.g., Danovitch & Severson, 2021; Turkle, 1984). We focus less on documenting youth's technology practices and instead seek to use the intuitive knowledge gained from those practices as a springboard for formal learning. Finally, we draw from *connected learning* in which, through community-supported pursuit of personal interests, youth learn knowledge and skills that can support their academic, civic, or career development (Ito et al., 2013).

Pilot methods

We collected several hours of video data with 5 youth aged 8-15. Using convenience sampling, all participants lived in major metropolitan areas, and 4 of the 5 youth had at least one parent with an advanced degree. Semi-structured interviews lasted 45 minutes and addressed topics drawn from the first author's 10+ years of informally talking with youth about technology (Table 1). Interviews were conducted on Zoom, automatically transcribed, verified by the second author, and collaboratively and thematically coded (Braun & Clarke, 2006).

Table 1
Sample interview topics and prompts

Topic	Interview Prompt(s)
1.Exponential Growth	How long would it take a great meme to get 100 views? 1,000 views? 1 million views?
2.Artificial Intelligence	How do AI assistants understand you and do what you want them to? If you got a different answer from an AI assistant and from an adult, whose answer would you trust?
3.Robotic Workforce	As robots advance, they do jobs that people used to do. People who had those jobs, what do they do now? What would you tell someone worried about being replaced?
4.Industrial Impacts	When you buy a t-shirt, what happened for it to be made and get to you?

Pilot findings

Related to ideas of exponential growth (Q1), participants identified a range of variables that affect content's view rate: number of followers, influence ("famous" or "regular" person), metrics (views or reactions), and timeliness ("in the news" or "just random"). Some participants offered sophisticated mathematical reasoning about exponential growth, characterizing powers of 2 before they were exposed to such concepts in school ("If you send it to 2 people, and those people send it to another 2 people, it keeps getting larger and larger").

About half the participants also offered detailed considerations of the environmental and human impacts of the clothing industry (Q4). They indicated an awareness of complex resource and supply chains as well as of the unintended consequences of industrial workflows: large plantations using land and water to grow cotton, factories using energy to spin thread and fabric and to sew fabric into shirts, stores selling the shirt, trucks using fuel to transport goods at every step. Participants also recognized the social, policial, and economic dynamics that shape those networks. One participant described such work as happening "in places like China, India. …because Americans don't have time for that" and discussed issues of cost of living ("maybe not good work, but it's a work that can provide enough"), wage theft ("there's some places that don't even pay their people"), labor relations ("the people who are actually in control … are less willing to pay [their workers] five times more."), and global economic dependence ("The work then gets shipped off to different countries … The country is completely dependent on that."). Another participant summarized these issues using an intuitive sense of ethical "balance:" "every time you're going to do good, you're also going to do evil." He discussed the impact of t-shirt production as a complex ethical dilemma, between generating jobs and low prices in some countries while destroying the environment in others.

We also found ways in which youth's previous knowledge about socio-technical systems was insufficient to sustain complex sensemaking. Most participants agreed that a social media post would continue to gain views indefinitely. Similarly, most participants expressed an understanding of AI as based on "very delicate coding" composed of endless if-then statements (Q2), likely the type of code they are familiar with from environments such as Scratch. Finally, all but one participant expressed no qualms about expanding robotic workforces (Q4). Participants were confident that replaced human workers could either become robotics technicians ("they could program the robots") or change careers ("there are a bunch of other jobs out there").

Conclusions

Our preliminary data suggest that youth indeed know some advanced knowledge pieces even without formal instruction on them, up to a certain limit. The topics addressed by the interview protocol are typically not yet taught in formal education to children of our participants' ages, suggesting our participants acquired these ideas through first hand experience with online content or through immersion in local or global public conversations. There is also great potential for educational designs and curricula to precisely address the missing pieces that are harder to glean from everyday experiences (e.g. balancing the novelty of technology with the ethics of its human implications). In expanding this pilot work, we aim especially to diversify our participant pool, including internationally, to access a wider range of youth perspectives (Kafai et al., 2010). We believe these preliminary findings justify further study of the "new pieces" of youth's intuitive knowledge. Educational designs and curricula that reflect and honor students' intuitive knowledge could better prepare them for life and civic participation in the 21st century.

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“More Than Just Making Stuff Explode”: The Impact of Engagement With Scientific Practice Beyond Disciplinary Content

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Abstract: As part of a larger project, this study evaluates middle school students’ learning from a technology-based, evidentiary reasoning unit. Post-unit survey responses indicate students developed a deeper understanding of the nature of scientific work and of productive scientific mindsets. These take-aways beyond content knowledge emphasize the learning opportunities and outcomes that can arise from engaging learners in authentic scientific practices.

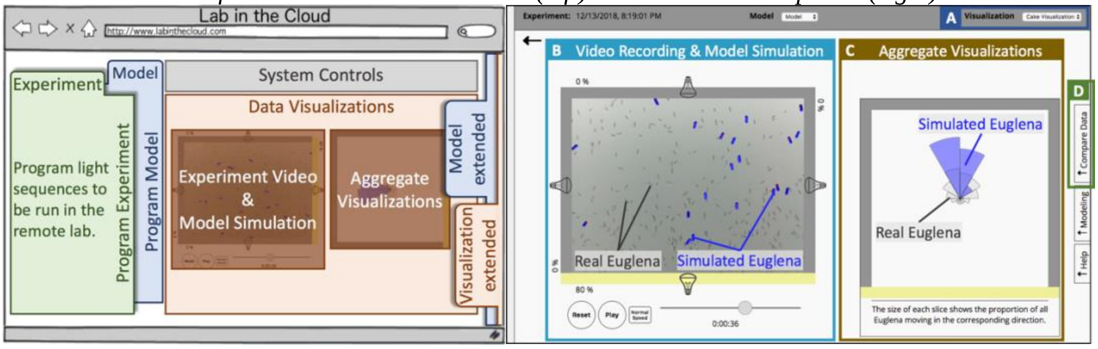
Introduction and background

Recent science education reforms work to shift science learning beyond a mere understanding of scientific content to include knowledge about the function and interplay of the different scientific activities, often referred to as understanding of the nature of science (NOS) (Williams & Rudge, 2016). Research suggests that students’ understanding of NOS be developed alongside their science content and procedural knowledge through practice-based teaching approaches (Duschl & Grandy, 2013). The design of practice-based learning activities that foster content, procedural, and NOS learning remains a persistent challenge (Williams & Rudge, 2016).

Acknowledging the intricate relationship between the design of practice-based science activities, how students engage in scientific practices, and what they learn about science through the activity, this poster addresses the following research question: what do students take away about the nature of science and how scientists work from engaging in a practice-based, technology-driven learning activity? We report on a middle school unit in which students coordinated real data with computational models to reason about the behavior of *Euglena gracilis*. Throughout, students had to make decisions about what kind of data features and patterns to use to evaluate their hypotheses and models. We propose that above-content take-aways emphasize the broader- than-expected learning opportunities and outcomes of engaging learners in authentic scientific practices.

Figure 1

Lab in the Cloud software environment overview (left) and visualization options (right)



The size of each slice shows the proportion of all Euglena moving in the corresponding direction.

Methods

Based on the Bifocal Modeling framework (Blikstein, 2014), which juxtaposes scientific models and real-world data for real-time comparison, we designed Lab in the Cloud (LiC), a web application that integrates a remote laboratory (Hossain et al., 2016) with a modeling and data visualization environment. In the Experiment area (Figure 1, green), students remotely controlled the lab’s lighting to vary conditions for live *E. gracilis*. They also programmed models (Figure 1, blue) to enact their theories of *E. gracilis* phototaxis. Students studied the resulting experimental and model data in the same visualizations (Figure 1, orange), both as an overlay (Figure 1, part B) and in aggregate (Figure 1, part C) (Bumbacher, 2019), to modify and refine their theories about *E. gracilis* phototaxis. The 76 participants (39 F, 37 M) were 7th grade students in a Northern California public school and all had the same life science teacher.We analyzed students’ answers to the nature of science question “Did you learn anything about science and how scientists work that you did not know before? If so, what did you learn?” through their post-unit survey responses. Through multiple rounds of independent and collaborative thematic analysis (Braun & Clarke, 2006), we refined the codebook presented in Table 1 and achieved Cohen's Kappa of at least 0.80 on 25% of the corpus. The remaining responses were coded independently.

Table 1
Codebook for students' reported learning from the E. gracilis phototaxis unit.

Learning Area	Example(s)	Students	# Ideas	
			Mean	St. Dev.
Nature of Scientific Work		**75%**	**1.2**	**0.4**
Experiments & Data Collection	"scientists learn new things and experiment with technology like using computers or microscopes."	29%		
Models & Tools	"I didn't know scientists used robots to mimic the animal or plant."	45%		
Interpretation & Argumentation	"If you don't have good evidence to support your claim, no one will believe what you are saying."	14%		
Scientific Mindset		**42%**	**1.3**	**0.5**
Patience & Perseverance	"you don't always figure things out the first time and that scientists need to be patient when they experiment."	12%		
Attention to detail	"scientists carefully observe different actions or outputs with precision and close observation."	28%		
Other:	"...scientists... could get proven wrong. But that is not a bad thing."	14%		

Findings

Almost all students (91%) reported learning science content (Table 1). Encouragingly, 75% of students reported learning about sophisticated aspects of NOS (or in a students' words, "they study more than just experiments and making stuff explode.") and over 40% reported learning about scientific mindsets. Neither of these areas were overtly discussed by the instructional unit and, thus, represent above-content learning. Students tended to report NOS learning about novel tools - software, computer modeling, and robotics - that go beyond mere experimentation and data collection. "Attention to detail" was the most common idea within reported learning about scientific mindset. Students' reported NOS and mindset learning can potentially transfer beyond the particular study of *E. gracilis* to other scientific reasoning in school and life.

Conclusions

This paper contributes to the small body of work on the impact of practice-based learning on students' understanding of NOS (Rönnebeck et al., 2016). The study was situated in a novel technology-driven activity that combines real data with computational modeling to engage students in evidentiary reasoning in disciplinary meaningful ways. The results indicate that engagement in this activity helped students learn about epistemically rich aspects of scientific work, such as the importance of carefully linking evidence to claims. We believe that these self-formulated insights could be solidified by teachers to help learners becoming participants of scientific conversations who use evidence from real-world data to critically review and evaluate scientific claims.

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Situating Evaluation: Theory Driven Evaluation in Practice

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Abstract: Theory driven evaluation is a social practice that contributes to the consequential production of people, knowledge, and resources. Evaluators are overlooked actors supporting the Learning Sciences community. Our poster explores how theory driven evaluation has been taken up in Canada and the United States. Using collective autoethnography, we show how evaluation is implicated in learning as becoming. We conclude with suggestions for how to engage with evaluation to support better designs for learning and becoming.

Introduction

Our prior work argued that evaluators play a consequential role contributing to the design and organization of learning (Weidler-Lewis & Frickey, 2021) when evaluation is understood as social practice (Schwandt, 2018). This conceptualization of evaluation is informed by the view of learning as social practice (Holland & Lave, 2009) and the ways in which learning is contextual, situated in activity, and mediated by cultural tools (Lave & Wenger, 1991). Furthermore, learning is a process of becoming of persons, knowledge, and tools (Packer & Goicoechea, 2000). We showed how boundary judgments enacted by evaluators shape practices by legitimizing some forms of knowledge and validating certain stakeholder's interests over others thereby implicating evaluation in perpetuating or disrupting dominant, logics many in the Learning Sciences intend to dismantle (Esmonde & Booker, 2017). This poster continues our nascent work moving from theory to practice as evaluators in Canada and the United States. We present three autoethnographic narratives detailing how theory driven evaluation was enacted in our work and the resulting implications for the becoming of persons, knowledge, and tools.

Theory driven evaluation

According to theory driven evaluation (TDE), evaluation should not only have scientific credibility but should also have "practical worth" (Chen, 2013). TDE is aligned with Learning Scientists who recognize relevance to practice as a significant criterion for rigor (e.g., Gutiérrez & Penuel, 2014). We argue TDE should also lead to practical action and inform questions such as "how ought we design for learning?" Practical action is facilitated by boundary judgments, judgments dictating what should be included or excluded from a given context (Schwandt, 2018). Boundaries are negotiated through collective sensemaking and require normative judgments (i.e., what is *good* or *right*). TDE helps to answer the question *what should be done* while recognizing that there is not a single or correct answer to what boundaries ought to be in an investigation. Therefore, TDE includes ongoing reflection regarding what decisions were made for and by whom with what consequences and impacts for whom. The work we are presenting in this poster represents this reflective practice.

Collective autoethnography as method

In autoethnography, researchers apply their analytic lens on themselves and their interactions with others to interrogate traditional research relationships and to understand broader cultural meanings through personal experience (Chang, 2016). Autoethnography is generally an individual endeavor yet critical methodologists recognize how collective autoethnography builds shared knowledge, sustains community, and works toward social transformation (Wężniejewska et al., 2020). We, the authors, are currently embarking on this process and are documenting our individual work in order to think collectively. As we make note of the dilemmas of practice we face, we are capturing how our boundary judgments are shaping the practices we are tasked with evaluating.

Autoethnographic narratives of evaluation in practice

Given the early stages of our research, we briefly describe our contexts and a few examples of the consequential boundary judgments we have enacted.

Frickey is evaluating a community organization in Ontario working to support folks living in poverty through means designed to shift attitudes toward poverty sufficient to impact public policy. Previously, the organization received multiple grants to develop and implement their program, including two evaluations, each completed by different evaluators. The data collected from these prior evaluations were to demonstrate impact to support continued funding for the program, however, key features of the program's theory of change were disrupted because of COVID-19. The data collected no longer supports its original purpose. During the lockdown, additional work not captured by the data was required for the program to function. Frickey is faced with the dilemma of how best to use prior data to retain its scientific credibility while maintaining its practical worth. Therefore, he must generate new *knowledge* by either reconfiguring the existing data and/or seeking new types of data.

Goulet-Langlois is evaluating a pilot project aimed at preventing reincarceration and sexual exploitation through the redesign of intervention practices with women transitioning out of prison in Québec. Prior to his involvement with the evaluation, the directors of the agency saw the evaluation as a means to demonstrate only outcomes that secure long-term funding by showing a reduction in recidivism rates correlated with their services. By reducing outcomes measure to only individual metrics like recidivism all the mitigating factors of women's lives were overlooked that could be taken up through evaluation including women's social, economic, and indigeneity status. *Goulet-Langlois* was able to engage stakeholders in sensemaking regarding how such reductions limited the ways in which women were seen and thus how this hindered the development of the pilot programming. Thus, TDE directly informed the production of *persons* (i.e., the women) in this context.

Weidler-Lewis evaluates developmental outcomes for youth. They are currently evaluating programming supporting children ages birth to five years by a state agency in the Midwest United States. The state mandates that evaluation use a "results accountability framework" that measures "how much did we do?" and "how well did we do it?" Prior evaluators used this framework to compare the number of children who had cases marked completely resolved to all others without attending to all the work done to support children who did not meet the completely resolved criterion. Weidler-Lewis's research into the amount of work done by the staff revealed that the data management system used to track children's development could be improved to document staff work at the different trajectories towards resolution and provide new categories to think with regarding what was going "well" and what was not. Thus, Weidler-Lewis's evaluation resulted in new *technology* for their practice.

Discussion and conclusion

Although the presentation of our findings is brief, our narratives demonstrate how our decisions as evaluators led to the production of knowledge, persons, and tools. In this way, we are consequential actors in designs of learning insofar as learning is taken as becoming. We argue that rather than separate evaluation as something outside of the scope of designs for learning, learning designers should seek out evaluators who take up the TDE perspective. Then, together, learning designers and evaluators can engage in joint sensemaking to see how each comes to make judgments that shape the practices we value. Together, we can design and evaluate with the aim of creating intentional opportunities for learning of the type that the Learning Sciences community is known.

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Using a Design-Based Research Methodology to Improve Competency-Based Grading

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Abstract: Competency-based grading (CBG) was implemented in an introductory computer science and a graduate-level pharmacy course to address the limitations of traditional grading schemas, which do not accurately reflect a student's competency. This study outlines how student perceptions of the CBG schema were collected through reflections, and a design-based methodology was used to identify course-level and universal recommendations for improving the CBG schema. In future iterations of the courses, the identified design moves will be implemented, and students' reflections will be analyzed to identify additional improvements to the CBG schema.

Introduction

Competency-based education (CBE) is a unique perspective on curriculum where the student engages with sources of knowledge, reconstructs knowledge, and takes responsibility for their learning. The instructor becomes a guide in the learning situation instead of the source of knowledge (Claassen, 1998). In this way, CBE emphasizes mastery of outcomes and uses various techniques to evaluate the degree to which students demonstrate competencies.

Real-world application of CBE needs more rigorous research (Pellegrino, 2014). The current study employed design-based research (DBR) to allow educators to integrate research, curriculum design, and practice (Joseph, 2004). The current study evaluated CBE within a computer science course and a pharmacy course taught by study co-investigators. Analyzing these courses with a DBR methodology allowed the instructors to better understand their respective course curricula by identifying real-world design moves.

Assessments are essential to CBE as they allow instructors to measure when a student has mastered a specific outcome or goal (Albanese et al., 2008). However, these assessments must resemble skills, activities, and functions in the real world. Assessments then become a learning experience in which learners apply their knowledge, skills, and values in an integrated manner. As a direct result, CBE assessments allow students to build knowledge rather than acquire it and demonstrate their competence in the activity.

Traditional A–F grading schemas calculate the final letter grade from activities averaged together. However, students may earn an "A" grade despite lacking competence in the core skills of the course. Both courses in this study opted for competency-based grading (CBG) to better evaluate the student's knowledge. Each course coordinator broke down the core competencies and redesigned their grading schema. Both courses used similar CBG structures when implementing a core set of activities requiring students to demonstrate minimal competency to pass the course. Each course started the new CBG schema by identifying the key activities required to demonstrate competency in the course learning objectives. However, both courses allowed students to earn a higher letter grade by providing additional assignments that helped further demonstrate student competency. This allowed each student to choose their path to learn the course material while having a consistent foundation. Any passing grade demonstrated that students had mastered all course objectives.

CBG now requires students to meet all course competencies with a 70% achievement in each category and a student will not pass the course if this requirement is not met. Once the core competencies are mastered, students can accumulate points from additional pathways to earn an “A” grade in the course.

Research questions

With traditional grading schemes, students may earn an “A” grade despite needing to be more competent in the core skills of the course. To address this issue within their respective classes, two courses implemented a CBG schema. Our overarching research questions to improve our CBG schema included: *How did students experience learning in a CBG context*, and *How can these experiences improve the learning experiences?*

Methods

The current study is the second iteration of a more extensive DBR project where we implemented a CBG schema in introductory computer science and graduate-level pharmacy courses (Barab & Squire, 2004). We collected student perceptions of the new grading schema via reflections. We then used network analysis to identify ways to improve CBG in the two courses and develop evidence-based recommendations. We used network analysis because it provides a holistic and expansive method of understanding the complexity of student learning experiences.

At the end of each course, consenting students (n=133) reflected on four open-ended questions that we anonymized. We then coded the responses at the sentence level in the MAXQDA Analytics Pro software by using open coding techniques within predetermined categories, including what worked, student struggles, and suggestions regarding the grading schema. Correlational analysis was used to correlate student's struggles, what worked, and their suggestions for improvement. The matrices were imported into the UCINet network analysis software (Borgatti, Everett, & Freeman, 2002) and the NetDraw network visualization software (Borgatti, 2002) for network analysis. Girvan-Newman cluster analysis was conducted, and resulting network maps were analyzed to identify design moves to improve the CBG schema within the context of each course. Relationships between student struggles and what worked well allowed us to leverage the strengths to address the weaknesses.

Findings

We created a network map of correlations at the $p<0.001$ confidence level that shows positive, significant correlations between student struggles and what worked for them. Girvan-Newman cluster analysis found seven clusters at $Q=0.724$ where cluster sizes represent betweenness. For example, students in the red cluster struggled with their grades being easily demoted, the desire for multiple attempts on core assignments, and a need for more practice. What worked well for these particular students was feedback about their learning, the satisfactory/unsatisfactory grading, and graded attendance. These students' experiences aligned with the self-determination theory principle of intrinsic motivation. The design moves that addressed these students' struggles were to improve the structure of how to achieve the goals of each assignment and potentially incorporate practice assignments or example assignments before the graded assignment. We worked on design moves not reported here for the last five clusters. In the next iteration of this study, the analysis will be completed again to identify further improvements in implementing the CBG schema.

Implications and conclusion

The learning sciences have a long history of designs for learning that explicitly aim for greater learner agency and empowerment. Though grades were assigned in these courses, the instructors were able to implement a system of ownership and empowerment that encouraged learner agency. We found that students identified with the self-determination principle of intrinsic motivation through increased autonomy and self-perception of competence, and we expect that these principles can be applied to other disciplines. Framing this study on motivation theory is beneficial in promoting attention, competence, and autonomy among students.

Using a CBG schema, the instructors have created classes that empower students to take ownership of their learning. This empowerment allows the students to learn in a way that meets their individual needs. CBG allows students to tailor their learning experiences based on how they want to learn. Instructors in both courses ascertained that this CBG schema set higher standards than the traditional points-based schema. When implementing a CBG schema, instructors should consider which skills their students require to be competent when leaving the course. As we continue to work toward a set of principles for CBG, we must maintain constant awareness that factors unique to each context will require significant adaptation of design principles.

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Creating Classrooms of Care: Exploring Secondary Mathematics Teachers' Agency in the COVID-19 Pandemic

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Abstract: This interview study explores how the shift to online schooling during the pandemic presented teachers the opportunity to think critically about their grading systems and the scope of mathematical content they addressed. Centering teachers' agency as they responded to the ever-changing and uncertain educational and social environment of pandemic teaching, we investigate how teachers achieved agency as they were driven to better serve their students' needs.

Introduction

It is well documented that there are numerous inequities entangled in institutional structures of U.S. schooling (Milner, 2021). Exacerbated by the pandemic, inequities associated with access to food, shelter, and healthcare as well as income insecurity have amplified opportunity gaps in teaching and learning (García & Weiss, 2020). At the same time, American students' lives during the initial years of the pandemic were marred with injustice as they witnessed multiple public police killings of Black citizens, an uptick in anti-Asian violence, and an insurrection in the seat of the U.S. government. All of these aspects complicated the already uncertain shift to online schooling for teachers to negotiate – they had to create an online learning environment that met the needs of students' personal lives and the broader context of learning during a pandemic. This context presented an opportunity for teachers to exercise agency in ways that aligned with their pedagogical goals. This poster explores secondary mathematics teachers who were explicitly committed to equitable and responsive teaching in ways that centered their students' needs and addresses the research question: How do secondary mathematics teachers agentically recreate practice in ways that align with their pedagogical responsibilities?

Theoretical perspectives

Teachers must negotiate a variety of demands, often requiring them to transform and (re)define their teaching practice according to their pedagogical responsibility – a highly personal aspect of their sensemaking comprised of their sense of obligations and informed by both institutional and moral commitments (Horn & Garner, 2022). This study centers teachers' agency as they responded to the ever-changing and uncertain educational and social environment, driven to better serve their students' needs (Deed et al., 2020). Agency is a dynamic and socially mediated phenomenon – deeply embedded in local contexts, larger social and institutional structures, and relationships (Clarke & Hollingsworth, 2002). We draw on Priestley and colleagues' (2015) temporal model of agency which identifies three dimensions of teacher agency: iterative, practical evaluative, and projective.

Methods

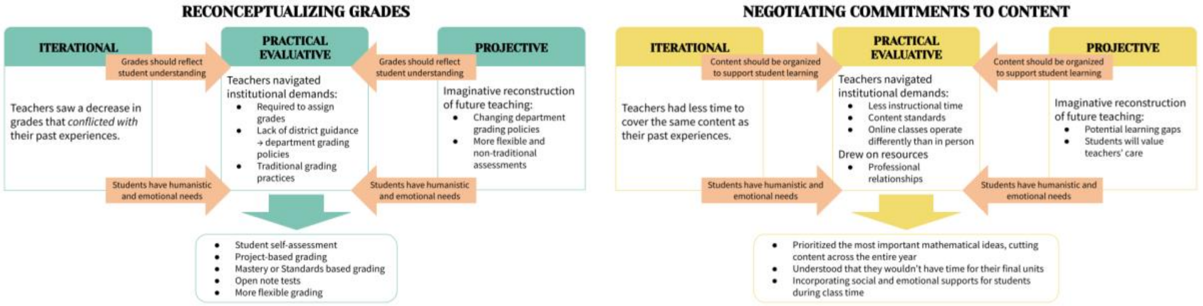
This study extends a four-year ethnographic study of eight experienced secondary mathematics teachers' learning, conducted in partnership with a professional development organization serving teachers in a large urban school district. At the onset of this study, our goal was to better represent the knowledge and questions that arise as we learn from and with teachers. As such, this interview study puts the teacher-as-researcher forward, recognizing them as experts in their experiences. Therefore, we designed an interview method we refer to as *reflexive longitudinal lifeworld interviewing* in which we developed interview protocols akin to those of lifeworld interviews (Brinkmann & Kvale, 2015) alongside of in-process data analysis (Emerson et al., 2011) of responses and content analysis of relevant current events (Altheide & Schneider, 2012) to inform subsequent protocols. Over the course of this analysis, agency emerged as a key phenomenon across participants. We then conducted cross-case, open inductive coding (Saldaña, 2021) to identify specific spaces in which teachers were reconceptualizing their practice followed by theoretical driven coding (Brinkmann & Kvale, 2015) informed by the temporal agency model.

Findings

We found that teachers in this study exercised agency during online teaching in two ways: by reconceptualizing grades and negotiating their commitments to mathematical content (summarized in Figure 1). During our study, teachers responded to decreases in students' grades in ways that aligned with two common pedagogical responsibilities: to reflect students' understanding and to students' wellbeing. They did so by incorporating practices like student self assessment and open note tests. In so doing, teachers also reimagined their grading practices beyond the COVID year to better align with these pedagogical responsibilities including committing to more flexible and non-traditional assessments and challenging department grading policies. Teachers were also forced to make decisions around the depth and breadth of mathematical content. Teachers in our study had fewer instructional days in which to cover the same content in their previous experiences. Teachers in our study prioritized what they considered the most important mathematical ideas to cut content across the entire year while also making space to incorporate social and emotional support for students during class time. These adaptations to their practice were rooted in two pedagogical responsibilities: to support student learning and to students' wellbeing. Teachers also acknowledged lasting effects – they anticipated potential future learning gaps, and they believed that students would value the care that teachers expressed more than covering content.

Figure 1

Agency in two Authoring Spaces: Reconceptualizing Grades and Negotiating Commitments to Content



Discussion

Throughout this study, pedagogical responsibility informed teachers' agency and reconceptualization of practice as they rebalanced their responsibilities to lead with an ethic of care and prioritizing their commitments to equity. We see agency as necessarily connected to teachers' pedagogical responsibilities and commitments. Teachers' reconceptualizations of their practice were anchored in their pedagogical responsibilities, and over time, they worked to set goals, enact their vision, and evaluate themselves against their commitments. Our focus on pedagogical responsibility and teacher agency offers a look into the institutional, ethical, and professional dilemmas or motivators teachers experienced as they taught through the pandemic.

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Reframing From Design Fields: Supporting Pre-Service Teachers in Designerly Thinking

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Abstract: Guided by contemporary theory and research from design fields, we propose a framework for conceptualizing K-12 educators' stances towards design that focuses on problem framing, information gathering, divergent thinking, and iteration. We use this framework to analyze data drawn from 28 pre-service teachers' conceptualization of design within the context of a design course taken by over 400 pre-service teachers. Our analysis demonstrated that most participants made only moderate progress in refining their thinking about design.

Theoretical framework

Insights from design fields suggest that a designerly stance towards design for K-12 educators focused on supporting second order changes would emphasize four key themes as follows: (a) view of the problem space (e.g., Buchanan, 1992; Norman, 2013; Schön, 1984), (b) approach to stakeholders and inquiry (e.g., Bang & Vossoughi, 2016; Christensen et al., 2016; Krippendorff, 2004), (c) framing and frame creation (e.g., Buchanan, 1992; Dorst, 2011), and (d) conceptualization of the design process (e.g., Norman, 2013; Owen, 2006). These elements overlap and interrelate with one another and share, in many instances, common themes. We developed a detailed rubric based on these four areas that we used to guide this study and data analysis leveraging the structure and ideas that Crismond and Adams (2012) used to in their framework for engineering education. As with Crismond and Adams, we developed pairs of contrasting statements for analyzing pre-service teachers' approaches to design on a scale from beginning to designer to "informed designer" whose "level of competence lies somewhere between that of the novice and expert designer" from the perspective of the design fields (Crismond & Adams, 2012, p. 743). Space precludes including the full rubric here, but we will share the full version at the conference.

Research questions

1. When viewed through the theoretical framing outlined above, how do pre-service teachers' understandings of design evolve in a course that includes an emphasis on design-based thinking from the perspective of the design fields as well as perspectives on design from the field of education?
2. Which aspects of design as defined in the theoretical framing come most naturally to pre-service teachers and which aspects require more support, revisions, or emphasis?

Methods, data sources, and coding schema

We employed case study research (Stake, 2005; Yin, 2014) to consider how, and the extent to which, pre-service teachers engaged in designerly stance towards design within the context of a mandatory five-week course taken by 400 students at a university in western Canada focused on a range of design processes in the field of education including perspectives from design fields (Design Council, 2007; Norman, 2013) as well as design perspectives in education including design thinking (IDEO, 2012). The bracketing of the boundaries for this case involved limiting the focus of the research to data gained from this course. In total, the team analyzed the work of 28 pre-service teachers across the 18 sections of the course who consented to allow their work to be used as data in this study. Data in this regard were drawn from three course pre and post reflections and design projects.

Findings

In the sections that follow, we analyze the data set in relation to our conceptualization of the four proposed themes for a designerly stance to design. Each theme is presented as a continuum from beginning designer through transitional to informed designer (Table 1).

Problem Solving vs. Problem Framing. Findings from this study indicated that conceptualizing the problem space was the most challenging area for participants. Pre-service teachers demonstrated almost no progress from Pre to Post in terms of Problem Solving vs. Problem Framing. Our analysis of the data suggested that most of the pre-service teachers in this study entered and left the course with a largely beginner's view of the problem space, particularly in relation to complexity. The majority of participants continued to view problems as uncomplicated and stable with the goals to be achieved largely fixed and predetermined (Schön, 1984).

Skipping vs. Doing research. One notable area where the participants demonstrated growth from Pre to Post occurred in the area of inquiry and research as shown in the table and figure. In particular, we noticed an uptick in attempts to gain empathy for stakeholders, particularly students. This shift can be most likely attributed to the emphasis that the course placed on design thinking perspectives highlighting the importance of empathizing with the needs of the 'user.' This view additionally aligns with prominent contemporary educational discourses emphasizing the importance of student-centered pedagogies. Thus, there was close alignment between the pre-service teachers' prior understandings and this aspect of design as inquiry.

Idea Scarcity vs. Idea Fluency. Our analysis of the data set suggested the pre-service teachers started at a more transitional stance towards divergent thinking and idea fluency but made little progress beyond that during the course. They overwhelmingly associated design with the creation of more active and engaging learning environments (in alignment with predominant student-centered discourses in their program) involving a shift away from traditional approaches to education rooted in teacher-centric pedagogies, passive learning, and content coverage. These student-centered discourses are heavily emphasized in teacher education programs, and it is therefore not surprising that the pre-service teachers had conceptual access to them. Participants demonstrated minimal progress during the course, however, in considering genuinely new and original frames that went beyond the typical student-centered frames of progressive education.

Haphazard or Linear vs. Managed and Iterative Designing. An area where participants demonstrated substantial growth occurred in relation to process. Pre-service teachers initially displayed a range of beginning designer and early transitional perspectives that shifted towards primarily transitional stances by the end of the course. In particular, participants became much more attuned to the iterative nature of design.

Scholarly significance

The proposed framework for analyzing educators' stance toward design, in line with theory from the design fields, focuses particularly on problem finding, as opposed to solely considering design in terms of a problem-solving mindset as has been the focus traditionally in education. Many approaches to design in education, including typical backward design frameworks, are generally taken up with a narrow focus on the disciplinary content standards and goals dictated by ministries of education. The ongoing presence of this tradition in teacher education programs may partially explain why education as practiced in K-12 classrooms has changed so little in North America over the last century (Payne, 2008; Tyack & Cuban, 1997). Findings from this study highlight the importance of approaching the design process more in line with design fields that focus on problem finding if we wish to better support future teachers in fostering the kinds of second-order changes that could transform schools.

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Supporting College Freshmen's Knowledge of Fractions With Serious Video Games

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Abstract: This study explores the use of two interactive serious video games, Slice Fractions and Slice Fractions 2, in supporting college educational opportunities program freshmen to develop knowledge and understanding of fractions. With a quasi-experimental design, we collected data from 14 participants, each finishing a pre-game interview, gameplay, and a post-game interview. Preliminary data analyses revealed that the participants scored significantly higher on the post-game assessment intended to measure fractional schemes/operations.

Introduction

Well-designed serious video games (SVGs) have great potential in mathematics education. Yet it is unclear how video games contribute to better learning. From the perspective of situated epistemic cognition (Hammer & Elby, 2002; Hammer et al., 2005), knowledge is emergent and comes from activations of fine-grained resources; stable activations of locally coherent sets of epistemic resources form frames, which are context-specific structures guiding one's interpretations and actions; to learn is to differentiate varying situations and flexibly draw on appropriate resources. The concept of frame is very similar to scheme, which comprises a perceived situation, associated activity, and expected result (von Glasersfeld, 1995). Because of the compatibility, while taking a broad situated epistemic cognition perspective, we draw on existing constructs and findings from the scheme theory to investigate the learning of fractions in gameplay.

Slice Fractions (SF1) and Slice Fractions 2 (SF2) are two SVGs that organically integrate mathematical content and game mechanics, offering a visual and action-based experience of fractions along with rich opportunities for inquiry, exploration, and strategic thinking. Previous empirical studies found SF1 to be helpful for Grade 3 students' learning of fractions, to the same extent as or superior to traditional instructions delivered by teachers or worksheet apps (Cyr et al., 2019; Gresalfi et al. 2017). Yet we still lack understanding of how the gameplay has contributed to students' knowledge and practices. Also, these games are not yet investigated with learners at other ages/levels. This study investigated the use of SF1 and SF2 as remedial tools in supporting undergraduate students who are economically and educationally disadvantaged compared to their other first-year peers, and enrolled in an educational opportunity program (EOP) geared to support them in both finances and learning. For this poster, we ask: How do SF1 and SF2 influence EOP students' fractional schemes/operations?

Methods

This study employed a quasi-experimental design. Each participant finished a pre-game session, gameplay, and a post-game session. Each pre- or post-game session included an assessment and a semi-structured interview focusing on one's knowledge of fractions and views of mathematics. Adapted from Norton, Wilkin and colleagues' (2009, 2018) studies, each assessment contained 24 items eliciting six fractional schemes/operations (4 items on each): the part-whole scheme (PWS), the partitive unit fraction scheme (PUFS), the partitive fraction scheme (PFS), the splitting operation (SO), the iterative fraction scheme (IFS) and the reversible partitive fraction scheme (RPFS). Depending on one's pre-game performance, a participant played the easier Slice Fractions (SF1) and/or the more challenging Slice Fractions 2 (SF2) for a total of 1-1.5 hours during the gameplay session.

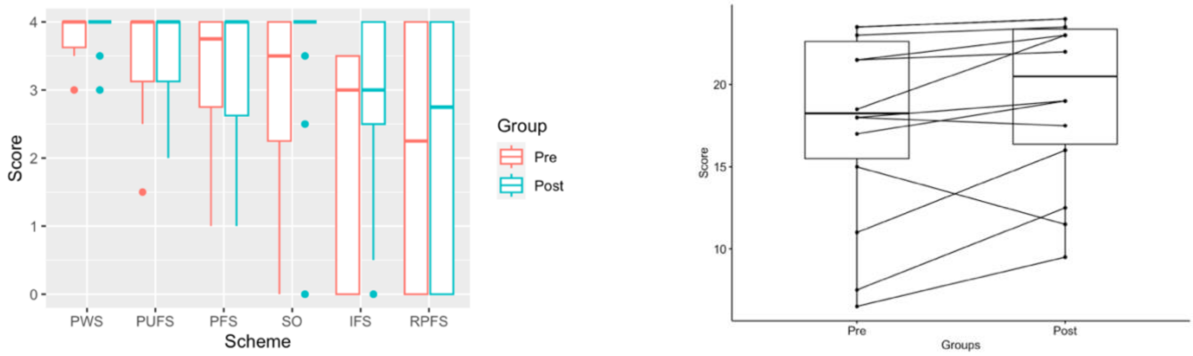
Participants were 14 EOP freshmen from a large public university in the U.S., with an average age of 18 years old. Seven were females, six were males and one was non-binary. Also, seven were African Americans, three were Asians (including South Asians), and four were Hispanic/Latinx (two participants had multiple races/ethnicities). All participants had fractions reviewed in a 5-week pre-college summer program and were taking intensive pre-calculus or calculus. Seven participants played SF1 and seven played SF2. To analyze the pre-and post-game assessments, first, we evaluated each item and assigned 0 (incorrect), .5 (correct with assistance), or 1 (correct without assistance). Then, we calculated the sums, so a participant received a score between 0 and 4 on each scheme/operation and a total score on each assessment.

Preliminary results and next step

Figure 1a displays the participants' pre- and post-game assessment performances on each fractional scheme/operation. The boxplots suggest that the participants as a group primarily made progress on items intended to measure the splitting operation (SO; $M_{pre} = 2.96$, $SD = 1.43$; $M_{post} = 3.57$, $SD = 1.11$), and the iterative fraction scheme (IFS; $M_{pre} = 2.11$, $SD = 1.66$; $M_{post} = 2.79$, $SD = 1.37$). Looking at the participants' overall performance, at pre-game assessment, they had an average score of 17.71 ($SD = 5.82$); at post-game assessment, the average score was 19.18 ($SD = 5.08$). Figure 1b shows the paired plot of the participants' assessment performances, which suggests that playing Slice Fractions (SF1) or Slice Fractions 2 (SF2) helped make an improvement on fractional schemes/operations. To better understand the impact of the gameplay on fractional schemes/operations, we evaluated the assumptions and conducted a paired t-test. Even though our sample size was small (< 30), following a Shapiro-Wilk test, we failed to reject the null hypothesis that the paired differences followed a normal distribution ($w = .91$, $p > .05$). Therefore, we could assume the normality of the data and proceed with a paired t-test. There was a significant difference between the participants' pre- and post-game performances on fractional schemes/operations[$t(13) = 2.36$, $p < .05$] with a moderate effect size (*Cohen's d* = .63).

Figure 1

(a) Boxplots of the Participants' Scores by Scheme/Operation; (b) Paired Plots of the Participants' Total Scores



(a) (b)

Although this is only the first step in a mixed methods analysis, we are nonetheless able to partially answer our research question: How do SF1 and SF2 influence EOP students' fractional schemes/operations? Our analysis here shows that the games helped the students improve their fractional schemes and operations, particularly the splitting operation and the iterative fraction scheme. Next, we will qualitatively examine the gameplay data and the interview data, comparing the participants' explicit knowledge of fractions and views of mathematics learning pre- and post-gameplay, as well as exploring themes in the participants' gameplay experience. Lastly, we will explore the similarities and the differences in knowledge of fractions exhibited in different contexts, from the perspective of situated epistemic cognition, thus triangulating the assessments, the interviews, and the gameplay.

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Knowledge Facilitating Epistemic Game Moves

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Abstract: This paper introduces a new category of knowledge, which integrates ideas from two existing frameworks: *epistemic forms and games* and *knowledge in pieces*. This category features knowledge elements that facilitate the enactment of moves made in epistemic games. Resources for *epistemic game moves* work synergistically with epistemological and conceptual resources during the enactment of epistemic games. The paper introduces the two foundational theoretical frameworks and then introduces the new category of knowledge.

Introduction

The importance of prior knowledge in learning is widely accepted. Constructivist perspectives view students' pre-instructional knowledge as abundant with resources for the construction of more formal knowledge. Research has documented resources for building knowledge of different kinds across a range of domains. This includes resources for developing both *conceptual* and *epistemological knowledge* (Goodhew et al., 2019; Hammer & Elby, 2002). Yet other research has documented resources for productive engagement in *scientific practices*, including argumentation (Hudicourt-Barnes, 2003), inventing and critiquing representations (diSessa et al., 1991), and conducting scientific inquiry (Warren et al., 2001). While this body of work describes a rich terrain of moves students enact during their productive engagement in scientific knowledge-construction practices, it does not model the knowledge underlying these moves. This paper offers a first-iteration description of knowledge underlying and facilitating such moves.

Theoretical foundations

Collins and Ferguson (1993) characterized the knowledge-building work of scientists as epistemic games. Just as the game of tic-tac-toe is constrained by the cross-hatch structure, epistemic games are constrained by corresponding epistemic forms. The forms are templates, which drive the moves scientists use to fill them out. Collins and Ferguson unpack the example of a list game. The list game is played to fill out the list form, which the scientist uses to answer the question: "What is the nature of X?" Playing the list game consists of moves such as adding elements to the list, removing elements, merging elements that are similar, and decomposing elements into more primitive elements. For example, a scientist trying to answer the question: "What is the nature of the Spotted Owl?" might generate a list of known characteristics including the owl's size, shape, color pattern, diet, and behavior.

Knowledge in pieces (KiP) is a theory of knowledge and learning that views knowledge as a complex system of smaller elements, which are drawn together in networks in response to the sense-making demands of a given context (diSessa, 1993). Novice knowledge systems are highly context dependent, meaning knowledge elements are activated inconsistently across contexts for which experts would draw on the same knowledge. The transition from novice to expert (i.e., learning) is characterized as a process of reorganization and refinement of the knowledge system. For this reason, KiP views elements of novice knowledge as *resources* for the construction of more expert knowledge. A goal underlying KiP research is the construction of theoretical machinery for producing computationally explicit models of human knowledge and learning. Towards this, a number of knowledge categories have been defined and populated with elements. This includes categories of conceptual knowledge (e.g., phenomenological primitives; diSessa, 1993) and epistemological knowledge (e.g., epistemological resources; Hammer & Elby, 2002).

A new category of knowledge

This paper introduces a new category of knowledge, which facilitates the enactment of moves made in epistemic games. For simplicity, I call the elements of knowledge in this category *epistemic game moves*. I hypothesize that these knowledge elements can be more precisely described as primitive elements. A number of these elements facilitate reasoning-specific moves and may therefore be described as reasoning primitives.

Epistemic game moves work synergistically with epistemological and conceptual resources to facilitate the play of epistemic games. Imagine the scientist trying to answer the question: "What is the nature of the Spotted Owl?" The scientist must draw on epistemological resources to know that the question can be answered by producing a list, and to know the nature of the list form and the rules for filling it out. The scientist must draw on conceptual resources to know the characteristics of the Spotted Owl. The scientist must draw on knowledge of epistemic game moves to fill out the list form by adding and removing characteristics of the owl, and possibly merging and splitting characteristics. Knowledge facilitating the addition and removal of characteristics involves discerning characteristics that belong to the owl's nature from irrelevant characteristics (e.g., number of owl sightings in a given year). Knowledge facilitating the merging or splitting of characteristics involves recognition of similarity.

There are many epistemic games, including temporal and spatial decomposition games, hierarchical list games, compare and contrast games, cross-product games, agent-based modeling, and analogical modeling. Each of these games can be described in terms of moves played to fill out a corresponding form or template. These moves are facilitated by knowledge belonging to the category introduced in this paper. In the case of temporal and spatial decomposition games, the moves involve knowledge that facilitates dividing a larger entity into smaller components. In the case of hierarchical list games, the moves involve knowledge that facilitates organizing elements according to nested relationships. In the case of the compare and contrast game, the moves involve knowledge that facilitates the identification of meaningful similarities and differences. In the case of the cross-product game, the moves involve knowledge that facilitates the organization of elements along multiple dimensions. In the case of agent-based modeling, the moves involve knowledge that facilitates the identification of system elements and the articulation of the rules governing their behavior and interactions. In the case of analogical modeling, the moves involve knowledge that facilitates mapping between elements common to both the phenomenon of interest and an analog. Considering the knowledge underlying the enactment of moves across epistemic games suggests a general relationship to knowledge involved in processes of analysis and synthesis.

Discussion

This work introduced a new category of knowledge, which facilitates the enactment of moves made in epistemic games. By studying the *epistemic game moves* of novices, we can design classroom experiences that build on students' resources to foster their development of expertise with epistemic games. While students' productive engagement in particular epistemic games has been described in the literature, the present work adds to the discussion by characterizing the knowledge underlying the moves involved in these games. The work is only in its infancy and while the theoretical constructs are inspired by classroom data, more systematic investigation is necessary.

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Climate Change Encounters Online: Epistemic Engagement and Emotions on Social Media

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Abstract: This exploratory study sought to understand how adults evaluated a simulated social media post on climate change, relating to meat consumption, by considering the epistemic actions on the post, and participants' subsequent epistemic engagement when prompted to explain their emotions. It extends work on epistemic cognition in information-complex environments and investigates the extent to which prompting reflection on emotions can serve as a means of supporting misinformation resistance. Some preliminary findings are presented and discussed.

Introduction and background

In their day-to-day routines, people turn to the internet to find answers about scientific issues that concern them. Despite the potential that social media platforms hold for raising awareness and increasing engagement with controversial issues such as climate change, information on social media may be misinformative, and purposely designed to elicit an emotional reaction (Zhou et al., 2021). When evaluating controversial information, when the information is novel or contrary to expectation, people can experience epistemic emotions, such as curiosity or surprise, that encourage closer attention to the epistemic qualities of the information, and more specifically to the source and evidence provided (Chevrier et al., 2019). Furthermore, the inherent interactivity of online information means that there is a range of available actions that can enable epistemic engagement with information in order to ascertain the source and the evidence provided. Online, epistemic engagement might manifest via *epistemic actions*, such as clicking on links to evaluate the claims in a post, clicking on the user profile, or even using search engines to retrieve additional information. Such actions can be regarded as epistemic since they are motivated by the need to evaluate the knowledge base for the information claims encountered.

Research examining how emotions influence actions taken during information evaluation has focused on sharing intentions (Bago et al., 2022), which may exacerbate the spread of online misinformation. However, in order to support individuals' resistance to misinformation, we also need to understand what motivates epistemic actions taken online when experiencing emotions. Barzilai and Chinn (2018) state that epistemic engagement varies across a range of situations, including in epistemically unfriendly environments such as social media. The authors theorize that emotions and self-regulation are aspects that should be taken into consideration when designing learning environments that aim to foster epistemic engagement. Emotion regulation is an aspect of self-regulation (Boekaerts & Cascallar, 2006); prompting reflection on emotions can heighten awareness about the emotions experienced and implicitly regulate intense emotional reactions (Torre & Lieberman, 2018). It is unclear how such prompts to reflect on one's emotions while evaluating controversial information bear on epistemic engagement.

In this exploratory study we examined how emotions and epistemic engagement manifest via online actions on a social media post focused on climate change, and the extent to which prompting reflection on emotions can enhance epistemic engagement with information. We therefore asked, during information evaluation of a controversial topic: (1) What epistemic actions are spontaneously taken and why? (2) To what extent does prompting reflection on emotions support epistemic engagement?

Methods

Thirteen undergraduate students participated in the study. Participants were presented with a simulated Twitter post focused on the impact of meat consumption on climate change. The post named a scientist and their academic institution, named a high-impact scientific journal, used argumentation to support the information claim, and included a URL. It also included an image which prominently featured the percentage of all anthropogenic emissions linked to livestock production. The username was blurred out. Participants could click to take any of the actions available on a typical Twitter post. Indicatively, these actions included, but were not limited to: liking, sharing, commenting on, clicking the user profile, bookmarking, or reporting the post, etc. Participants were informed that they could use the internet as they normally would. A manipulation check with 25 participants indicated that the social media used could elicit emotions.

Data were collected using a cognitive semi-structured interview and via screen recording during the evaluation task. Participants were first asked questions about their routine social media habits, were then presented with the social media post and asked to verbalize their thoughts and to take any actions they would normally take. Participants were then asked to explain their actions and were then prompted to reflect on their emotions using a set of emoji cutouts; they were asked to select the emoji(s) that most closely represented the emotions they had experienced, and to put them in order of intensity. This process was repeated with additional posts that used different rhetorical appeals. The average duration of each session was 27 minutes. We coded the data for actions based on the participants' trace data and the emotion(s) explicitly verbalized. Epistemic engagement was examined on the basis of the reasons provided for (a) the action and (b) the emotions experienced, and was coded using the AIR model (Chinn et al. 2014) to capture verbalized epistemic aims, criteria and processes. To answer our research questions, we examined co-occurrences of spontaneous actions and epistemic engagement (RQ1) and verbalized emotions — via prompted reflection —and epistemic engagement (RQ2).

Preliminary findings and discussion

In our first research question we sought to understand what actions were taken on the post and why. Preliminary analyses indicate that participants took a range of epistemic actions on the post including clicking on the URL, searching for additional information on the named scientist and checking the user profile; these actions were motivated by the need to evaluate the source and evidence for the information provided. Additionally, participants also deferred to the opinions of valued others, by stating that they would share information with a more knowledgeable peer, or by clicking on the comments to evaluate how others are responding to the information.

In our second research question, we asked whether our intervention supported epistemic engagement. The actions participants took prior to the intervention were spontaneous and immediate, and the explanations suggest they were motivated by epistemic aims. During the prompt participants paid closer attention to the language used, or the data on the image, while reporting curiosity or surprise. Beyond these emotions, participants also reported feeling sad or worried, and in such instances, they focused on how the information implicated them in contributing to climate change. The latter emotions seemed to turn attention to the topic, rather than the epistemic qualities of the information, but were often experienced alongside epistemic emotions, such as curiosity.

Analyses are ongoing, but preliminary findings suggest that when faced with the controversial topic of reducing meat consumption participants took epistemic actions to evaluate the knowledge claims appearing in the post, particularly by clicking the link. During prompted reflection on emotions participants paid closer attention on the language used in the post and the evidence provided (i.e., the data on the image). Examining how epistemic engagement manifests on social media when emotionally responding to information, can provide insights on how to support epistemic practices that bolster misinformation resilience on social media. Which epistemic actions on social media are driven by epistemic aims, criteria and processes and which emotions can enhance such engagement? Additionally, although the study takes place in a simulated social media environment, which divorces it from the socially inherent nature of the authentic setting, it provides some initial indications as to how emotions can support or constrain epistemic actions. Findings may inform instructional design aimed at bolstering misinformation resilience; moving beyond the cognitive aspects of evaluation and integrating the emotional and behavioral dimensions of evaluating information online may heighten emotional awareness and enacted epistemic engagement during online information evaluation.

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Following the Becomings: Intra-Actions in Collaborative Creative Making

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Abstract: With this study, we attempt to follow the becomings in collaborative making to understand the intra-actions among the various entities of the situated making context contributing to emergent creativity, by specifically looking at a making context where novice makers collaboratively work on design problem solving**.** Our findings suggest that the collaborative making is sociomaterially entangled, *making together with* human and non-human entities is highly relational and dynamic resulting in emergent creative acts.

Introduction

The new materialist and posthuman frameworks open alternative possibilities to look at learning and creativity with agency conceptualized as emergent manifestations and *becomings* through intra-actions among the entities within the phenomenon, decentering humans from the sole center of actions (Barad, 2003, Pickering, 1993). The notion of matter as being in a constant state of reconfigurations can challenge human-centric approaches in learning and points to rethink learners-non-human encounters (Barad, 2003; Haraway, 1985). The emergent outcomes from the encounters of humans and non-humans thus become unpredictable and cannot be reduced to human actions. Here, we extend the notion of agential cut and intra-activity (Barad, 2003) to *making together with*, to see the intra-actions among the various actors in making contexts that can result in emergent meanings, creativity, and learning. We place *making together with*, as a lens to acknowledge, understand and appreciate the relational and dynamic connections among the human and non-human entities entangled in any making contexts. *Making together with* upholds the idea of flattened ontology which avoids privilege to human entities and considers all material entities as possible actants (Latour, 1996). In this article, we attempt to follow the becomings in collaborative making context to understand the intra-actions among the various entities of the situated making context contributing to emergent creativity (Sawyer & Dezutter, 2009), where novice makers engage in design problem solving.

Methods

Data for this study was collected as part of a Lego Mindstorms-maker workshop where seventh-grade students from an English-Medium school in the city of Mumbai, India engaged in an engineering design problem. Two teams- A and B- were formed randomly and they worked on designing a cleaning robot, where the robot is required to clean at least two of the following trash materials- paper bits, water droplets, eraser dust, and pencil dust. Along with the Lego Mindstorms kit and the supplementary materials (cleaning mop wipes, cardboard, and sponge), each team was also provided with a cost-calculation sheet and a workbook. A facilitator was allocated to each team to take observation notes and provide technical and logistic support. For our analysis, we followed the making activities of Team A, which consisted of two female participants (A1 and A2) and a male participant (A3). We conducted the analysis with data sources as video, photographs, design artifacts and field notes. We followed theories of new materialism and adopted the methodological process of thinking with theory (Jackson & Mazzei, 2012). We plugged the theoretical concept of intra-activity into the data sets in order to gain a deeper understanding of the entanglements in the making process. Instead of coding or categorizing, we looked for ‘‘hot spots,’’ where the data ‘‘glow’’ and ‘‘create a sense of wonder’’ (MacLure, 2013), and the identified hotspots were illuminated through the lens of posthumanism and new materialism.

Findings

We found that the making actions were "messy" and "meshed" with human and non-human elements of the situated making contexts. An instance of *making together with-lego components-makers-facilitator* influencing the flow of creative actions, in making a four-wheeled robot with a cleaning unit attachment is illustrated as below:

A1:	[places the lego EV3 brick over the drive unit].. the brick is falling out.
Facilitator:	Why don’t you use these [points to the slots on lego EV3 brick sides]
A2:	[Checks the lego EV3 brick slots]
A3:	Hey.. plug these [points to lego beams] into the brick holes and then to the drives

Figure 1

Facilitator placing the lego parts in front of the makers (a), Team A visiting Team B's workplace (b), Makers attaching the mop wipe with the sponge using stapler (c), Teams racing with the robots (d)


(a) (b) (c) (d)

Here the makers tried to fix the lego brick onto the vehicle chassis. As the facilitator placed the box of lego frames, beams, and connectors near the makers (see Figure 1(a)), makers and materials engaged in repetitive cycles of adding, connecting, falling, resisting and removing the lego beam and frames to the brick until a stable structure was arrived at. In this instance of becoming of the cleaning robot structure, we see that makers, facilitator, lego kit listening to and responding to each other actions. Also, we see that the *time* intra-acting with the makers, materials, and facilitators as the facilitator gave a sense of the time to complete the making by counting seconds. The leaking time has pushed the team to look for quick and cheap alternatives as the cleaning mop wipe was attached to the sponge combination using a stapler (see Figure 1(c)). Time was always an actor in the entire making process, but this particular instance showed how time shaped the *becoming* of the creative outcome.

Facilitator:	Time is up.. I will count to 10 now
A3:	No,, no.. we need only few seconds.. [looks for bands]
A1:	[Finds stapler] No.. with this [hands over stapler]
A2:	[Attaches sponge with the cleaning mop wipe using stapler]

The designed robot was able to clear out majority of the trash materials from the *test floor*, which made team B to perform the robot task with the same trash materials. As soon as the task was completed, A2 of team A proposed the idea to race with the robots, and both teams engaged in racing with the cleaning robots without changing any design. Thus, *the cleaning robots became racing robots* and *the testing floor became the racing arena* (see Figure 1(d)). This unexpected and unscripted play was short-lived as the facilitators interrupted the racing in between and instructed teams to get back to the work tables.

Discussion and conclusion

In this study, we included human and non-human agencies to understand the *making together with* various entities of the situated making context, leading to emergent creative acts. Makers and materials engaged in repetitive cycles of resistance and accommodation while materializing ideas as in the case of mounting lego EV3 brick (Pickering, 1993). The relational dynamics of the entities involved in the making were evident in situations where the *floor* turned to *test floor* and then into *racing arena*. The making *grew* across space and materials as the makers entangled with sketches, Lego kit, supplementary materials, and visited team B in another room (see Figure 1(b)), to review making. The *actant* time revealed itself towards the end of the making activity. We think about the spontaneous learning which could have emerged via unexpected modes of play, if the *racing* was not stopped.

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Pedagogical Practices Associated With Sophisticated Pedagogical Scenarios Using VR Simulations in Science Courses

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Abstract: In the context of the documented decline of student interest in science, ascribed to a high level of concept abstraction, the sheer quantity of science concepts and teacher-centred teaching approaches, we tested the potential of desktop VR (DVR) simulations to engage students. The literature shows that the activities and support built around the simulations themselves are of utmost importance. In this design-based research involving 39 faculty and 5,780 students, the research team and the pedagogical team accompanied teachers in their development of pedagogical scenarios, with tools derived from the NRF/Jeffries (2022) model in nursing simulations. Scenarios were documented through individual teacher interviews. A multilevel regression analysis to predict the students' behavioural engagement showed that the scenario score, associated with high-quality scenarios, is the single and most important level-2 variable associated with the teachers. Pedagogical practices associated with high-scores scenarios were analysed and compared to those associated with low-scores for the prebriefing, briefing, simulation and debriefing phases. Sophisticated scenarios are characterized by more activities in the briefing and debriefing phases, as well as by collaborative activities.

Introduction and theoretical framework

Despite the increasing importance of science and technology and STEM programs in our society and in higher education, we are observing a slow but continuous decline in student interest in science and technology, starting in high school (Potvin & Hasni, 2014). The high level of abstraction of science concepts, the very wide scope of science content (in biology, for example) and teacher-centred approaches have been identified as possible explanatory factors. Active learning and student-centred teaching strategies have been identified as a promising solution (Freeman et al., 2014). VR simulations allow for errors and offer access to rare or inaccessible realities or specialized equipment, while improving the learning and understanding of both theoretical concepts and laboratory techniques and arousing interest (Martinez-Jimenez et al., 2003). In the domain of desktop virtual reality (DVR) simulations, the instructions, activities carried out before and after the simulations seem to be more important than the simulations themselves, particularly when coupled with gaming elements (Merchant et al., 2014). This led us aim at exploring the pedagogical and didactic potential of scenarios that involve virtual reality simulations for postsecondary science learning. In another portion of the project (Wall-Lacelle et al., to be submitted), a multilevel regression with the students' behavioural engagement as dependent variable led to the identification of the scenario's quality score as an important variable associated with the teachers level. This led us to identify practices associated with high-score scenarios, which is the focus of this article. The concept of a pedagogical scenario is present in instructional design literature, but it is also present in health sciences literature, where pedagogical scenarios are constructed to precisely describe the sequence of activities carried out by students before, during and after a simulation. We relied on an adaptation of Jeffries (2020) framework used for nursing simulations, that describes activities that can take place at different moments; pre-briefing and briefing (before the simulation) and debriefing (after the simulation). Because of its simplicity, we relied on Chamberland et al. (1998) typology to classify teaching methods and activities along three axes; 1) teacher-centred vs. student-centred; 2) mediatized or non-mediatized; 3) the group organization: individual, team or class, and coded them along their modality (face to face, remotely synchronous, remotely asynchronous). From the students' perspective, the research is grounded in Pintrich's (2003) expectation/value motivation model and Fredricks's (2004) view of engagement (questionnaire).

Methodology

This design-based research project (Brown, 1992) involved the participation of 39 teachers (8 university teachers and 31 college teachers) and 5,780 students from one university and six colleges in three distinct iterations corresponding to the following semesters: winter 2021, fall 2021 and winter 2022. Courses and labs in the winter 2021 semester in Quebec were taught almost totally remotely. A mixed methodology relying on both individual questionnaires and individual interviews (teachers) was deployed. The participants were volunteer science teachers and their students. The teachers used Labster simulations that are contextualized in real-world problems and are somewhat gamified in some kind of mission. The team of researchers and educational developers assisted them through collaborative scenario design activities in each discipline (biology, chemistry, physics). After living one of these pedagogical scenarios, the students had to answer a motivation and engagement questionnaire. The pedagogical scenarios were analysed and rated based on 11 criteria derived from the NLN/Jeffries model (2020). Each pedagogical practice in the scenario was then classified and we classified scenarios in 3 categories.

Results

The pedagogical practices associated with the high-score scenarios were compared to those associated with low-score scenarios for each phase: prebriefing, briefing, simulation, debriefing. Regarding the prebriefing phase, the high-score scenarios rely more on student-centred activities (blue), as well as on non-mediatized activities (red). These prebriefing activities are also more often carried out in person (grey), while the low-score scenarios did them remotely, either asynchronously or synchronously. Overall, the high-score scenarios have far more briefing activities than the low-score scenarios, relying heavily on teacher-centred activities with the class. Teachers give logistical instructions, present the whole scenario and/or the learning objectives and the simulation itself and point out the most important aspects or key elements. During the simulation phase, the high-score scenarios also rely on teacher-centred activities aimed at providing student support (for ex., circulating around the class to answer the students' questions). While the low-score scenarios rely mainly on individual activities, the high-score scenarios rely mainly on collaborative activities, as well as on non-mediatized activities, in face-to-face settings. For example, many teachers had the students work in teams, with a roadmap containing questions to be answered, or had them work in teams using a whiteboard. Overall, the high-score scenarios have far more debriefing activities than the low-score scenarios, relying on student-centred activities, often along with teacher-centred activities with the whole class. They also rely on non-mediatized activities and in-person activities.

Discussion and conclusion

The results show that high-score scenarios differ from low-score scenarios in multiple ways. The former are richer and more complete, which is not surprising, and rely on far more activities in the briefing and debriefing phases. Furthermore, in the simulation phase, they rely on teamwork and analogue documents to be completed during the simulation by team members. The activities during the simulation in the low-score group tended to be individual and asynchronous, which likely means they were assigned to students as out-of-class assignments with little or no guidance or support. The activities in the high-score group tended to be face-to-face, in class, for all phases. This context offers teachers a better chance to give more complete instructions, to monitor the students' progress, to lead debriefing discussions or teamwork and/or to wrap up with a review of the most important things to remember. The evolution of the context from remote to face to face may also reflect some ot the evolutions of the scenarios with courses gradually moving from remote in winter 2021 to face to face in winter 2022.

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The Role of Whole-Class Conversations in Supporting Early Elementary Students' Engineering Design Sense-Making

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Abstract: We consider how intentionally planned and facilitated whole-class conversations can "make space" for students' sense-making about engineering problems and solutions and position them with epistemic authority to contribute to collective thinking. We conducted a case study on a first-grade engineering lesson that included whole-class Idea Generation and Design Synthesis Talks. We found students sense-making as they refined their design proposals and analyses in light of classmates' contributions to the whole-class conversations.

Introduction

For elementary students, the task of constructing an artifact for an engineering design challenge offers an opportunity to construct knowledge. As they design solutions to problems, students can build knowledge about how designed systems work, how they interact with the natural world, and how they influence people and society. However, for engineering design experiences to be sites of knowledge building, students need support to engage in *sense-making*, both individually and collectively. Sense-making involves developing understandings of the world through generating, using, and refining one's ideas in interaction with other people, representations, tools, and objects (Schwarz et al., 2020). In this paper we consider how Design Talks—intentionally planned and facilitated whole-class conversations that can be incorporated in engineering design lessons—can "make space" for students' sense-making about engineering problems and solutions and position them with epistemic authority to contribute to the class's collective thinking (Engle & Conant, 2002; Haverly et al., 2020).

With a team of elementary teachers and engineering education researchers, we have been exploring five different kinds of Design Talks. Here we focus on a case where a teacher implemented two Design Talks within a lesson—Idea Generation and Design Synthesis Talks. We ask: *How did these Design Talks make space for early elementary students to participate in sense-making about engineering designs?*

Table 1
Design Talks are whole-class conversations that can connect students' engineering design work to NGSS practice standards (talks need not be implemented sequentially)

	Framing Question	Sample Teacher Prompts
Impact	Should we design this? Who and what will be impacted?	If we designed this solution, what might happen?
Problem-Scoping	What do we need to consider to solve this problem?	Whose perspectives should we consider in solving this problem?
Idea Generation	What are multiple possibilities for solving the problem?	What ideas do you have for solving the design problem?
Design-In-Progress	Why did a design perform as it did? What features should we change?	Why do you think this device performs in this way?
Design Synthesis	What are similarities and differences in our designs? What can we learn from these patterns?	What are different categories of solutions?

Data collection and analytical framework

This qualitative descriptive case study comes from a first-grade engineering design lesson on designing a tool to help Kindergarteners more easily use the monkey bars. The lesson took place at a suburban elementary school in the northeastern U.S. during a curriculum unit on plant and animal structure and function. Researchers video recorded all large-group talk among the class of 14 students and all small-group interactions of one focal group of students. We selected this lesson's two Design Talks for further study after we noticed that multiple students were offering contributions and that multiple ideas were at play in the space; we also were interested in these conversations given that they involved the youngest learners in our project.

In conducting this research, we were grounded in the perspective that learning engineering involves increasing participation in its disciplinary practices. To look for evidence of the practice of sense-making, we drew on the notion of epistemic authority (Carlone, Mercier, & Metzger; 2021; Engle & Conant, 2002). We explored when and how students exercised authority to make contributions to the class's collective thinking.

Findings

The lesson opened with an Idea Generation Talk that offered opportunities for students to brainstorm multiple solutions to the problem. The teacher, Ms. M, began the talk by displaying a photo collage of plants and animals that excel at vertical movement and inviting her students to brainstorm: "So we want to design something to help kindergarteners be able to use [the monkey bar] structure. These pictures of some plants and animals might give you some ideas of what we could design. What are you noticing?" In the resulting 10-minute large-group conversation, 12 of the 14 students voiced contributions and connections. Defying the stereotype that first graders fixate on their own ideas, these students worked with a wide range of design ideas, refining both their own and others' ideas as the conversation evolved. The first five students to propose ideas suggested gloves and shoes with special features for jumping, stretching, and sticking. Then, showing epistemic authority to evaluate and refine the community's ideas, a sixth student noticed that if the tool was "too sticky, they can't, what if they can't swing?" Ms. M valued this different way of contributing, pointing out a new problem nested within the solutions proposed so far, and invited more thoughts. Additional students weighed in with new designs that had features to decrease stickiness or detach once the Kindergartener was ready to swing to a new bar. For instance: "when you're about to swing, there's these little slots, that keep out a couple more of those things, so then you can swing a little better."

After students drew individual sketches of their design ideas, the teacher facilitated a Design Synthesis Talk. She asked each student to display their sketch and briefly describe their idea to the group. Then she asked the class how they might summarize the set of ideas into four or five "big ideas" to tell the Kindergarteners. Students pointed out that one group of ideas prioritized sticking to the monkey bars, another group focused on reaching farther, and another group focused on jumping. These categories reflected not just different design parameters but altogether different functions for playing on the monkey bars. Ms. M wrote these categories across the top of the white board, and each student considered the main function of their idea and posted their sketch under what they thought was the best heading. Some students saw that their design had characteristics of several categories, and they asked for advice from classmates. This realization of a difficult choice and request for help from other students showed that they saw their peers as having authority to contribute to the class's work. Thus, in this Talk, we observed that students were positioned with epistemic authority to identify common themes across their solutions and advise each other on how to classify different solutions.

Conclusion

In this case study we found first graders engaging in serious engineering design thinking during two Design Talks where they collaboratively generated and then compared ideas. Initiated by carefully framed open-ended prompts and sustained by Ms. M's responsive facilitation moves, the Design Talks were participation structures that enabled nearly all the students to author themselves as contributors to the class's knowledge about possible structures and functions that might solve the kindergarteners' monkey bar problem. These findings highlight the promise of Design Talks for making space for students' shared sense-making in engineering.

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Co-Designing for Environmental Engagement: Moving Inside People Outside and Moving Outside People Outdoors

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Abstract: We developed, with youth, a framework categorizing how people interact with nature. Our framework, *inside* versus *outside* versus *outdoors*, was developed using assets-based co-design principles with a small group of young men. Artifact analysis from co-design sessions found that our group readily applied this framework to community park infrastructure, community and individual behaviors observed within parks, and to support conversations involving participants' personal values and sociocultural contexts.

Language to frame how people approach nature

Educators focused on promoting caring environmental attitudes have often emphasized first connecting people with nature. Sobel (2004) talks about how people must have "an opportunity to bond with the natural world to learn to love it before being asked to heal its wounds" (p. 9). But what constitutes the natural world? Sweitzer, Davis, and Thompson (2013) located their place-based climate change educational efforts in National Parks, investigating how the love and care people have for these exemplary natural places might inspire climate change action. Certainly, national parks are part of the natural world, but many people don't have access to these kinds of exemplary natural spaces. Focusing only on this type of nature to foster connection may introduce inequity. Researchers have responded to this limited outlook by exploring how people connect to the nature found within places that are more urban and human constructed – which can also be deeply imbued with human emotion and meaning, and therefore hold power as contexts to support nature-connectedness (Lim & Barton, 2010).

This is not to say that the nature in human constructed places like playgrounds within urban parks is exactly like the nature in large, protected, undeveloped areas like national parks. However, these differences are not easily captured by current language. We might use terms like wild, uncultivated, undeveloped, untouched, or native to describe a national park, but these same terms could also be accurately used to describe the grassy median found between each direction of a large freeway. During work with youth, researchers and participants collectively adopted language that spoke to the different kinds of nature found in a freeway median versus a national park. Further, we found that by using a simple categorizing language of *inside*, *outside*, and *outdoors* we were able to talk more clearly about the different sociocultural values we and our families held in a neutral way, allowing for generative conversations about how different people connect, or do not connect, to nature.

Context, methods, and analysis

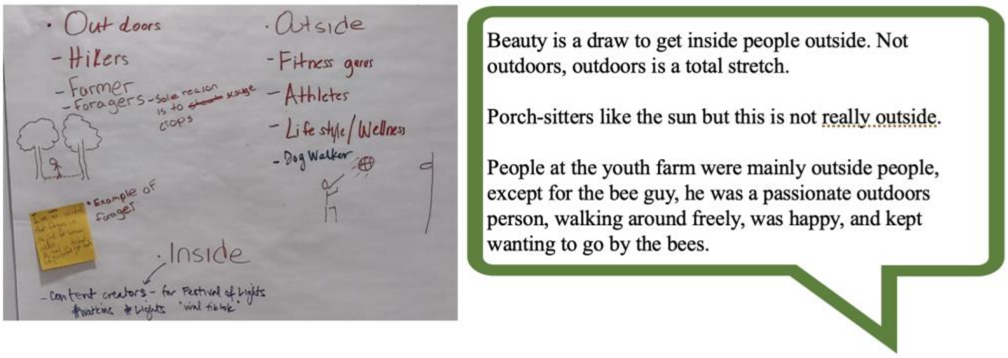
We worked with four youth, ages 16 to 19 and self-identifying as Black men, during a six-week, county-sponsored youth employment program. This program, located in a suburban area adjacent to a major metropolitan city, involved work and mentorship with municipal employees to support park sustainability and plant cultivation efforts. Twenty hours of each 40-hour week were led by the authors. Through assets-based co-design, which highlights naming and using participant's assets and capacities to build community capital (Wong-Villacres et al., 2021), we collectively explored how community members used different local parks and how Wi-Fi connectivity within those parks might support environmental education. As part of information gathering to support our program goal, in an early session we listened together to an interview, conducted by Jen White, of writer Baratunde Thurston (Harven & Remington, 2022). In that interview, Thurston and White discuss how the idea of "going outside" versus "going outdoors" differed for them as children. This struck our group very powerfully. We quickly adopted the categorizing language of *inside*, *outside*, and *outdoors*. In this poster we present our qualitative analysis, using structural and value coding (Saldaña, 2021) of 18 co-design artifacts that captured group reflection and brainstorming and journal entries written by the researchers at the conclusion of every session. We report how we collectively developed *inside*, *outside*, and *outdoors* as a framework to determine ways to promote opportunities to reflect on and situate the park users we observed, ourselves, and our families.

Findings: Three framework applications

Analysis indicated that our group used the framework of *inside*, *outside*, and *outdoors* in three primary ways. First, we used the language to frame a clearer understanding of community park infrastructure and community and individual behaviors observed within parks. In analyzing the design artifacts, we observed that our group readily recognized how park areas fit within the framework in straightforward ways. For example, built installations such as playgrounds and basketball courts were “outside areas,” while unpaved nature trails were “outdoors.” As seen in Figure 1, participants found the framework useful to categorize people and activities that we had observed within various parks. Athletes, “fitness gurus,” people interested in lifestyle and wellness, and dog walkers as outside people, while hikers, farmers, and wild food foragers were outdoors people.

Figure 1

Co-developed ideas of how people might be categorized in the inside/outside/outdoors framework. On the left are captured ideas within a group brainstorming session. On the right are examples of some of the ways youth participants enacted these categorizations within group discussions.



Beauty is a draw to get inside people outside. Not outdoors, outdoors is a total stretch.

Porch-sitters like the sun but this is not really outside.

People at the youth farm were mainly outside people, except for the bee guy, he was a passionate outdoors person, walking around freely, was happy, and kept wanting to go by the bees.

We also observed the framework supported conversations about values. Journal entries recorded conversations in which inside people were discussed positively as content creators that might be enticed to bring their inside activities outside. Discussions about the value of being outside versus inside (fitness, mental health, and more connection to food), what might constitute each context, and what people might fear about being outside, such as being around insects, was also supported (see Figure 1). When discussing the challenges of shifting outside people (which many youths self-identified with) to outdoors people, a discussion of safety issues tied to race was sparked.

Perhaps most powerfully, we found the inside/outside/outdoors framework supported conversations involving participants’ personal sociocultural contexts. Analysis of researcher journals indicated that our group was able to use the framework to place themselves and their family members in the park space, and therefore in nature. For example, a researcher recorded how our youngest participant discussed their father as an inside person that only was outside to bring him to the park when he was young. This was the first time this participant shared anything about his family. As researchers who identify as older, non-black woman (one of us is White and one of us is Asian American) we found this categorizing language, supported through an asset-focused design approach that allowed participants to challenge beliefs about themselves and appreciate their strengths, broadened conversations and opened space to talk about values across socio-cultural backgrounds.

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Guide, Safety Net, Project Tester, and More: Investigating the Roles of Facilitators in an AI Summer Camp

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Abstract: Summer camps have become popular for introducing K-12 learners to computer science (CS) and artificial intelligence (AI) in informal learning environments. Facilitators play crucial roles in guiding and engaging learners in these contexts, but there is limited research on their roles in informal AI learning. This paper examines facilitators' dialogues with campers in a middle school AI summer camp, identifying eight major facilitator roles. The roles differed depending on group dynamics and project phase. The paper provides empirical grounding to define facilitators' roles in AI learning and guide the design of professional development for camp facilitators.

Introduction

Informal learning settings, such as summer camps, are becoming more popular in AI education due to their less structured nature and lack of school-based performance evaluations (Callanan, Cervantes, & Loomis, 2011). Research has shown that summer camps improve students' learning, build confidence in AI and STEM fields, and encourage interest in pursuing future careers in STEM (Bhattacharyya, Mead, & Nathaniel., 2011; Yi, Gadbury, & Lane, 2021). AI summer camps often introduce innovative technologies such as machine learning and conversational AI and employ hands-on and project-based learning, aligning with the constructionists' view of learning. However, engaging young learners in hands-on activities and project-based learning is often challenging without proper guidance and facilitation (Roque & Jain, 2018).

Facilitators play a critical role in constructivism learning, particularly in informal learning settings, as they often determine the quality of the camp experience (Owens & Browne, 2021). However, there is currently no comprehensive framework for understanding facilitators' roles in AI education. Previous frameworks have focused on specific aspects of facilitation or specific contexts (Wang, 2008; Owens & Browne, 2021), making it challenging to apply them to AI learning. Therefore, this study aims to explore the interaction dynamics between facilitators and learners in an AI summer camp and provide a theoretical ground for defining and systemizing the roles of facilitators in informal AI learning. This research addressed the following research questions (RQs): **RQ1.** What are the roles of camp facilitators in informal AI learning settings? **RQ2.** How do the facilitators' roles vary by facilitators and the project phase?

Methods

A basic interpretive qualitative methodology (Merriam & Grenier, 2019) was used to label the interactions between the facilitators and campers and draw themes from them. Before the study, we obtained approval for this study from the University of Florida's Institutional Review Board.

In the summer of 2021, we conducted an in-person two-week-long AI day-camp to provide middle school learners with a learning opportunity to design and develop conversational AI in the southeast region of the United States. Fourteen campers participated, including two girls and 12 boys, 11 Black/African American, and 3 White/Caucasian students. We recruited seven camp facilitators, including five undergraduate, one graduate student, and one post-doctoral researcher, four women and three men, 2 Black/African American, 2 Asian, and 3 White/Caucasian.

The data was collected over the three days in the second week. On day 6, campers brainstormed the project ideas; on day 7, they engaged in the initial chatbot development, and on day 8, they did final touch-ups and connected the projects to Google Home speakers. Each camper pair was assigned to one facilitator and their interactions were recorded using OBS software on the study laptops. The recordings were later transcribed and anonymized by the research team.

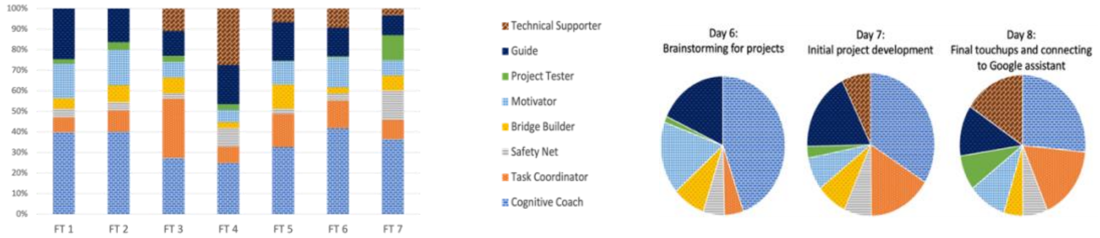
This study framed facilitation into four categories; cognitive, social-emotional, managerial, and technical and defined the interactions in each category (Graesser & Person, 1994; Owens & Browne, 2021; Wang, 2008). Two researchers labeled one full recording together for further refinement of the initial coding scheme. They worked independently to label 20% of the transcription and iteratively reviewed and improved the coding scheme until satisfactory inter-rater reliability was met (Cohen's kappa = 0.85). Then, the rest transcriptions were labeled independently. We grouped the similar interactions yielding eight themes. To increase the credibility of our findings, we conducted a member checking and data triangulation using facilitators' daily reflection notes.

Results

After coding 1,847 interactions between facilitators and campers, we derived eight themes, which we present as eight primary roles of facilitators; Cognitive Coach (624; 33.8%), Guide (288, 15.6%), Task Coordinator (247, 13.4%), Motivator (198, 10.7%), Technical Supporter (168, 9.1%), Bridge Builder (126, 6.8%), Safety Net (117, 6.4%), and Project Tester (79, 4.2%). We are also interested in how the frequency of each role varied among facilitators and by project phases (see Figure 1).

Figure 1

Distributions of facilitators' roles by individual facilitators (left) and different phases of the project (right)



The variation of distribution among individuals was due to the need to adjust their roles depending on the campers. For example, campers in FT 4's group may need more help with technology because of limited digital literacy. In contrast, FT 6 might need to act as a motivator more because campers were easily distracted. Facilitators also adjusted their roles depending on the project phases. For example, "Cognitive Coach" and "Motivator" peaked on day 6 because it was a Monday, and many campers needed a refresher and review on the concepts. "Technical Supporter" emerged from day 7 when campers started developing their projects, and the percentage enlarged to day 8 as they advanced the projects using more complex features in Dialogflow. In contrast, "Bridge Builder" began to decrease on day 8, as campers had already spent enough time building rapport with their partners.

Conclusion

By examining the roles of facilitators in AI summer camp settings, this study provides insights into the competencies required for camp facilitators and designing professional development for them. This study's findings can contribute to the development of a comprehensive framework for understanding facilitators' roles in AI education, ultimately supporting the growth of AI and STEM education.

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Programming Time: Exploring Time as a Cultural Construct Across Novice Computational Platforms

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Abstract: Public critiques of technologies and the algorithms that power them have pushed designers to critically consider for whom they design and who they include in design processes. In education, similar critiques highlight how computational technologies designed for novice learners commonly privilege certain ways of knowing and being. In response, this poster explores how the cultural construct of time is represented across computational platforms for novices and what this means, particularly for Indigenous learners and designers.

Introduction

Issues of (mis)representation and lack of representation of minoritized groups have shaped the underlying computational models that drive technology "innovation." This has caused profound harm to these groups, particularly Indigenous communities. Given that industry leaders in technology design, such as Apple, Google, and Microsoft, cannot resolve this misrepresentation (Eubanks, 2018; Noble, 2018; O'Neil, 2016), education scholars also find similar issues in education technologies (Litts et al., 2021). The solution requires acknowledging how these technologies and novice computational platforms are themselves instantiations of cultural systems that privilege particular ways of knowing and being in the world.

As an example of how misrepresentation is embedded in novice computational platforms, scholars have found that Indigenous cultures tend to use event-based time intervals that rely on events, seasons, natural cycles and elements, social norms, etc. (Sinha, 2019), rather than the quantified time-based metric interval systems such as clocks, seconds, minutes and hours (Sinha et al., 2011), which many novice computational platforms tend to rely on. In response to this persistent need for novice computational platforms to design for diverse interpretations and representations of time, we investigate the research question: *how do novice computational programming platforms represent the cultural construct of time*? To address this question, we analyzed how time is represented in 45 computational platforms designed for novice learners. Our analysis illustrates how these platforms can privilege particular cultural ways of knowing and being. Findings highlight opportunities to design for accessible forms of programming that align with Indigenous representations of time.

Methods

We curated a list of 45 novice computational platforms that are frequently used in K-12 settings using search terms such as "block-based computational platforms," "digital storytelling platform," and "immersive storytelling platforms." Across platforms, we searched for representations of "time" as either a programming element on the platform or in tutorial blogs on the platform's online community. We identified time features in 29 of the 45 platforms and conducted further analysis to identify the specific ways in which time is represented.

Findings: Representing time

For this poster, we share how time is represented in three platforms: Scratch, Alice, and MIT App Inventor. These serve as illustrative examples of how time is represented across platforms. We found that there are accessible and simple ways to represent time functionality in a game or story. For example, in Scratch, the "current ()" block can be used to report the year, month, date, day of the week, hour, minute, or second in a project. The block displays time in a 24-hr format, and a date based on the device's local time. This affords learners to include a 24-hr clock and a Gregorian calendar date in their projects. However, it becomes more difficult to include date-time in other formats. For example, adding a 12-hour clock requires more complex coding (see Figure 1).

Figure 1

Comparison of 24-hour clock (left) and 12-hour clock (right) in Scratch.

```
when clicked
forever
  set Time to join current hour join : join current minute join : curren
```

In Alice, time is represented in projects using the event-listener option. For example, the event listener "addTimeListener," can execute actions after a certain time has elapsed. In the code snippet below (Figure 2a), after myFirstMethod is executed, the "walking footsteps" audio file plays after a delay of 0.25 seconds. In Figure 2b, to implement an animation where an eagle flies to a log and sits on it, the duration of each move - forward, up, down during flight can be controlled via the "delay-duration" option to further smoothen the visual effect in the scene.

Figure 2

Time in Alice. (left to right) (a) addTimeListener (b) Animating Eagle's flight

```
this myFirstMethod

this addTimeListener 0.25 add detail
declare procedure timeElapsed  e getTimeSinceLastFire
do in order
    this playAudio new AudioSource footsteps_walking_slow_01.mp3 (3.89s)
```

```
declare procedure myFirstMethod
do in order
    do together
        do in order
            this.eagle flyingPose
            this.eagle foldWings add detail
        this.eagle move FORWARD , 1.0 , duration 2.0
        this.eagle move UP , 1.0 , duration 2.0 add d
```

MIT App Inventor also provides learners a range of approaches to integrate time in their games and stories. Objects can be moved or transformed on canvas by setting the time intervals. Timer event is the most general method to define those set time intervals. Objects' properties can also be used to define those intervals. For instance, one can specify the "TimerInverval" property to control the animation effect. When moving the object, the smaller the interval, the faster the object will appear moving. The interval is defined in terms of milliseconds. Additionally, it also allows users to add a specific amount of time (e.g., hours, days, years, etc.).

Discussion

The novice computing platforms we examined provided accessible support to facilitate the representation of time in quantified time-metric intervals (seconds, minutes, hours) and dates using months and years after the Gregorian calendar. However, the platforms we explored do not inherently or explicitly provide structures and blocks that allow users to represent time with events, seasons, life, natural, and cosmic cycles, which are fundamental to Indigenous cultures and stories (Sinha, 2019). We envision a future where these platforms provide accessible structures and representations to easily integrate real-world elements and connections by, for example, drawing on weather or location data. While experienced users may rely on advanced skills to replicate event-based time intervals on these platforms, the existing underlying biases in the structures and representations pose significant limitations for novice users. Insights from our analysis reifies the argument made by scholars (e.g., Litts et al., 2021) to (re)examine the deeper design structures of the computational platforms and the implicit biases in their design toward the goal of designing culturally sustaining/revitalizing computational tools for all.

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Exploring Students Interpretations and Values of Documentation in Creative Learning Domains

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Abstract: Within creative domains, documentation is often central to demonstrating outcomes, process and progress. We deployed a design probe to elicit and externalize conceptions of documentation across the same cohort of 11 students in two semesters. We demonstrate the values of documentation to be coherent across background, time, and experience of the student participants. We also share insights on nine main roles documentation plays for students and discuss how documentation plays an important role in communicating work and building self-confidence and motivation for project-based work.

Introduction and background

Documentation is an important but under-studied aspect of learning within creative domains such as art, architecture, design, and making (Sawyer, 2017; Peppler & Keune, 2019). The act of documenting not only enables students to internally reflect on the process of creative inquiry, but it also makes learner's thinking externally visible (Brown, 2002; Ritchhart & Perkins, 2008), reveals struggles and accomplishments (Barron & Darling-Hammond, 2008; Cross, 2007), affords formative assessment (Braun et al., 2019), and enables feedback on learning process and product with stakeholders (Braun et al., 2019; Keune et al, 2022). In this poster, we characterize how students describe documentation activity and its purposes in higher education project-based course settings. Our guiding research question is: *What are the values of documentation that undergraduate student learners self-report?* We developed a series of design probe activities deployed to the same group of eleven undergraduates in Fall 2020 and Spring 2021. The probe invited students engaged in interdisciplinary creative technology programs to reflect on the perceived values of documentation in their creative process. The contributions of this work are: a set of reflective probe activities designed to externalize student valuing of documentation and a coding scheme to characterize documentation values.

Methodology and results

We opted to use a design probe methodology to elicit student perspectives. Four activities were prepared: a mind map task on the term 'documentation'; an image markup task to annotate objects and tools that support their documentation; a diagramming task to map a recent project and how documentation was involved; and an exercise inviting participants to list reasons why they value documentation. *This last activity is the focus of this analysis.* The activities were deployed over the course of a single week, and each took ~15-20 minutes to complete. The development of our design probe, participants, a preliminary analysis of the Fall 2020 data, and example outputs from probe activities can be found in (Chen et al., 2021). To analyze student reflections, we adopted a grounded theory approach (Corbin & Strauss, 2005) and inductively code participants' responses. Throughout our iterative analysis, two coders presented outcomes to the research team to address ambiguities and to ensure reliability.

Across Fall 2020 and Spring 2021, participants responded with 237 value statements (Fall=110; Spr=127). From this, 9 organizing categories were identified. All categories appeared in both Spring and Fall data. Table 1 shows the categories, their definitions, the total number of statements per category (*Frq*), and the number of participants that identified each category in the activity (*Ps*).

Table 1
A Summary of the Categories for the Values of Documentation.

Category: ***Documentation for…***	**Definition:**	**Frq**	**Ps**
… Reflection	Documentation is used to **self**-reference prior project work, and work in progress.	**59**	10/11
…Communication	Documentation is used to accurately inform or persuade, and receive feedback	54	**11/11**

	from **others**.		
…Demonstration	Documentation is used to demonstrate the project attributes and personal capabilities to **others**.	40	10/11
…Self-Regulation	Documentation helps **individuals** build self-confidence, provide motivation for project making	24	8/11
…Record Keeping	Documentation is used to store, archive and organize records of learning artifacts.	17	7/11
…Project Management	Documentation helps with project management: e.g. organizing, multitasking, time management	11	6/11
… Creative Process	Documentation artifacts help support **individuals** generating, exploring, comparing ideas, and showing iterations.	11	6/11
…Proof	Documentation is used as evidence to track accountability to **others**.	6	5/11
…Requirement	Students complete documentation as an **expected professional output** or **course assignments.**	6	5/11

Discussion, conclusion and future work

Documentation is at the heart of creative dialogue with oneself, one's collaborators, and with the extended creative community that learns from and builds on the precedent work of each other. As a key practice in creative-, project- and studio-based learning, documentation acts as a point of both *inward* reflection — an internal motivation for learning —, as well as, *outward* communication — an external motivation of learning. Our work has aimed to better characterize this from a student-centered perspective and highlights that our student participants value these internal aspects in 4 main categories, documentation: for reflection; for self-regulation; for record keeping; and for sustaining the creative process. For the external aspects, students valued documentation: for communication, for demonstration, as proof, and as a requirement.

Preliminary evidence suggests that some students do experience and value documentations' role in fostering self-regulation and in how it provides intrinsic motivation to advance the quality of project work, encourage iteration, as well as, to seek self-improvement of skills and performance outcomes. A better understanding how, when, and why documentation moves from required educational outcome to a valued personal practice is needed. We believe that our design probe paired and coding framework has utility in increasing understanding of documentation as an intersectional practice in creative learning environments; where there are no right answers, but rather choices to be negotiated around which direction to take.

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Educators' Ideas About Dignity and How to Support it in Schools

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Abstract: Teachers play a central role in creating dignity-affirming environments. We explored educators' shifting conceptualizations of dignity over time and the ways they envisioned creating conditions for dignity in schools. Educators conceptualized dignity as respect, inherent worth, kind treatment, a sense of feeling seen and heard, and something that was characteristic of being human. Educators articulated conditions that enabled dignity-affirming classrooms.

Introduction

Within schools and classrooms, dignity is always at stake (Espinoza & Vossoughi, 2014) and policies, practices, and interactions can either affirm or thwart the dignity of its members (Worline & Dutton, 2017). Dignity is a complex concept that involves both rights and responsibilities (Mevawalla et al., 2021). Espinoza and colleagues (2020) define dignity as "the multifaceted sense of a person's value generated via substantive intra- and inter-personal learning experiences that recognize and cultivate one's mind, humanity, and potential" (p. 326). Dignity is contingent upon the opportunities for meaningful learning experiences and the treatment of others, as well as an ethical "anchor" that guides responsibilities toward others (Mahalingam, 2019).

Relationships are at the heart of teaching and learning, and teachers therefore play a central role in recognizing students' inherent worth and in creating dignity-affirming environments. Teachers design learning experiences that can affirm dignity through offering meaningful opportunities for participation, such as when students see themselves in the curriculum. The affirmation of dignity requires repeated opportunities for meaningful participation, characterized by shared decision-making, being seen and heard by those in power (Espinoza et al., 2020), and awareness of the "invisible labor, invisible identities and invisible sufferings" (Mahalingam, 2019, p. 244) in schools. While dignity can be a transformative lens for the "the ways we design and animate educational environments and ought to be a central tool for educators…" (Espinoza et al., 2020, p. 327), there are few empirical accounts of how educators conceptualize dignity. We add to this literature an account of educators' ideas about dignity as they participated in a course sequence focused on cultivating compassion and dignity in schools. We ask: *What conceptions of dignity do educators hold? How do educators envision creating conditions for dignity within their schools and classrooms?*

Methods

We investigated our research questions using interview data collected from educators pursuing a graduate certificate in education focused on creating more compassionate and dignity-affirming school environments (see Penuel et al., in press). Dignity features prominently as a theme in the courses through instructional materials and contemplative practices that explore self-compassion in relation to dignity, and the idea of common humanity as a basis for extending compassion to all beings (see Jinpa, 2015). The 25 participants were PK-12 educators in the certificate program, principally from rural areas. Analysis relied on interviews conducted over Zoom at three time points during educators' participation in the certificate (start, middle, and end). The first interview asked about current understandings of compassion and dignity. The second and third interviews asked educators about course experiences and how, if at all, their conceptions of compassion and dignity changed. Interviews were transcribed verbatim. We focused on 56 excerpts about dignity and followed a multi-step, open coding analysis process.

Results

The most common word used in educators' definitions of dignity was "respect" (n = 23). For Tania, dignity meant showing respect for who people are, "honoring someone's being." For Sharon, it meant "respecting [students] for who they are." After the conclusion of the certificate, Sharon went further, noting that dignity meant "treating [students] with respect for who they want to be and how they want to be." For some educators, dignity meant showing respect for others across lines of difference (e.g., of beliefs, identities). According to Danielle, "Dignity is creating…for the differences around you and holding them to the same respect that you hold your own facets of your identity." Payton said that dignity meant being "more open-minded about all the different types of people and kids that we have here."

The second most common conception of dignity was that it is something that is characteristic of being human (n = 19). Kayla said, "People should be treated with some dignity just because they're people, right? It's part of being human." After completing the certificate, Justin said that dignity was "honoring people just for being human but realizing also that there's something about them that is really magical, and trying to figure out what that is, in every single person." Another common conception was of dignity as inherent worth (n = 18). Brooke commented that dignity "doesn't change" and is "exactly the same in every person," but at the same time recognized it was contingent upon others' actions. Ellison indicated that the dignity inherent in others calls for a response of the self, to honor the dignity of others: "The dignity inherent in other people calls on the dignity in me for a response. There's like this pinging and we're all pinging off each other and dignity is when I can honor the same spark in them that I know is in me." Two other categories of responses to the question of what dignity means emerged: dignity was about treating people kindly (n = 7) and about feeling heard and seen (n = 5). Both are relational dimensions, with the first focused on responsibilities of the actor conferring dignity on another, and the second a quality that is perceived in terms of how others treat them.

Educators also offered images for how to create conditions for dignity in schools (n=11). Five comments pertained to building relationships of respect toward others. For Danielle, dignity involved "creating space for the differences around you" and showing respect for all facets of others' identities. Dominic said that promoting dignity meant "you create an atmosphere where folks [who] have different experiences can feel valued." Brandi suggested that the best way to create conditions for dignity was to keep an open mind in conversations. One educator explained that it was important for students to recognize their own inherent worth and to speak up for themselves when not being treated well. Six educators spoke about dignity in relation to curriculum. One spoke of highlighting the dignity of figures in history and characters in readings. Another spoke of the need to have texts available that reflect the cultural identities of students. A third emphasized the need for students to see themselves reflected in the curriculum. Two others noted that they brought dignity as a topic directly into the curriculum, through engaging their students in discussions of human rights.

Discussion and conclusion

Educators' conceptualizations of dignity largely aligned with the literature, including that dignity refers to the inherent worth and value of a person and that it is an important aspect of what it means to be human. We identified some important extensions in educators' conceptualizations. First, while some scholars distinguish between dignity and respect in that respect needs to be earned (e.g., Hicks, 2011), educators often connected these two concepts. Students deserved to be respected and treated with kindness because of their inherent worth. Educators also recognized that dignity was about feeling seen and heard, a feature indicative of meaningful participation (Espinoza et al., 2020). We view these conceptualizations as educators' emergent understandings that dignity is socially affirmed and validated (Espinoza et al., 2020). Educators also began to articulate the conditions that enabled dignity-affirming classrooms and schools. These included: a) honoring and validating students' diverse identities and experiences, b) developing systems to address interpersonal conflict, create community, and encourage healing, c) designing curriculum where students could see themselves, d) engaging students directly with the topic of dignity within the curriculum, and e) creating an environment that recognized and elevated student voice. These are important steps toward creating dignity-affirming environments through offering opportunities for meaningful participation. Future research should continue to investigate what meaningful participation looks and feels like within schools, not only from educators' perspectives, but also from students' and their families' perspectives.

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Holistic Individualized Coaching: Foregrounding Teachers' Psychological and Affective Attributes to Support Learning

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Abstract: In this study, we sought to explore if and how teachers' participation in the Holistic Individualized Coaching (HIC) model oriented them to observe and respond to students' thinking in meaningful and efficient ways. Results show that while teachers responded in diverse ways to the coaching experience, attending to their underlying psychological and affective attributes (e.g., beliefs, teaching efficacy, emotions) facilitated overt and subtle shifts in knowledge, emotions, efficacy, and perceptions.

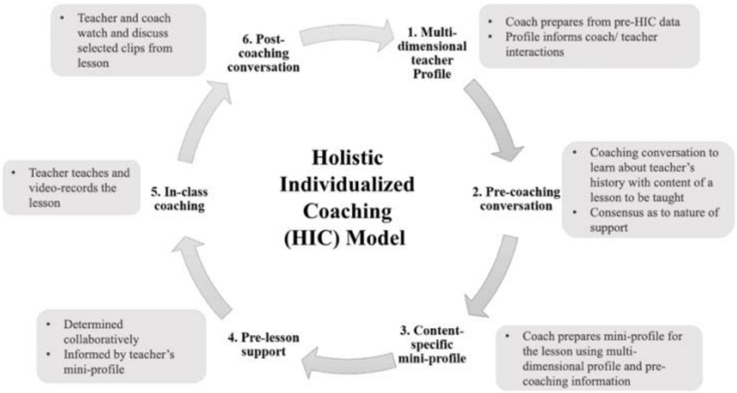
Introduction

Teachers' beliefs (Fives & Gill, 2015) and emotions (Cross Francis et al., 2020) impact their ability to teach mathematics effectively. Empirical findings show that coaching can significantly improve teachers' instruction as well as student mathematics learning (Darling-Hammond et al., 2017; Gibbons & Cobb, 2016). However, existing coaching models tend to overlook the effect teachers' psychological and affective attributes have on their capacities to learn and teach. We examined the impact of a Holistic Individualized Coaching (HIC) approach on the emotions and efficacy beliefs of two elementary mathematics teachers in Ghana.

Methods

HIC takes into account the teacher as an individual by attending to the their emotions, beliefs, identity, knowledge and current instructional practices. HIC not only taps into teacher's content knowledge, but engages teachers in conversations addressing key disciplinary ideas, effective pedagogical approaches, strategies to unpack and understand students' thinking, and psycho-social-emotional attributes that undergird teachers' actions. It involves six steps (Figure 1) that engage teachers' content knowledge, pedagogical approaches, strategies for understanding students' thinking, and psycho-social-emotional attributes.

Figure 1
Holistic Individualized Coaching (HIC) Model



The two participants in this study, Rayna and Dustin, were both elementary teachers who taught at a public and private school in Ghana respectively. **Rayna** initially reported medium levels of enjoyment and low efficacy in relation to her math teaching. She believed math to be primarily about quick and accurate computation while acknowledging a need for critical thinking. Her instruction focused on direct instruction and practice exercises. **Dustin** reported high levels of enjoyment and efficacy related to math. He wanted to make learning more interactive while expressing the firm belief that in math class "students must listen first, as it helps in assimilation". We used multiple data sources including: 60-minute interview transcripts from interviews conducted prior to coaching about previous math experiences; self-efficacy and math emotions surveys; and, transcripts of post-coaching conversations. We used invivo coding to analyze interviews identifying statements about math-related beliefs, teachers' vision for their teaching, emotion and efficacy. Surveys were analyzed and results integrated with qualitative data on the same construct to create a comprehensive picture of the teacher's psycho-social-emotional attributes.

Findings

Rayna: Overt shifts in teacher efficacy and emotions

Rayna engaged in five HIC cycles around number concepts, working with the coach to design lessons that incorporated manipulatives to support students' learning (e.g., base ten blocks). They focused on foregrounding strategies to attend to challenging concepts based on Rayna's prior experience in teaching the topics. As the lessons unfolded, Rayna was able to see how students made mathematical connections and drew meaning from the manipulatives. Rayna consistently reported that students had responded well to the lessons, sharing excitedly in one post-coaching conversation, "*I thought my teaching was good".* The coach worked with Rayna to review students' work, and in doing so supported Rayna in figuring out useful strategies for the range of topics students struggled with. The coach intentionally focused on supporting Rayna in broadening her math knowledge and facilitation skills around topics she found challenging to teach, in efforts to create mastery experiences and strengthen her efficacy. Rayna was able to effectively use some of the strategies the coach shared to support the students' understanding of number concepts. During the post-coaching conversation, Rayna expressed positive emotions, stating, "*I think they fully grasped it. I am so happy about it, extremely happy! Ah, this work has given me more confidence when it comes to teaching math. It has really made me come to like it.*"

Dustin: Subtle shift in instructional beliefs

Dustin's first coached lesson focused on completing number sequences. He encouraged students to apply a procedure to identify missing numbers in the sequence, directing them to "*find the two closest numbers, then subtract them and divide*". In the post-coaching conversation about this clip, Dustin justified his emphasis on the use of this procedure. The coach encouraged him to consider what might happen if the students used any two numbers, as well as what they might have learned from exploring that possibility. These types of conversations frequently occurred, in which the coach encouraged Dustin to allow students to explore, and he pushed back foregrounding the importance of efficiency in timebound contexts (i.e., "the smart way"). Because of Dustin's strong content knowledge, high knowledge and teaching efficacy, and strong identity as a math teacher leader in his school, the coach navigated the conversations responsively by gently nudging Dustin as to not challenge his math identity or threaten his efficacy, while supporting him to see the value of a more student-centered approach. In a later lesson on application of the associative property, the coach suggested that students draw pictures on dot paper to reflect doubling and halving, and work on contextual problems. Dustin agreed to incorporate the pictorial representations but opted to exclude the contextual problems. His openness to only one of the coach's suggestions reflected a subtle shift in Dustin's perspective in transferring more of the intellectual work in lessons to students. We regard this as a subtle shift, as his statement *"I get you; I should have let them do it"* was related to that specific lesson and did not seem to carry over to the next lesson.

Discussion and conclusion

We foreground these examples to show that framing interactions with teachers based on who they are as professionals and learners increases their receptiveness (subtly in some cases) to changing their instructional practices. These shifts may initially be overt or subtle depending on the teacher, the context, and the approaches the coach uses during the interaction. This study has notable theoretical and practical implications. First, we note that the application of HIC (i.e., leveraging comprehensive information) increased teachers' receptiveness to reconsidering their perspectives and practices in both subtle and overt ways. Second, we advocate for an expansion of current approaches to teacher PD to include coaching models that acknowledge the contributing role of psychological and affective attributes to teachers' work. Thus, in addition to the skills currently described as essential for coaching (Gibbons & Cobb, 2016), coaches need deep knowledge of the range of constructs that inform teaching and how to use this information to enhance teachers' instructional practices.

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Exploring Computer Science Identity Development Among Undergraduate Computer Science Majors

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Abstract: Disciplinary identity may play a significant role in determining one's persistence in a field. This study documents undergraduate computer science major students' evolving computer science (CS) identity as they participate in the CES|CS program. Drawing on data from two identity measures (CUPID and STEM-PIO) and student interviews, we present a case study of two students' evolving CS identities over two years.

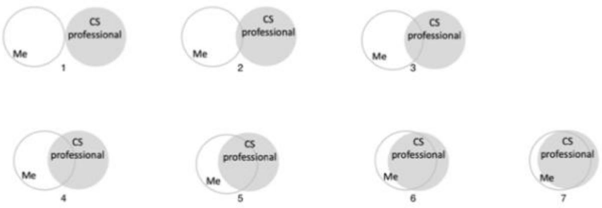
Introduction

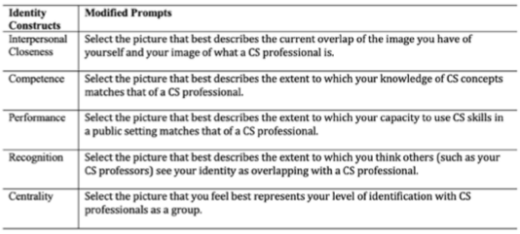
Attrition rates for students in computer science, particularly those from historically underrepresented or minoritized groups, remain high, despite many initiatives to recruit and retain such students (Howles, 2009; Kena et al., 2015; Mahedeo et al., 2020). The Community-Engaged Scholars in Computer Science (CES|CS) program provides diverse, academically talented, low-income computer science (CS) students with scholarships and a comprehensive suite of structured opportunities to learn from and contribute to the computer science community. The program activities are designed to support the development of a strong disciplinary (CS) identity by promoting engagement in the CS community both within and outside the university.

Methods

We draw on prior work on computing identity (e.g., Lunn et al., 2021) to explore CS students' disciplinary identity over time. We use two existing, validated instruments to measure CS identity. A modified version of the Conceptual Understanding & Physics Identity Development (CUPID) (Mahadeo et al., 2020) instrument assessed students' perceived recognition, interest, and performance/competence, with responses based on a 5-point Likert scale (1= not at all; 5 = very much so). Recognition items include: (R1) My family sees me as a computer-savvy person; (R2) My friends/classmates see me as a computer-savvy person; and (R3) My instructors/teachers see me as a computer-savvy person. Interest items include: (I1) Topics in computing excite my curiosity; (I2) I like to peruse forums, social media, or online videos about computer-related topics; and (I3) Computer programming is interesting to me. The Performance/Competence items include: (P/C1) I can do well on computing tasks (e.g., programming and setting up servers); (P/C2) I understand concepts underlying computing processes; and (P/C3) Others ask me for help with software (applications/programs). A modified version of the STEM Professional Identity Overlap (STEM-PIO) (McDonald et al. 2019) instrument, shown in Figure 1, was used to assess perceived recognition, performance, competence, typicality, and centrality. Each instrument was administered to students at the end of their 1st year in the program (Aug 2020); midpoint (December 2020), and end (May 2021) of their 2nd year in the program; and again at the end of their 3rd year in the program (May 2022). Interviews were conducted at the mid-point of their 2nd year in the program (January 2021).

Figure 1
Modified STEM-PIO Pictorial Representations & Prompts





Identity Constructs	**Modified Prompts**
Interpersonal Closeness	Select the picture that best describes the current overlap of the image you have of yourself and your image of what a CS professional is.
Competence	Select the picture that best describes the extent to which your knowledge of CS concepts matches that of a CS professional.
Performance	Select the picture that best describes the extent to which your capacity to use CS skills in a public setting matches that of a CS professional.
Recognition	Select the picture that best describes the extent to which you think others (such as your CS professors) see your identity as overlapping with a CS professional.
Centrality	Select the picture that you feel best represents your level of identification with CS professionals as a group.

Findings

Based on the interview data and students' responses to the CS identity instruments, preliminary findings provide valuable insight into the evolving nature of Greg and Camila's (pseudonyms) CS identity. Figure 3 provides a snapshot of Greg's identity shifts over time. Greg described his experience in *CES|CS*:*"…it's been a lot more… thoughtful about like design and how you want to proceed, what ways you want to improve on certain things and the people you meet. It's been a lot more positive."*

Figure 3

Greg's scores on the CUPID & modified STEM-PIO instruments

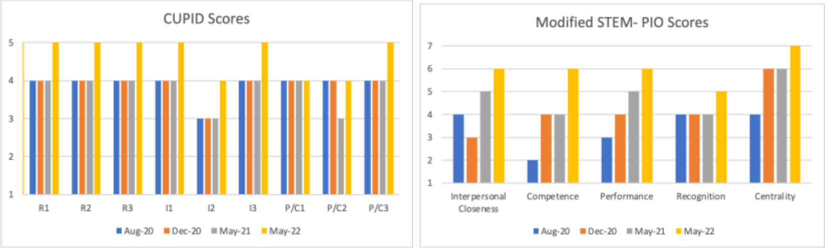
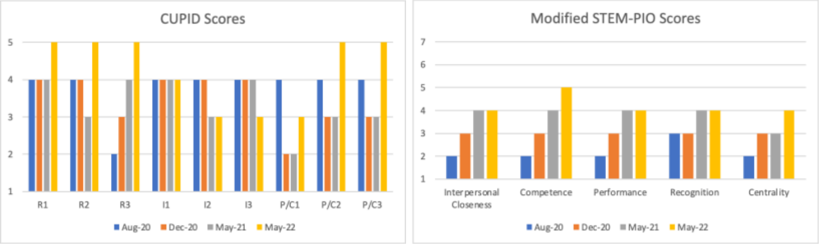


Figure 4 shows Camila's CS identity shifts over time. Camila described her experience in *CES|CS*:*"…it's [CES|CS] definitely made me feel secure, and made me feel like, I'm, gonna be successful as a CS major…."*

Figure 4

Camila's scores on the CUPID and modified STEM-PIO instruments



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Designing for Belonging: Partnering With Community-Based Educators to Develop a New App for Creative Expression

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Abstract: In this poster, we share an example of designing for belonging in a new app for creative expression, developed in collaboration with community-based educators who are working to expand learning opportunities for children and families from marginalized groups. These partners are not recruited for a single participatory design event, but rather partnerships are emergent, ongoing, and part of a larger shared process to support more expressive, collaborative, and equitable computational experiences. We discuss three core design considerations that prioritize designing for belonging in the app influenced by global partners.

Introduction

Children from marginalized communities have rich cultural resources yet too often are introduced to computing in ways that require learners to respond with a single, predetermined answer rather than inviting young people to express their unique interests and identities (Resnick & Rusk, 2020). In this paper, we describe the central role of community-based educators in the design of OctoStudio, a mobile app for creative expression with computational tools. The project has been motivated and shaped by long-term relationships with educators who organize creative learning opportunities for children, families, and educators in their communities, including in Brazil, Chile, India, Mexico, South Africa, Uganda, and the United States.

The intention for OctoStudio is to enable learners from diverse cultural backgrounds to create interactive projects based on their ideas that reflect the world around them and to seamlessly share their creations with friends and family. The work is grounded in constructionist and creative learning approaches (Resnick, 2017; Roque, 2016) and informed by research on the importance of learners to be able to express their ideas, interests, and identities to broaden participation in computing and motivate deeper learning (National Academies, 2021). In each aspect of the design process, we have drawn on designing for belonging principles (Powell & Menendian, 2016) and foregrounded partner voices in decisions about how best to address needs and interests of their communities and integrate their rich cultural perspectives (Garcia & Lee, 2020).

OctoStudio is designed to make it easy to create with code on mobile devices, addressing the unique constraints and affordances of mobile phones, including the limited screen size, built-in sensors, ease of access to photos and sound recording. Learners can select or create their own characters, backdrops, and sounds, and choose from a palette of coding blocks to design interactive projects. The app is currently in alpha prototype phase. Iterative design cycles engage community-based partners in exchanging ideas relevant to their local context, trying out the app in their communities, and participating in reflection and design discussions with each other and our university-based development team. Data collection to understand this dynamic process includes thematic analysis of sessions with partners to understand perceptions and tracing ways that partner feedback is shaping design decisions.

Key design considerations

In this section we describe three design considerations that prioritize designing for belonging in the app and that have been influenced by and iterated with partners. These design considerations are not simply a list of features, but attention to multiple levels of design, including system infrastructure, available assets, and tools (Table 1).

1. **Welcoming through seamless integration with local technology tools and practices:** Our global partners have expressed strong interest and need for more tools for creative expression that can run on mobile phones and that are not dependent on online connectivity. Thus, we have prioritized designing the app to work on locally available mobile devices and to provide quality experiences with no or intermittent data connectivity. Partners have been instrumental in prioritizing features, balancing trade-offs, and considering how to creatively leverage the existing data infrastructure of different locations globally. The app is designed so that all creating and saving of projects takes place offline, without requiring any internet connectivity. Based on partner feedback, we have also prioritized making projects easy to share with family and friends by enabling learners to screen record their creations without use of data and by leveraging free, cross-platform, messaging platforms.

2. **Inviting learners to recognize themselves and their worlds:** The app is designed to provide learners with a wide range of expressive tools and a diverse media library for creating their projects. Although the images

of people in the standard emoji library provide a choice of six skin colors, they lack racial and cultural representation in important ways. Based on feedback from partners, our team has redesigned images for the app library, making changes to more than 90 emojis of people, including body types, headwear, and hair texture and styles to support broader representation of racial, cultural, and gender identities. Partners have also guided the development of backdrop images and sound clips to make the media library more familiar and relatable for children in their communities Partners have contributed local photos (e.g., a neighborhood scene from Limpopo, South Africa and a pathway with street art murals from São Paulo, Brazil). The app provides examples and tools to highlight ways that learners can create their own characters, backdrops, and sounds.

3. Encouraging contributions through creative tools across physical environments: The app is intentionally designed to facilitate both ease of creating anywhere and integrating personally meaningful images and sounds users encounter on-the-move. Coding blocks support multimodal expression (motion, text, color, sounds, vibration), creative tools for adding your own media (sound, photo, paint, and text editors), and sensing blocks that enable physical interaction (shake, tilt, touch, magnet sensing). These novel tools allow learners to construct interactive projects that enable them to engage with their bodies and physical environment. For example, the "*when I shake*" block starts actions if the learner shakes the phone, which opens up a variety of projects based on dance, music, sports, and other forms of movement and output that extend beyond the device.

Table 1

Examples of app design to address three levels of design considerations

Leveraging Infrastructure	**Diversifying Media Assets**	**Providing Creative Tools**
Sharing with no or intermittent internet connectivity	Revised emojis to support more diverse representation.	Coding blocks that support interactivity with physical world
 Hola 🙌, les comparto mi proyecto, se llama México a través del tiempo 💓 11:45 AM [redacted] ¡Qué bueno! @[redacted] 11:59 AM *Educator in Mexico sharing her project on WhatsApp app*	 *Examples of standard emojis versus revised emojis in app*	 *Example project that plays drum sound when you shake the phone.*

Discussion

Work with partners has illuminated how designing for belonging happens at interconnected levels from macro to micro considerations. Integration of system-level infrastructure and communication practices is coupled with careful attention to designing individual assets and tools that encourage creative expression and agency.

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Choosing, Imagining, and Changing as Agency in a Mixed-Reality STEM Learning Environment

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Abstract: We explore how student agency was enacted in small, medium, and large ways that impacted the emergent design of a technology-enhanced science learning environment. Small acts corresponded to students choosing how to participate, medium acts when students' imagination was supported, and large acts when students' ideas changed the curriculum. We analyzed video data from 21 class videos to highlight the design trajectory from the first iteration (one 5th-grade classroom; topic: moths and adaptation) to the second (four 4th-grade classrooms; topic: food webs). Our findings suggest that supporting choice and imagination led us (researchers and teacher co-designers) to make curricular changes to follow students' ideas (e.g., an activity about decomposition to figure out how plants get their energy). Future learning environment designs should be responsive to all three types of student agency.

Motivation and theoretical framework

Agency has been shown not only to enhance student motivation and engagement in STEM, but also to connect social change to disciplinary learning (Goulart & Roth, 2010; Basu, 2008). However, agency has been difficult to operationalize, and even within science education, scholars conceptualize agency differently (Arnold & Clarke, 2014). For Arnold & Clarke, agency was defined as "the discursive practice of positioning oneself or being positioned as responsible" (p. 751). The National Research Council (2009) has reported the temporal aspects of agency that may help teachers identify moments to encourage student agency: "A sense of agency or belonging can be experienced retrospectively when reflecting on past events, it can be experienced in relation to current activities, and it can be projected into the future through imaginative acts regarding what one might become" (p. 74). Agency has also been defined as the capacity to act on one's knowledge of science (Basu, 2008; Barton & Tan, 2010) or "a person's capacity to engage with cultural schemas and mobilize resources in ways that did not exist before, creating new contexts and practices" (Varelas et al., 2015, p. 517). This wide range of definitions (from responsibility based on how one chooses to position oneself, to acting from one's imagination, to the capacity to act) suggests the importance of understanding and conceptualizing sub-types of agency. From this range of definitions, we argue three contexts when agency is relevant for students: moment-to-moment interactions, dreaming about the future, and acting on the dream to realize a desired future or outcome.

In this paper, we propose three different types of agency that build up to students taking social action: choosing (small; Rodriguez, 2015; National Research Council, 2009), dreaming (medium; Carlone et al., 2015), and changing (large; Arnold & Clarke, 2014). We present empirical data from the Generalized Embodied Modeling and Science through Technology Enhanced Play (GEM-STEP) project about learning through embodiment in a mixed reality environment to provide examples of these three types of agency. These examples show how agency impacted children's learning and our iterative co-design process. Specifically, we ask: How does the co-design/co-facilitation process between researchers-teachers-students support student agency?

Methods

The data for this study comes from the GEM-STEP project, where students play within a system that tracks their location and shows them on a shared visualization as an agent within the scientific phenomenon of study (in this case, moth adaptation and terrestrial food webs). Our curricula leveraged embodied modeling technology that enabled students to appear as and control agents within a simulation on screen with their movement (e.g., a moth hiding from an artificial intelligence-controlled controlled hawk, a robin eating and gaining energy from an AI-controlled beetle, and carbon dioxide molecules that meet up with water molecules at an on-screen zoom-in of a plant leaf's chloroplast; See Figure 1).

Authors 1-3 time-indexed and content logged (Derry et al., 2010) 21 days of video (9 days of the moth unit; 3 days x 4 iterations of the food web unit) and iteratively watched these videos as an author team to refine hypotheses (Engle et al., 2007) about moments when students are engaging in small, medium, and large acts of agency. We noted moments when teachers and researchers give students choice as small agency moments (e.g., "Are we ready? Are we all where we want to be [in the tracking space]?"). When children asked creative questions or made observations that required imagination, we noted those moments as medium agency (e.g., “I ate the garden, but I couldn’t eat [another student’s name]”). When students made a suggestion that led to real change in the activity design or curriculum, we noted those as large agency moments. We also tracked overall how our planned design decisions did or did not support all three types of agency, and what unplanned design decisions occurred in response to students’ small, medium, and large acts of agency.

Findings

We identified planned and unplanned design decisions that impacted student agency in the moth and food web iterations. For example, within the moth curriculum, we planned for students to have choice (small acts of agency), but students surprised us and created their own moments of medium agency when they made up narratives about moths facing imminent death and the hawk “birdie” being broken. Because the moth iteration somewhat restricted students’ agency to use their bodies to engage in the activity (i.e., staying still and hiding on a tree from the hawks was a popular strategy), we also intentionally designed the food web activities to require more movement in order for kids to engage (i.e., eat the moving beetles when you are a snake or robin). This design change opened up more opportunities for both small and medium acts of agency.

In the food web unit, we expanded the possibilities of students' imagination by designing the game so that children can take the perspective of multiple animals. Through the food web activities, students began to wonder and worry about the plants: Where do they get their energy from? In response to their concerns, we added a decomposition activity to meet students’ desires to learn more about the connection between producers and decomposers. Although we saw large moments of agency the fewest amount of times than the other two types of agency, we plan to ask children, “Why should we care about food webs?” in order to understand what socio-environmental connections or changes children may suggest.

Future directions

Overall, because this project builds on the tradition of iterative design-based research, we are fortunate to make changes to our curriculum in real-time response to students’ choices, imagination, and sociopolitical agency. We hope this inspires other science learning environments to design curricula and activities in a way that can be responsive to students’ agency.

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Designing Teacher Professional Development Using Conjecture Mapping to Support Teachers' Computational Thinking Integration Efforts

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Abstract: This poster presents our efforts to (a) design a scalable competency-based teacher professional development that provides continuous support to increase middle school Social Studies, Arts, and Language Arts teachers' capacity to make sense of computational thinking integration opportunities within their teaching context; and (b) examine how different elements of teacher professional development influence teachers' capacity to make sense of computational thinking integration opportunities in their teaching context.

Introduction

Given the benefits of integrating computational thinking (CT) into the K-12, it is crucial to support teachers in understanding both CT and instructional practices to help students gain CT skills (Ketelhut et al., 2020). Previous efforts focused on teacher professional development (TPD) interventions have largely involved short-term workshops with limited follow-up activities that do not provide substantive support to teachers, especially teachers who do not have a background in CT, to integrate CT into their teaching. Additionally, while existing research has begun to establish CT's relationship to the disciplines of math and science (Weintrop et al., 2016), fewer efforts have looked at how humanities teachers (e.g., Language Arts, Social Studies, and Arts) make connections between CT and their subject area (Yadav et al., 2017). There are also TPD efforts that are focused on coaching, co-designing, and/or co-teaching with scalability concerns due to the amount of time and resources needed to support teachers and coaches (Margolis et al., 2017). Finally, only a few studies (e.g., Margolis et al., 2017) have investigated how specific characteristics of TPDs influence teachers' knowledge, skills, and attitudes toward CT integration in K-12. Therefore, this study aims to (a) design a scalable competency-based TPD that provides continuous support to increase middle school Social Studies, Arts, and Language Arts teachers' capacity to make sense of CT integration opportunities within their teaching context; and (b) examine how different elements of TPD influence teachers' capacity to make sense of CT integration opportunities in their teaching context.

Methods

This study utilized design-based research, particularly, conjecture mapping to design TPD (Sandoval, 2014). The initial conjecture map was created based on the high-level conjecture that teachers require scaffolds and TPD opportunities to engage in enhanced disciplinary teaching via CT and to make sense of CT integration opportunities within their teaching context.

Phase 1: Co-design with CT experts

We worked with expert teachers and experts in computer science and CT education, to ideate CT-integrated learning experiences. Based on the ideated lessons, we identified and categorized an initial set of design principles for each discipline.

Phase 2: First implementation of teacher professional development

Eight teachers participated in the first iteration of the TPD during Summer 2021. The TPD consisted of seven days of professional learning that included knowledge-building sessions, designing CT-integrated lesson plans, and mock instruction with associated peer observation and feedback. After professional learning, each teacher received one-to-one support to design CT-integrated lesson progressions and discuss implementation plans related to this planned instruction. Those individual sessions were planned based on individual teachers' pedagogical and content needs. Finally, teachers participated in a whole group meeting to discuss the potential challenges they might face during implementation and whether they need any additional support from the team. Finally, to support the TPD efforts, we identified CT integration pathways in Social Studies, Arts, and Language Arts and associated practices with high-level examples (Caskurlu et al., 2022). We also developed self-paced online building blocks that include (a) three general building blocks (i.e., abstraction, algorithms, and patterns and data practices) to build an understanding of CT and (b) subject area-specific building blocks that focus on CT integration pathways with concrete examples and scaffolded activities.

The following data sources were used to examine how different elements of TPD would influence teachers' capacity to make sense of CT integration opportunities in their teaching context: semi-structured interviews after design fellowship, one-on-one check-in meeting video recordings, teacher lesson progression design documents, and TPD video recordings. Data were analyzed using thematic synthesis.

The review of the first implementation data showed that TPD supported teachers to conceptualize CT and make connections between CT and their subject area. The initial high-level conjecture remained the same. However, the results also revealed a need for including (a) more collaborative activities where teachers design lesson plans together and provide feedback to each other; (b) additional resources related to computational tools; and (c) more concrete examples of applications of CT integration practices in the classroom. Accordingly, we made the following revision on the existing embodiments and added new ones:

- Professional learning: Additional collaborative activities were added to create a community of inquiry among teachers.
- Design fellowship: In addition to teacher professional learning sessions, the second iteration included a design fellowship where teachers designed CT-integrated lesson progression with support from the research team and presented their design and provided feedback to each other.
- CT integration pathways and associated practices: In addition to revising CT integration pathways and their practices, additional resources including a description of each pathway and how it looks like in practice aimed to clarify the content and make them accessible to teachers.
- Remixable unit concepts: We created remixable unit concepts that can be used to remix content by customizing it and/or to make adaptations to design CT-integrated unit progressions to provide more concrete examples of how CT integration pathways can be implemented in classrooms.
- Inspiration library: We created a repository of resources that address CT, CT tools, CT integration ideas, and/or curricular resources.

Phase 3: Second implementation of teacher professional development

Eleven teachers participated in the second iteration of TPD, and six continued working closely with us into the Fall semester as design fellows. The following data were collected: (a) a pre-survey asking teachers about their previous CT experiences and their perceptions of CT integration pathways; (b) TPD video recordings; (c) a post-survey asking teachers about their experiences in the TPD and their perceptions of CT integration pathways after TPD; (d) design fellowship video recordings; (e) implementation reflections; and (f) semi-structured interviews.

Data analysis is still in progress, but the preliminary results showed that the design iterations of the TPD provided unique affordances that helped teachers conceptualize CT, envision concrete applications of CT practices to their teaching, and design CT-integrated units. Teachers also noted that they established future collaborations with other teachers to co-design CT-integrated units. The conjecture map resulting from this process advances our understanding of TPD around CT integration in terms of the teaching and learning approaches used in TPD.

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A Teacher Community in the Making: Contradictions as Uniting and Driving Forces for the Creation of Culture

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Abstract: This participatory design research study supports a group of mathematics teachers teaching at different schools in Turkey as they design their community within a non-profit organization. The method of formative interventions is used to support teachers' expansive learning while creating their community and its unique culture. The study examines how teachers identified their common contradiction as an initial step of community building.

Objectives and context

Teacher communities have long been acknowledged as mediums in which teachers can sustain their professional development and produce solutions to their problems of practice, and these communities have been promoted as a part of educational reform processes (Horn et al., 2017). On the other hand, when trying to design these communities and make them operative among teachers, researchers have mostly overlooked the fact that the development of teacher communities is a matter of cultural creation and change (Engestrom, 2016; Stigler & Hiebert, 1999). This ongoing study addresses this gap by employing the method of formative interventions, a type of participatory design research approach in the learning sciences, to support a group of mathematics teachers in designing their community with its novel cultural practices and artifacts (Engeström, 2016; Gutiérrez et al., 2016).

Participant teachers in this study teach in different schools and at various levels, and, all of whom are engaged in a non-profit organization called Teachers Network, which promotes teacher empowerment by supporting teacher solidarity in communities. After some unsuccessful attempts to establish a community among mathematics teachers in the network, one of which I participated in as an observer, I consulted with facilitators from the network, and we made a call to network mathematics teachers to design a community. Unlike typical formative interventions, in which practitioners from the same organization transform their work practices, this method has been implemented to create a community by a group of teachers who do not share the same workplace but are all part of the generalized mathematics teaching activity system of Turkey, which is centralized with a Ministry of Education, a common curriculum, and high-stakes testing for school enrollments.

Theoretical framework, research questions, and method

In formative interventions, based on Engeström's (2016) theory of expansive learning, practitioners are supported in a way that specific epistemic or learning actions that characterize the expansive learning process (questioning, analyzing, modeling, examining, implementing, reflecting, consolidating and generalizing) would emerge. Drawing on the methodological tools that Vygotsky (1997) employed in his double-stimulation experiments, expansive learning is mediated by two types of tools: the "first stimulus," which helps practitioners face the contradictions in their activity system that gave rise to persistent dilemmas in their practices that they couldn't solve alone, and the "second stimulus," which is put into action to design a novel solution (Engeström, 2016).

The completed first of three phases of this project included mediated tools and activities that supported questioning and analyzing actions. The overarching research question of this study is "How does a group of teachers who teach at different schools design their professional community during a participatory design process?" This paper answers the following sub-research questions: How did teachers exercise questioning and analyzing learning actions, and how did the mediating tools support these actions? What kind of common contradiction did teachers identify, and how did it function in designing the community?

To answer the research questions, focusing on the practitioners' conversations and written artifacts, I primarily drew on video recordings of eight online or hybrid community meetings that lasted between 129 and 172 minutes and artifacts. The expansive learning actions from the transcripts were coded deductively utilizing Maxqda software, which was followed by the inductive analysis of the context specific sub-types of them.

Findings

The book *The Teaching Gap* (Stigler & Hiebert, 1999), which compares mathematics teaching practices in three countries (Germany, Japan, and the USA) and conducts a critical evaluation of the cultural and structural factors that affect these practices in the U.S. and Japan, constituted the backbone of the activities during the first phase. The community read the book part by part, wrote reflection papers, and discussed it with my questions, which invited them to reflect on their experiences as mathematics teachers in Turkey. The book was selected since it had a strong potential to trigger teachers into questioning taken-for-granted aspects of their practice, which they could not find opportunities to reflect on during the rush of their regular practice. Questioning action has emerged in three interconnected aspects of mathematics teaching in Turkey: the cultural codes (e.g., whether children are provided with space to control their learning), the curriculum (e.g., the scientific rationale behind it), and the teacher learning systems (e.g., professional development opportunities, collegial interaction).

According to Engeström (2000), contradictions "manifest themselves through disturbances, ruptures and small innovations in practitioners' everyday work actions" (p. 153). The tools and activities helped make these disturbances explicit to teachers. These problem areas mentioned above have been manifestations of an overarching contradiction that emerged in the community meetings as a repeating discussion topic: The lack of a robust, common-orienting "framework" or "structure" in the country that mathematics educators share and work toward achieving, that teachers follow to collaborate, and that introduce "alternative codes" to the dominant cultural codes of teaching that limit the possibilities of equitable and meaningful student learning. Teachers were experiencing this as a contradiction since, despite the lack of a shared orientation, teachers had been introduced to various approaches through professional development activities and curricular materials that the Ministry of Education disseminated, which could not go beyond being a "haphazard collage of experience and workshops, pasted together with little connection," preventing teachers from achieving a sustainable improvement in their classrooms (Ball & Cohen, 1999, p. 27). As teachers found space and time to delve into these problems in community, they started to interpret these supposedly arbitrary and unrelated problems in the light of this contradiction (Engeström, 2000). Demet (a pseudonym), one of the participants, elaborated on the contradiction that manifested as repeating disturbances in her practice, which she expressed in her reflection paper as *experiencing a vortex of trial and error that was getting bigger and faster every day*.

Teachers in the community did similar critiques, referring to their own teaching experiences, in different sessions or in the different sub-groups that we created for group activities, sometimes using different terminologies. After six sessions, I put the teachers' comments and critiques about this issue together and prepared short video clips. We watched and discussed these clips along with the questions that invited teachers to clarify what they meant there, whether they referred to the same problem in their sayings, and whether they agreed with each other. In this way, *teachers' individual questioning action turned into a collective one, and they naturally started a collective analysis* on whether curricular materials actually provided the "structure" that they needed. The remaining parts of the intervention were built on the energy of this contradiction (Engeström, 2016); the community planned various activities to further their analysis (e.g. contacting curriculum makers) and developed long-term goals toward modeling their community (e.g. designing the community's orienting framework for teaching mathematics by reading scientific resources). During these discussions, "mathematics teaching" has been identified as the object to expand through the community's activity, and it turned into a motive (Engeström, 2016).

Significance

This analysis has shown that through the use of participatory design research methods, researchers can facilitate the development of a teacher community as a cultural creation process. Furthermore, it illustrates how formative interventions help practitioners from diverse workplaces identify common contradictions as the initial step toward designing a novel professional community as a solution to these contradictions.

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Connect: A Tool for Collaborative Interview Data Analysis

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Abstract: A growing scholarly interest around participatory approaches has acknowledged that interaction between researchers and participants is still constrained. However, little is known about methodological tools that allow researcher-participant collaboration that defy these strict roles. Thus, we are designing Connect, a tool to support researcher-participant co-interpretation of discourse data from interviews. In this paper, we synthesize previous work leading to our design, describe Connect, and expound goals and principles guiding our design.

Introduction

In the learning sciences, research has demonstrated how the values and perspectives of participants shape the goals of research projects and interventions (e.g., Bang & Vossoughi, 2016). A growing scholarly interest around participatory approaches has acknowledged that interaction between researchers and participants is still constrained, and improvement in this area is needed to open avenues for epistemic diversity (Philip et al., 2018). However, little is known about tools that allow researcher-participant collaboration in which roles are de-settled to generate more democratic knowledge construction (Bang & Vossoughi, 2016; Philip et al., 2018). Thus, in this paper, we describe a tool to aid in *collaborative data analysis between "researchers" and "the researched*." This tool is situated within quantitative ethnography (QE) methodology (Shaffer, 2017).

Prior work

The research leading to the design of *Connect* is based on previous studies of the professional identity of English teachers in Costa Rica. Vega and Arastoopour Irgens (2021) explored the identity tensions and negotiations of pre-service and in-service teachers during their teacher education program and in their transition to teaching. In a pilot study, Vega used on-the-fly annotations of ENA discourse networks (Shaffer, 2017) based on the teachers' interpretations (Vega & Arastoopour Irgens, 2021). The network creates node-link representations of relationships between coded data. In interviews, Vega (2022) added annotations that teachers suggested or that they deemed necessary. This pilot study inspired a tool prototype, which adapted ENA features, such as creating node-link representations of discourse, such that teachers could participate in the data analysis process without the background knowledge needed to use ENA. This prototype was created on Google Slides with a drag-and-drop option for users to create visual representations of their interpretations. Altogether, this research has shown how 1) data visualizations provide a space for joint cognition, 2) co-constructed interpretations build a fuller picture of the research phenomenon, and 3) joint sense-making enhances new interpretations in research., a tool to augment researcher and participant collaboration.

Connect: Goals, description, and design principles

Inspired by our findings, we propose *Connect*. The following are the main goals guiding our design:

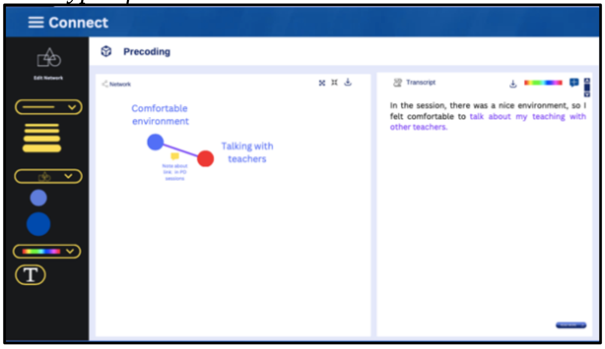
1. Engaging research participants in QE data analysis: *Connect* integrates QE participants' voices in a research stage in which they have traditionally had limited participation. Acknowledging barriers in terms of time commitment and expertise, *Connect* provides a space for participants to shape knowledge construction.
2. Expanding existing tools: QE scholars have developed a range of researcher tools. ENA, in particular, is focused on meaning-making and facilitates multiple data interpretations (Buckingham Shum et al., 2021). These functionalities can be expanded towards collaborative ends. *Connect* reworks these functionalities to leverage researchers and participants' expertise and bridge theory and practice.
3. Involving participants in tool co-designing: A human-centered approach to design requires roles, interaction, functions, and attributes of tools to be determined by researchers and all stakeholders (Buckingham Shum et al., 2019). *Connect* involves participants' perspectives to design and improve the tool.

Connect is designed for researchers and participants to analyze interview data in a collaborative space by logging in and working simultaneously. An initial screen allows the users to upload transcripts with spreadsheet or text file extensions and start using features to annotate transcripts and create and annotate data visualizations.

The collaborative space includes two sections: (a) the transcript (right hand-side of Figure 1) and (b) the network (left hand-side of Figure 1). On the transcript side, the users view the interview transcript. From left to right in the upper left corner, they have the following tools: (1) a downloading button, (2) a color bar to color-code data segments, (3) a comment button to annotate the transcript, (4) arrows to navigate the transcript. The design principles underlying our decisions for this segment of the tool are based on the fundamental principle of QE of grounding interpretation in the discourse. Codes and broader interpretations stem from the data and are verified in relation to evidence in the discourse. Therefore, the transcript is visible in the tool and users interact with the text by providing additional information not captured in previous interviews and co-constructing preliminary codes. These features will enhance co-interpretations that are fully grounded in the data.

On the network portion of the tool, users create networks representing important themes or codes identified in the transcript. The left menu includes the following elements for network construction: (1) a drop-down feature to insert lines with different levels of thickness, (2) a drop-down button to insert nodes of varied sizes, (3) drop-down feature to customize colors for dots and lines, (4) a text tool to add text to the network. The design principles for this segment of the tool are inspired by node-link representations in ENA inch which larger nodes represent more frequent occurrences of the codes and thicker links represent more frequent co-occurrences between codes. However, in ENA, the networks are constructed via sophisticated statistical tools, which require coded data and expert knowledge. Coding and modeling the data is typically a time-consuming and specialized process, which may not be realistic for participant engagement. Thus, we have adapted features of ENA, which that are helpful in data analysis conversations and would not require time-intensive tasks. From our previous research (Vega, 2022), we determined that these features will be accessible for participants. Next steps will be to develop a web-based version of *Connect* using R Shiny and Javascript and conducting user testing.

Figure 1
Prototype of Connect



In the session, there was a nice environment, so I felt comfortable to talk about my teaching with other teachers.

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Computational Tinkering With Movement in Embodied Models

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Abstract: We suggest that tinkering is implicit in movement and changes to movement while exploring embodied models, as students must interpret and react in real time to the system outcomes. Using movement analysis, we explore the ways that physical movement fosters and reflects computational tinkering across episodes in two embodied science models. We argue that patterns and shifts in movement may be a window into the computational growth that takes place as learners participate in the modeling environment.

Introduction

Embodied cognition asserts that cognition is deeply rooted in the human body and its interactions with the real world (Barsalou, 2008). Studies show that leveraging students' physical movements to explore scientific and computational models can support sensemaking and foster new science learning (Planey & Lindgren, 2020; Zhou et al., 2022). However, the impact of embodied experiences on students' computational practices has yet to be explored. Research has shown that cycles of exploration and tinkering, or playful experimentation, support learners' sensemaking as they learn scientific phenomena and gain computational fluency with models (Wagh et al, 2016). Tinkering enables learners to engage computationally and conceptually as they pursue questions of interest and then notice and explain the resulting outcomes of their tinkering (Martinez & Stager, 2013). We suggest that tinkering can emerge in new ways, via movement, within computational embodied models due to the physical nature of the modeling experience. We extend and explore the concept of tinkering within the physical world by examining activities built on the Generalized Embodied Modeling: Science through Technology Enhanced Play (GEM-STEP) platform (Danish et al., 2022), an embodied science modeling environment.

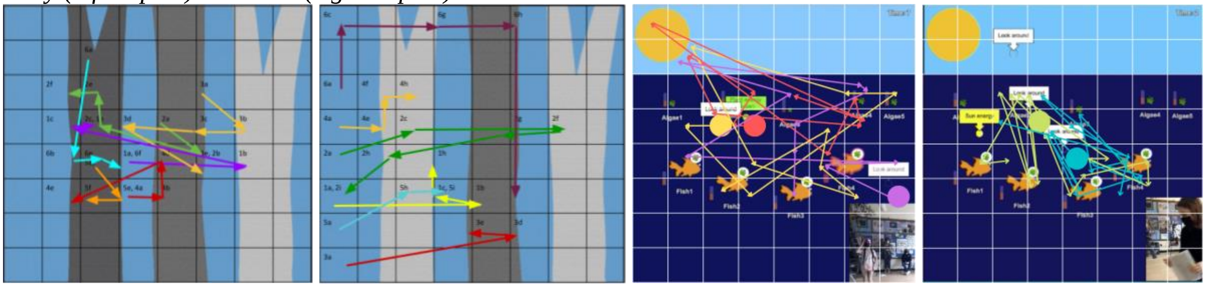
Methods

We explore two cases of embodied science models in the GEM-STEP mixed reality platform, that allows learners to control agents in a model with their movement by wearing tracking tags. Two classes of students (5th, 6th) explored either a moth camouflage model or an aquatic ecosystem embodied model. In the moth camouflage model, students embody moths with hidden wing colors and must use a system level match meter to find a tree on which to safely camouflage. In the aquatic ecosystem model, learners bring agents (algae, fish) energy from the right source (sun, algae) to keep the system alive and stable. We use video and screen recordings to conduct movement analysis (Gudmundsson et al., 2011) on an early and later round of each model, comparing movement in three categories of tinkering: *success rate* (quantitative measure of success), student *initial positioning* (where students stood at the start of the model), and *strategy & movement* (patterns of movement and coordination at the group level).

Findings

In the early round of the moth camouflage model, learners started by positioning themselves in a slightly distanced cluster in the center of the model (*initial position*) then moved independently of each other (*strategy & movement*), resulting in unintentional matches. Due to this independent movement, the number of matches fluctuated over the round of the model (*success rate*). Based on initial explorations, students deliberately started the round off of trees to ensure the round started with zero matches. They implemented a strategy where only one learner at a time walks forward until the match meter identifies a safe tree, resulting in decreased speed but greater accuracy (*success rate*). In the early round of the aquatic ecosystem model, students started in a cluster in the center of the model (*initial position*) then each made scattered movements across the model to interact with all agents in the system (*strategy & movement*), resulting in a less stable system (*success rate*; 196 seconds, 2 of 4 fish alive, low energy). In the later round, students devised a strategy to make energy transfer more efficient by distributing energy transfer tasks (*strategy & movement*) and started the model between agents that they were tasked with supporting (*starting position*). They further adapted their previously discussed strategy after observing that fish were at risk of dying, communicating and employing a new strategy in the moment. This resulted in a longer period of stability and healthier agents (*success rate*; 221 seconds, 2/4 fish alive, high energy).

Figure 1
The moth camouflage model (left pair) and aquatic ecosystem model (right pair) with movement tracked for in early (left in pair) and later (right in pair) rounds.



Discussion and future directions

Across both models, students used initial movement based explorations to construct and revise strategies that resulted in greater success in later rounds. The moth model case captures tinkering across rounds while the aquatic model case additionally captures tinkering within a round. We suggest that movement can be understood as a window into learners' computational tinkering that emerges during computational embodied contexts. Within this space, students' cycles of engagement with models are synchronous, meaning that they can change the rules of their characters as they assess system level outcomes while actively using models. The synchronous nature of the embodied models gave students opportunities to tinker with the model rules, test theories in real time, and adapt as their understanding of the computational and scientific system evolved. This synchronicity can be challenging and complex for students, as it requires negotiation and coordination of strategies and goals with peers, and additionally requires learners to observe and make sense of the potential system level impacts of others in the embodied model.

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Uncovering Factors That Generate Relatedness to Place and People During In-Person Field Trips (FTs) to Inform the Design of Virtual FTs

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Abstract: Virtual learning experiences are on the rise, but those experiences are far-off from offering similar experiences to in-person field trips. Students reported on their experiences during a field trip to illuminate factors that may contribute to the benefits of field trips. Among the findings, students reported that gaining expository information about a place was the main contributor to feeling connected to that place. Results provide initial design guidance when building virtual field trips.

Introduction

This research examines the qualities of a successful school field trip to inform the design of Virtual Field Trips (VFTs). In-person field trips can generate lasting memories and meaningful connections between participants. Research shows that field trips provide benefits in place awareness and science learning (e.g., Ardoin et al., 2018). Digital tools might also build a sense of connectedness, but there has been less development on how to foster this type of non-academic learning in the digital arena (Reich & Ito, 2017). Technologies for creating VFTs have become increasingly available (e.g., Pano2VR) and some are simple enough that students can create their own VFTs (e.g., Thinglink). In the best of worlds, VFTs can bring every student to places and people that would otherwise be infeasible, while also supporting some of the otherwise unique in-person learning experiences.

To design VFTs that generate similar effects to in-person experiences, we need to understand the factors that promote beneficial in-person experiences so they can later be designed into VFTs. We refer to the outcomes of field trips as benefits because in the literature they are usually reported as benefits. We identified two benefits from existing research about field trips 1) **Connection to place**: After attending a field trip, students report higher connection with a place. For instance, students report a higher commitment towards ecological behaviors (e.g., recycling) when they feel connected to nature (Otto & Pensini, 2017). 2) **Connection to people**: During a field trip, participants build connections to others that seem to last or that they feel deeply about (Richmond et al., 2018). In this study we begin to explore factors that contribute to those benefits by measuring students experience after the field trip.

Methods

Participants and procedures

Fifty-seven students from a school located in Bogota (Colombia) participated in the study. The study was approved by the Stanford Institutional Review Board. Two weeks after returning from a field trip organized by the school students completed a survey using a *Google Forms* link. The school's wellness coordinator administered the survey based on the instructions we provided. Students did not receive a time limit to answer each question.

Measures

We designed a survey with open-ended questions targeting the two main benefits: 1) connection to place and 2) connection to people on the field trip. The first question of each section asked students to name which activity achieved the two main benefits. Additional questions in each specific section asked students about why and how the activity contributed to a particular outcome. Research shows that not only the context but also the people who are present in that place may contribute to creating a connection to place (Ardoin, 2018).

Coding

Two procedures were implemented for coding students' surveys. The first procedure coded the activities that the students listed in response to the first question of each section (e.g., rafting; town race; art workshop). For the questions that asked students why and how in relation to the activity, we coded responses based on grounded theory analysis. The coding protocol was updated in an iterative review-revise process informed by conversations and analysis rounds among the researchers.

Results

Table 1 shows the percentages of reasons for each of the selected benefits. For instance, if an activity generated connection to place what were the reasons provided by the students? One thing that stands out in the descriptive results of Table 1 is that there are different factors that produce the selected benefits. Also, the social factor plays a different role when producing connection to place in comparison to connection to others.

When asking students why the chosen activity made them feel connected to the place, their responses suggest that what contributed most was learning about the place during the activity. For example, finding a clue and learning about an historical event of the town. In relation to how people (friends or guides) helped students feel connected to the place, on average students mentioned as influencing factors receiving an instruction or experiencing an emotion. When looking at connections to others, the question probed for qualities or emotions that made students feel this connection. For qualities, students mainly focused on the social component.

Table 1
Reasons for Connection: Codes and Percentages of Student Responses for the Two Selected Benefits

	Social	**Location**	**Fun**	**Happiness**	**Felt supported**	**Other emotions**	**Instruction**	**Learning**	**New/novel**
Connection to Place									
Activity	8%	***42%***	0%	0%	0%	9%	7%	***29%***	4%
People	14%	3%	10%	6%	12%	***22%***	***30%***	3%	0%
Connection to Others	***27%***	0%	9%	***22%***	8%	***30%***	2%	1%	0%

Discussion and scholarly significance

The current exploratory study tried to identify some of the factors that lead to the reported benefits of in-person field trips. In this sample we found that different features affect different outcomes. The social factor plays a different role in the two elected benefits. Another finding is that activities where students can learn about the place, often through expository instruction, generate a connection to place. While field trips may be associated with direct experience, direct explanation can also happen during a field trip and seems to support connection to place. Finally, emotions play a key role in generating the selected benefits. Concurrently, a good next step is to engage in design experiments to figure out how to design for the identified factors that, by hypothesis, would improve the benefits of VFTs.

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Proposal and Evaluation of "proactive-Accentuated Nodding" to Enhance Active Listening in Presentation Education

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Abstract: This study proposes "proactive-accentuated nodding (PAN)" to enhance active listening in presentation education. PAN means to nod saliently without missing the relevant point of nodding. The evaluation in a university class showed that PAN reduced subjective distance between the listeners and the speaker as well as the listeners and other listeners, and to facilitate listeners' awareness of flaws in the presentation. On the other hand, the speakers rated their satisfaction with their own presentation lower when listeners conducted PAN.

Introduction: Proactive-accentuated nodding

Presentation education has focused on becoming a good speaker. However, as ethnomethodology (Sacks 1992) and the collaborative communication model (Clark 2008) indicate, talk is not a one-way act of information transmission from the speaker, but is a collaborative act that is established through interaction between the speaker and listener. If this is the case, education for "good talk" will require learning to develop not only good speakers but also good listeners. In this study, "nodding" is taken up as a basic research for fostering "good listeners" and examine how encouraging listeners to engage in "proactive-accentuated nodding (PAN)" affects both listeners and speakers. Here, "proactive" means nodding actively without missing the relevant point of nodding. “Accentuated" means nodding with large movements. The former encourages cognitive effort of intentional listening, while the latter encourages the conscious expression of understanding and agreement as a physical expression that is salient for the speaker. This combination is the essence of the active listening, which is actively involved in the collaborative organization of talk, and hence PAN is well suited for training as a listener.

Experiment

The effectiveness of PAN was piloted in a university presentation class for 58 Freshers. Students were divided into groups of five and gave an oral presentation of their arguments to the other students in the group using slides they had prepared (they had approximately 7 minutes). Presentations were made on MS-Teams (the facial image of each was displayed on their screens). No special instructions were given for the first two presentations (henceforth N-PAN condition), and after the two presentations were completed, they were instructed to perform PAN for the next three presentations (henceforth PAN condition).

To measure the effect of PAN, a questionnaire survey was administered to listeners and speakers after each presentation. The first is the IOS scale (Aaron et al. 1992). In the IOS, Listeners rated the subjective overlap between themselves and the speaker as well as the distance between the self and the other listeners on a scale of 7 (7 being the most overlapped and 1 being no overlap at all). The speaker rated the overlap between himself and the audience. The audience then responded to 11 items (5-point method) related to their understanding of the presentation, their relationship with the presenter, and their relationship with other audience members, while the presenter responded to 11 items (5-point method) related to their self-evaluation and satisfaction with the presentation and their relationship with the audience. After the class, the participants reported their impressions of the presentation activities incorporating PAN in an open format.

Results

First, the impact of PAN on the audience is shown. First, it was found that <u>the subjective distance between themselves and the presenter was originally close, but PAN brought them even closer</u> (mean IOS rating of 5.53 (SD= 2.00) for N-PAN condition and 5.09 (SD=1.90)) for PAN condition. This difference was significant (t=2.14 (186), p<.05*). Second, <u>the subjective distance between themselves and the rest of the audience was originally close, but PAN brought them even closer</u> (mean IOS rating of 5.66 (SD=2.36) in the N-PAN condition and 5.20 (SD=2.51)) in the PAN condition, and this difference was significant (t=2.00 (186) , p<.05 *). Third, <u>PAN had</u>

the effect of making the audience aware of the shortcomings of the talk. The score for the item "I can explain the bad parts of the presentation to others" was 2.84 (SD=1.16) in the N-PAN condition, but 3.15 (SD=1.03) in the PAN condition, and this difference had a significant trend (t=-1.89 (186), .1>p>.05 +).

Next, we show the impact of the PAN on the speakers. First, it was shown that the subjective distance between the presenter and the audience was originally far and was not changed by PAN (mean IOS rating of 2.57 (SD=1.80) for N-PAN condition and 2.38 (SD=1.66) for PAN condition). Second, we found that PAN lowered presenters' satisfaction with and evaluation of their own presentations. The score for the item "satisfied with my presentation" was on the positive side in the N-PAN condition (3.74 (SD=0.775), but shifted to the neutral side in the PAN condition (3.03 (SD=1.13). This difference was significant (t=2.63 (186) , p>.01 **). The score for "I am sure the audience enjoyed listening to my talk" also decreased from 4.04 (SD=0.58) in the N-PAN condition to 3.59 (SD=0.57) in the PAN condition (t=2.16 (186) , p<.05 **).

Discussion

The act of nodding indicates affirmation, understanding, and empathy (Hewes 1989), and the PAN asked the learners to listen to the presentation so as not to miss the places where such nodding was relevant. In their post-activity reflections, learners stated, "I was able to listen to the presentation with an awareness of where I could relate." and "For I was able to listen carefully to the presentation, it was easy to empathize with the presenter." Such comments suggest that PAN was effective in promoting active empathy with the speaker. In addition, large movements may have made it easier to see nods from other audience members even in the online presentation. These may have reduced the subjective distance between the listener, the speaker, and the other audience members by the IOS scale.

On the other hand, PAN had the effect of making the audience aware of the shortcomings of the talk. This is a side effect of actively searching and listening for points to nod. In other words, by listening to the presentation while looking for points to nod, it is possible that the audience also became aware of the weakness and insufficiency of the talk. The comment such as "I was able to pay attention to detailed information." suggests that PAN made the audience pay attention to parts of the presentation that they would normally ignore, thereby making them aware of the inadequacies of the presentation instead of overlooking them.

The effect of PAN on the speaker was severe: PAN did not reduce the subjective distance between the listener and audience. Furthermore, it lowered their evaluation of and satisfaction with their own presentation. This result is in sync with the study of Pertaub et al. (2002), who found that it is the neutral audience that raises the self-evaluation of a talk, while the positive audience gives only the same level of self-evaluation as the hostile audience. Furthermore, in the present practice, everyone in the class knew about the PAN, and the speakers were aware that the nodding of the listeners was, in a sense, exaggerated and excessive. For this reason, the simple positive effect of nodding could not be achieved. In addition, it can be pointed out that the PAN may have reorganized the activity of the classroom presentation. The true audience of the class presentation is actually the instructor who conducts the evaluation, and the other students as listeners have no agency for the presenter. In this sense, students do not have to worry about the evaluations of other students. However, with the introduction of PAN, other students become active listeners and evaluators who listen while looking for the appropriate place to nod. This may have placed a psychological burden on the presenter to be evaluated.

Conclusion

In this study, proactive-accentuated nodding was proposed. Evaluation of PAN in the college class showed that PAN had a generally positive impact on listeners while having a negative impact on speakers. We also noticed that the introduction of PAN may have reorganized the in-class presentation activities themselves. In the future, we intend to examine the causes of these results through more detailed analysis and to identify ways to design learning methods for better listening.

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Examining Preservice Mathematics Teachers' Instructional Moves in Promoting Student Agency

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Abstract: This study investigated how elementary math novice teachers (NTs) promoted student agency as they practiced enacting a lesson to engage students in the mathematical practice of defining. We conducted an interaction analysis of video recordings of two NTs' rehearsals to understand how NTs' instructional moves promoted or truncated students' agency. The results highlight ways in which NTs enacted contradictory moves as they attempted to promote students' agency and suggest where NTs might need support.

Introduction

Researchers and educators have sought to encourage students' engagement in mathematical practice (Lehrer et al., 1999). A key aspect of fostering disciplinary practice is promoting student agency, where students contribute and defend their ideas and comment on their peer's ideas (Clarke et al., 2016). Despite its value, promoting student agency can be challenging (Clarke et al., 2016). Research provides some images of more experienced teachers promoting student agency (e.g., Priestley et al., 2012). However, less is known about the teaching moves that preservice novice teachers (NTs) enact when attempting to promote agency in mathematical practice. In this study, we examined the ways that two elementary NTs promoted or truncated (took away) agency as they engaged students in the practice of mathematical defining during a rehearsal. In a *rehearsal*, an NT practices teaching a lesson to their peers, who act as students or observers, while a teacher educator provides feedback (Lampert et al., 2013). We focused on defining because it can be an accessible entry point for children to engage in mathematical practice (Lehrer et al., 1999). We asked: How do NTs promote or truncate student agency to engage in defining?

Theoretical perspectives and methods

We conceptualize *disciplinary practices*, such as defining, to consist of socially-negotiated and historically-situated forms of activity of the disciplinary community (Ford & Forman, 2006). In classrooms, students can engage in defining through activities in which they contrast examples and non-examples of a mathematical object to collectively author a definition (e.g., Lehrer et al., 1999). Because we are interested in how NTs distribute agency while engaging students in defining, we drew upon the sociological perspective of agency which examines agency as a function of the surrounding social structure (Clarke et al., 2016). This perspective involves examining opportunities for teachers to support students to take responsibility for and exert some level of control over their learning. We are therefore interested in how NTs' interactional moves (e.g., eliciting students' thinking) position students as authors of definitions. We thus drew on positioning theory, which provides a lens to understand how social interactions are enacted based on social attributes of the participants (Davies & Harré, 1990).

This study was conducted within a math teaching methods course for future elementary teachers within a teacher education program in Eastern Canada. NTs in the course learned about promoting student agency in defining through analysis of classroom videos, discussion of a reading, reflecting on their experiences when defining, and co-planning a definitions lesson. In addition, within their math and science teaching methods courses, NTs also worked to develop a set of core teaching principles (e.g., children are sensemakers) and practices (e.g., positioning students competently) (Lampert et al., 2013) intended to promote student agency by centering students' voices during instruction. Data came from one class. A subset of NTs participated in a rehearsal to support authorship of geometric definitions. Of the 20 NTs who conducted definitions rehearsals, 11 agreed to participate in this study. NTs conducted the rehearsals in groups of 2-3, with each NT teaching part of the lesson (~7-10 minutes). NTs were provided with two different definition lesson plan templates that they could use. To allow for a fine-grained analysis, we selected two NTs (Sam and Liz (pseudonyms)) who taught different lessons. We conjectured this might present a greater variety of ways in which student agency was promoted or truncated. Sam had taught a grade 2 lesson to define triangles. She started by asking students to discuss whether a shape was a triangle and then had them construct triangles and justify their constructions. Throughout their discussion, they collectively wrote rules for triangles. Liz taught a grade 4 lesson. She asked students to compare within and across groups of shapes, pre-sorted into types of quadrilaterals, to construct definition rules for different quadrilaterals.

To understand the nature of the NTs' moves when teaching, we drew upon Erickson's (1992) approach to interaction analysis. First, we delineated the rehearsal videos into episodes that began when the NT started teaching and ended when the NT stopped teaching (Lampert et al., 2013). We then transcribed the episodes, focusing on both verbal utterances and actions, and used conventions to capture emphasis, overlapping/latched talk, and pauses. We identified aspects of organizational structure by noting shifts in the topic or focus of discussion. We then identified participation structures to determine where agency was distributed by asking: Who is the primary speaker(s)? How are others participating (e.g., Agreeing?). Finally, to characterize the interactional moves that NTs used to promote or truncate agency, we asked a set of analytic questions about each turn of talk.

Results and discussion

Our results indicate that while the NTs made efforts to promote students' agency in defining, they nonetheless struggled in how they sustained students' agency. We provide two illustrative examples. First, the NTs sometimes *framed defining as a collective activity* for students to contribute rules and properties by using words such as "we" and "us". For example, Liz introduced the discussion by stating, "Ok, so we are gonna write some rules about how group A is different from any other quadrilateral that we sorted." Yet, at other times, Liz used language that *framed defining as individual activity* in which she was the sole author. For example, Liz asked students about the name of the "angle" of a square shown. After a student said, "a right angle," Liz responded, "A right angle. So in (group) A, I am noticing that…the squares have right angles-yeah," hence adding a new rule to the definition of square by herself. Even when another student drew attention to other shapes with the same property, Liz did not open the proposal for discussion but instead wrote it down as a rule for the shape. By fluctuating between the use of "I" and "we," she sent mixed messages about the distribution of agency. Second, both Sam and Liz *extended students' agency for participation to new students by asking for additional rules or properties*. They did this by recruiting more ideas on the same topic. For example, after Sam had already asked students to comment on why the example she had presented was a triangle, she asked, "What's something else that can tell us it's a triangle by looking at the picture?" In both rehearsals, this move allowed multiple students to participate in authoring definitional rules. However, NTs also *did not encourage discussion about students' proposed rules*. Instead, as seen in the example with Liz, when students introduced correct ideas, the NTs labeled the proposals as "rules" and wrote them on the board as rules. By shifting the authority to themselves, the NTs truncated students' agency.

Our study makes a contribution by characterizing novice teacher practice in promoting student agency when supporting mathematical practice. Our results highlight the complexities involved when NTs attempt to promote student agency. Given that the rehearsals were organized around core practices (Lampert et al., 2013), one would expect NTs to enact these practices with fewer difficulties. These core practices served as starting points for NTs to promote student agency (e.g., by inviting collective participation for students to contribute rules and properties). However, NTs also enacted these practices in ways that truncated students' agency (e.g., by revoicing too soon). Our results may help teacher educators anticipate ways that NTs may truncate agency.

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Pragmatic Imagination: A Tool for Seeding Participatory Design

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Abstract: This study explores the design and use of activities that seed and support district-wide teacher participation in developing a garden-based learning program. Participants envisioned and shared preferred futures for school gardens by fostering pragmatic imagination in a process of thought and action. Thematic analysis of artifacts establish five preferred futures that can serve as a foundation for ongoing participatory design framed in relation to future possibilities as well as past and present circumstances.

Introduction

Garden-based learning in the US is a century-long participatory design agenda within school communities, among schools and their local neighborhoods, and, most recently, across a national network of support organizations (i.e., sgsonetwork.org). As part of a researcher-practitioner partnership, this study positions school gardens as everyday project sites for integrating STEM opportunities and, by the same token, integrating student garden experiences across subject areas. This study aims to contribute to scholarly discussion on the role that possible and preferred future scenarios play in co-designing and continuously improving education programs. To this extent we employ the idea of pragmatic imagination (Pendleton-Julian & Brown, 2018) as theoretical inspiration for seeding the co-development of curricular activities and projects using an existing garden-based learning framework (Zuiker & Wright, 2015). In particular, the study examines the enactment of activities that challenge teachers to envision preferred future possibilities for a garden-based learning agenda over the next 10 years. Our design intention is to engage participants in exploring what is and what can be by grounding participatory design in creating possible future scenarios This preliminary effort interrogates emergent, future-oriented qualities of the outcomes generated through these activities.

Theoretical framework

Grounded in pragmatic philosophy, the idea of pragmatic imagination assumes that thought and action are irreducible aspects of experience (Alexander, 1990). Moreover, thought and action in educational and participatory design processes alike depend not only on how judgments situated in the present moment relate to habits developed through past experience but also how they relate to imagined possibilities projected into the future (Pendleton-Julian & Brown, 2018). Therefore, imagination from a pragmatic perspective is a critical partner in reasoning; it is a gap-filling process (Pelaprat & Cole, 2011) utilized to frame problems and envision possible resolutions (Steen, 2013). While the idea of pragmatic imagination is theoretically rich, embodying it in the design of participatory design agendas the learning sciences (e.g., Zuiker et al., 2017) remains limited. To seed interplay among past, present, and future as resources for participatory design, the following design study addresses this gap by fostering pragmatic imagination around possible future scenarios for garden programs.

Design

Two activities embody pragmatic imagination by challenging teachers to push the boundaries of the present toward possible futures. First, groups co-constructed a map of their school and local communities in order to identify allies and prospective partners. Second, groups discussed the future of garden-based learning in their schools in order to co-construct a newspaper frontpage from the future, including a headline and short lede about programmatic successes in the year 2032 (cf. Finlev et al., 2018). Underlying these activities, engaging with an extended timespan, like future headlines, can invite optimistic goals and increase empathy while potentially also reducing blind spots (McGonigal, 2022). Headlines, therefore, constitute a single written artifact grounded in both the relational task of partnering and the aspirational task of envisioning preferred futures.

Methods

A total of eleven teachers enacted our designed activities for 30 minutes during a monthly district-wide development meeting in the US southwest. Four pairs and one triad completed both activities, generating five future newspaper headlines and ledes. Thematic analysis (Preiser et al., 2022) organized inductive coding of the headlines in conjunction with their ledes, allies, and prospective partners.

Findings

Our thematic analysis resolved five themes: formal learning initiatives, expanding garden initiatives to home, expanding garden initiatives to the community, connecting gardens to in-school facilities, and within-garden initiatives. For example "Growing Minds and Gardens in the district community" aligns with the theme *within garden initiatives* because the group imagined a pollinator, vegetable, and indigenous plants garden; and with *expanding garden initiatives to the community* because the lede links the garden to a community farmers market. In this section we describe each theme in order to arrive at judicious interpretations of the future-oriented qualities of the activity outcomes. Four of the five groups imagined different ways to use the garden for *formal learning*, including ways to integrate the garden (partly) with the academic curriculum (e.g., using the garden as a habitat for science lessons), incorporating nutrition into the program (e.g., by working with a chef), implementing environmental education, and providing outdoor experiences for students (e.g., creating an outdoor classroom). Two groups had ideas on how to *expand gardening learning to home*. One group imagined allowing students to take food from the garden home, and another group suggested the garden project could connect with existing initiatives such as ones that provide farm fresh food bags. While all groups were interested in connecting to their local community, one group imagined *expanding school facilities for community use*. Their idea was to start using school spaces for neighborhood support by using the garden as a community garden, organizing farmers markets with cultural activities, giving access to a ‘food forest’, and building relationships with alumni. In addition, two groups imagined *connecting the garden with other school facilities* by using the harvest from the garden for meals in the school cafeteria. Finally, two groups imagined *possibilities within their garden*. One group imagined creating a pollinator and vegetable garden and growing indigenous plants, while the other group imagined a thriving ‘clean’ garden with edible plants. The 5 thematic descriptions above illustrate how participants projected and explicated current efforts to develop curricular activities and projects onto preferred futures for their shared agenda. At the same time, the themes also expansively frame participatory design by seeding aspirational goals in the immediate present purpose of curriculum development. Discussion considers affordances of future-oriented qualities for participatory design processes.

Discussion

We conjecture that the idea of pragmatic imagination can be a powerful tool for seeding participatory design. Findings demonstrate aspirational goals that amplify a present moment design agenda by projecting future possibilities associated with thinking about and acting through a district-wide, garden-based curriculum development agenda. The positive and opportunity-based qualities underlying these headlines can serve as a robust foundation for ongoing participatory design at the intersection of the past, present, and future of this agenda. In the upcoming months, we will be using the data we gathered during the activity to explore how teachers imagined embedding their future school garden within social networks as well as how teachers showed agency during the activity needed to put their ideas into action. In addition, we will use the results of this paper to make a video of the ideas the teachers imagined for their future garden and present that to them so we can use their feedback to reflect on our results. As we think this pilot study showed the potential of its ability, we think it is important to conduct additional research that provides insight into the working mechanism of how knowing, making, and playing are bound together by the imagination (i.e., Pendleton-Jullian & Brown, 2018).

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Toward a “Queering” of Mathematics: Understanding the LGBTQ+ Experience and Designing to Disrupt Normative Learning Practices

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Abstract: The experience of LGBTQ+ students in mathematics has been underexplored despite mounting evidence of discrimination, hostility, and retention in higher education and the workforce. This poster presents a qualitative pilot study which draws on semi-structured interviews to understand how one’s queer identity informs their experience in mathematics. Grounded in sociocultural learning theory and queer theory, it further aims to distill emergent design principles for a “queering” of mathematics that deconstructs and disrupts normative learning practices.

Introduction

With the sociopolitical turn in mathematics education, issues of power, identity, and equity have become especially important, undermining previously held perceptions of mathematics as culture-free and unbiased (e.g., Gutiérrez, 2013). Despite mounting evidence of discrimination, hostility, and retention in higher education and the workforce (e.g., Freeman, 2020), LGBTQ+ students have largely been left out of the discourse around minoritized populations in STEM, and mathematics in particular. Only relatively recently has such work started to emerge with visibility studies centering the experiences of LGBTQ+ students (e.g., Forbes, 2022) and curriculum design studies focusing on more inclusive pedagogy and content (e.g., Rands, 2009). Though advocating for inclusivity and representation in course design is important, what is needed is a more consolidated push toward a “queering” of mathematics in learning design at large that calls for a rupturing of existing norms and practices and a deeper rethinking of who and what gets privileged in mathematics spaces, with implications for the design of more equitable learning environments in mathematics (Dubbs, 2016). In this poster, I present preliminary findings from semi-structured interviews with graduate students who identify as queer to address the following research questions, guided by sociocultural learning theory: *How does one’s queer identity inform their perceptions of and experience in mathematics? How do we design for a queering of mathematics which deconstructs and disrupts normative learning practices?*

Toward a queering of mathematics

Once a slur, the term “queer” has been reclaimed in recent decades, in part as a transgressive act and in part as affirming identity. Definitionally, queer can be understood one of two ways: as pertaining to a minoritized gender or sexual identity (i.e., signifying an LGBTQ+ identity) or as pertaining to queer theory, a critical theoretical lens that challenges, deconstructs, and disrupts what’s normative, with an orientation toward action for social justice (Rands, 2009). The act of “queering” in the latter case then represents a subversion of norms toward equity. Applying queer theory in the learning sciences has been a relatively recent endeavor, with some disciplines and contexts emerging as more “queerable” than others, namely those in the humanities and social sciences (Rands, 2009; Dubbs, 2016), for their centering of social issues, with math not intuitively subject to be queered. Rands’ foundational work on “queering the unqueerable” identifies two approaches to a queering of mathematics, an “add-queers-and-stir” approach toward representation and inclusivity and “mathematical inqu[ee]ry,” an inquiry-based approach beyond inclusivity toward social justice.

Methods

In this exploratory pilot study, situated in the context of a 4-year minority-serving public institution in Southern California, with an HSI and an AANAPISI designation, I interview queer graduate students (n=4, ongoing) to understand how one’s queer identity informs their perceptions of and experience in mathematics, toward distilling emergent design principles for more equitable spaces for mathematics learning. Interviews are being conducted in person, or over Zoom, and are audio recorded, including questions around one’s experience as a queer person in mathematics, with other topics touching upon the tools, materials, and spaces of mathematics learning. In my analysis, I engage in iterative thematic analysis to surface emergent themes around queer students’ experience in mathematics, informing subsequent design goals.

Findings

In my preliminary analysis, the following themes around current curricular practices emerged as salient in informing identity and perpetuating an idea of mathematics as a space for dominant groups in the field (i.e., white, male, straight): *reinforcing the binary; math as impersonal; math as stagnant; math as gendered; importance of intersectionality*. Table 1 below presents a brief description of each theme and a corresponding data excerpt. In reflecting on their experiences, participants further painted a line of contrast between mathematics and the humanities or social sciences, where aspects of identity are made visible and more welcome, which is in line with extant work (Rands, 2009).

Table 1
Emergent themes

Theme	Description	Data excerpt
Reinforcing the binary	Math reinforces binary stereotypes.	*“Math is supposed to be this simple, sequential, binary thing… it always has a specific outcome.”*
Math as impersonal	No space for one’s identity in math.	*“You are not supposed to bring anything of you or from your background.”*
Math as stagnant	Math hardly changes over time.	*“What you’re learning has already been known, and there's only for you to now learn that.”*
Math as gendered	Math is perpetuating gender norms.	*“Most of the classes I took were very like male-dominated.”*
Intersectionality	Aspects of identity as intersecting and tightly connected.	*“I can't isolate my queerness from everything else that I am.”*

These five themes further presented opportunities for points of disruption of current norms and practices toward more equitable spaces for mathematics learning, configuring design goals to aim for (i.e., designing to disrupt the prevalence of the themes above). As such, a queering of mathematics should aim to dissipate binary divides and the focus on discrete outcomes and weave in considerations of math on a continuum (e.g., by considering different problem-solving approaches and the plurality of what counts as mathematics). It should further present opportunities for bringing one’s intersectional identity to the classroom (e.g., by leveraging applied mathematics in context and integrating personally-relevant, mathematics-integrated projects and products) and consider ways of challenging the notion that math is stagnant by shifting class structures and teaching practices (e.g., by shifting focus to collaboration as opposed to individual work or by drawing on different materials in the teaching and learning of mathematics).

Discussion

This exploratory pilot study sheds light on the experience of queer students in mathematics and contributes to a pressing call for a queering of mathematics toward more equitable learning opportunities for LGBTQ+ students (Dubbs, 2016). It lays the groundwork for further work to expand upon the design recommendations above and concretize them with a design implementation. With no consolidated approach on how to queer mathematics, a promising starting point, for instance, would be calling into question the dominant tools and materials that are in use in mathematics spaces.

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Scientific Practices in Professional Coffee Roasting

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Abstract: This poster expands imagery about who and what counts as "scientific" through examinations of non-laboratory, scientific workplaces. Using participant observation and microethnographic analyses of professional coffee roasters, we demonstrate that their senses are (1) used as scientific instruments, (2) coordinated with more normatively recognized instruments, and (3) prioritized over those instruments in moments of conflict. This analysis offers ways to recover the body in scientific work—a growing concern in the era of the Next Generation Science Standards.

Introduction and methods

American K-12 science education is modeled after the practices of professional scientists (NRC, 2012). These practices convey science as a disembodied, objective, and value-neutral enterprise—an image of science some call the "Legend" (for an extensive review, see Miedema, 2022). Recent scholarship calls for the body, along with its embodied practitioners, to be recovered and recentered in scientific activity (Latour, 2004; Maslen & Hayes, 2022) and science education (Hardahl et al., 2019; Stevens, 2012; Varelas et al., 2022). This poster responds to such calls and expands both who and what we count as scientific through close-up examinations of *non-laboratory, scientific workplaces*. Systematic investigation of these workplaces stands to reshape and expand our images of science, which in turn, shape the ways that science education is conducted in schools. In this poster we present an image of science developed from one of these everyday scientific contexts, that of professional coffee roasters among whom we have conducted ethnographic fieldwork. The work represented here builds upon prior attempts to expand understandings of what should count as science and mathematics (e.g., Bang et al., 2012; McDermott & Webber 1998; Stevens, 2000; Stevens, 2013) by locating the body as irreducibly central to roasters' workplace practices.

We began participant observation (Becker & Geer, 1957) at coffee roasteries in a large Midwestern American city in May 2022. We have since participated alongside and observed roasters in their workplaces, at professional conferences, company-wide trainings, and coffee courses. This poster draws from a broader corpus that consists of audiovisual data (Erickson, 2006), semi-structured and photo-/video-elicitation interviews (Harper, 2002), as well as field notes, jottings, memos, and annotated photographs (Emerson et al., 2011). In total (and ongoing), these sources represent roughly 200 hours and 250 pages of data.

Through interaction/microethnographic analysis (Streeck & Mehus, 2005; Stevens & Hall, 1998) we developed three claims about the scientific work of coffee roasting. The senses are (1) *used as scientific instruments*, (2) *the senses are coordinated (Hutchins, 1995) with more commonly understood scientific instruments*, and (3) *the senses, as scientific instruments, are prioritized over other instruments when they provide conflicting information*.

Findings: The senses as scientific instruments

Interaction analyses showed that coffee roasters' senses act as instruments to generate evidence and warrant claims. This evidence takes the form of evaluative statements like, "that smells great" or "that smells burnt, and we should try again." Roasters also generate evidence in the form of specific flavor and aroma experiences like "strawberry," "chocolate," and so on, and warrant claims about the quality of coffees with such statements.

Roasters coordinate their senses with more normatively recognized scientific instruments. For example, a roasting team in our study used an instrument known as a ColorTrack. This is a $7,000 device that analyzes the color of raw and roasted coffee and resembles spectrophotometers found in laboratory science. Roasters used their senses of smell and sight in coordination with the ColorTrack to determine the roast level (i.e., light, medium, dark) of coffees and to iterate on successive roasts of experimental coffee products.

What the senses 'said' often conflicted with different instruments (such as the ColorTrack), a situation Stevens and Hall (1998) term a "breakdown." These moments are when we learn that the body is a roaster's *most important* scientific instrument. Stevens and Hall write, "Breakdowns occur when routine ways of working are disrupted. And disruptions can appear at different places in a system of activity" (p. 140). When a roaster's senses conflict with their various representational media (e.g., ColorTrack, time, and temperature values), the senses are given priority. We have not observed a single instance of the instruments overruling the senses.

Discussion

In this poster we argued that coffee roasting not only involves scientific work and practices, but that the body is its key scientific instrument. Data showed that much of this sensing is coordinated (Hutchins, 1995; Stevens & Hall, 1998) across members of the roasting team and between internal representational states (the senses) and external representational media (data and material artifacts). Moreover, roasting involves highly disciplined ways (Stevens & Hall, 1998) of perceiving the world which in our fieldwork we can see through breakdowns in roasters' activity. As roasters resolved these breakdowns, we found our argument: that the body is *the* most important instrument—rather than an auxiliary instrument—as roasters prioritize their senses over conflicting forms of instrument-generated data. In advancing this argument we aim to contribute to ongoing conversations within science (e.g., Latour, 2004; Maslen & Hayes, 2022) and science education (e.g., Hardahl, 2019; Varelas et al., 2021) that challenge the erasure of the sensing, agentive body in images of science (Stevens, 2012).

Ongoing conversations about the body's role in science education are needed, as they influence how we teach and learn science. In our broader research program, we seek to also question the who and where of scientific practice, where the laboratory remains the default standard of what counts as science. Our examination of coffee roasting, the first of many planned sites for the investigation of *everyday scientific practice*, stepped outside of the lab into the wider world of how science is used. The roasters in our study inspire us to imagine potential transformations of science education; in the future we hope that this line of research will inform reconstructions of disciplinary education in science and beyond (Stevens et al., in preparation).

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Mathematics Learning Supported by App: An Experience With Students From a Public School in Maceió (Brazil) in a Learning Sciences Project Identifying the Arithmetic Discourse Profile

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Abstract: This work brings a qualitative research is being carried out by the Federal University of Alagoas and is based on an intervention in a public school in Maceió, Brazil. Using the Arithmetic Discourse Profile analysis tool and its criteria, we were able to assess the level of students' mastery of mathematical operations by integrating the use of applications with concrete material. The results showed that in relation to the criteria of focus on goal or on procedure and bondedness, students still have difficulties hesitating when talking about procedures, expressing uncertainty. Regarding the objectified/syntactic mediation, flexibility, agency/external authority criteria, there was an improvement, demonstrating that the use of integrated applications with concrete material for learning mathematical operations is effective.

Introduction

Nathan, Walkington and Swart (2022) explain that "mathematical cognition emerges from the interaction of symbolic, verbal and sensorimotor knowledge and processes; symbol systems are important disciplinary representations that encode formal knowledge, but their arbitrary, abstract, and amodal (i.e., ungrounded) nature presents challenges for learners". Thus, mathematical cognition is a complex process that also implies the subject's interaction with the environment, with the object and with the other in the construction of knowledge as a social practice.

On the other hand, it is necessary to analyse what discourse the students construct about arithmetic and the learning of mathematical operations and, therefore, is essencial observe and collect information about the participation processes, procedures used and identity in the narratives produced along the learning path, examining students' verbal interactions and writing by doing a procedural assessment. Therefore, the analysis through the Profile of Arithmetic Discourse proposed by Heyd-Metzuyanim, Tabach and Elbaum-Cohen (2022) using the criteria of Objectified/syntactic mediation, Flexibility, Agency/External authority, Focus on goal or on procedure, Bondedness will enable assess the extent to which a student masters arithmetic discourse by showing signs of understanding of basic arithmetic operations. In this sense, we present the initial results of a research involving the use of Apps integrated with concrete material to improve the learning of basic arithmetic operations, considering the use of technologies in the teaching-learning process, as recommended by the National Common Curricular Base, educational document Brazilian.

Pedagogical intervention using apps integrated with concrete materials

The experience reported in this work is an initiative that originates from the Academic Actions Committee of the Community of Learning Sciences Brazil (Ca.Br) from one of its functions, which is to articulate actions with Universities. The project started in August 2022 with 5 meetings in the workshop for teachers and 2 days of intervention at school, in classes from 1st to 5th grade of Elementary School.

Thus, in this work, we present the initial results of the intervention with two students who have difficulties in basic arithmetic operations and, for that, we use an App integrated with concrete materials to improve mathematical learning. To carry out the pedagogical intervention, we designed a map, with the methodological route in 3 steps, called Map of the learning process supported by App integrated with concrete materials: 1. Embodiment: use of App involving basic mathematical operations integrated with concrete material, in this case, golden material and open abacus. 2. Mediated Process: individual follow-up of the student while using the App, observing how student perform the operations (using mental calculation, verbalization, finger counting, use of paper and pencil), what difficulties student have (at that moment, the teacher intervenes with questions integrating the use of concrete materials to support the learning process with the use of the App, asking the student to explain his reasoning and if the doubt persists, the teacher explains demonstrating with the two resources – the App and the concrete material). It is a phase of learning monitoring, intervention and explanation for students. 3. Outcomes: triple collaborative process: between the student – integrated didactic resources (App and concrete material) – teacher mediation. It is expected an improvement in learning and the development of mathematical skills and competences such as understanding the algorithm of operations, agility in mental calculation, diversity of ways of performing mental calculation (by grouping and decomposition) and justification of mathematical procedures used to resolve operations. For this intervention, the App was used "Funny Mathematics" available on PlayStore, two kits with golden material and two abacus. The App features the four basic arithmetic operations: addition, subtraction, multiplication and division. It has an attractive layout with characters.

Findings and discussion

We will describe the results of 2 students who are in the 2nd year of Elementary School, aged 7 and 8 years old. The intervention was mediated by two monitors from the Matedtec team of the Federal University of Alagoas (Brazil). The first action of the intervention was the presentation of the App and how it works. The students knew about the golden material and the abacus because they participated in another intervention carried out the week before. At the beginning with smaller numerals, they were able to carry out the operations, although with greater slowness and in subtraction, they had the help of the golden material. As the numerals introduced consisted of tens, there was greater difficulty and mediation with the golden material was intensified, at the same time that they counted using their fingers. They do not master addition and subtraction operations that require regrouping and several times when asked about the meaning of 1 or 2 tens, they had difficulty to answer. So, it was necessary to use the abacus and show the orders and classes and then, as they were able to understand the orders and classes of numerals up to tens and the Matedtec team intensified the integration of operations with the App and golden material, the students were able to perceive that the noun 1 ten, 2 tens mean numbers/quantities (Objectified/syntactic mediation). With the use of the golden material and the abacus, the students realized that there is more than one way to carry out calculation procedures and in the different rounds they started to vary the procedures (Flexibility), as well as they started to pay more attention to the monitors' speeches during the mediation by examining verbs and pronouns related to the operations, which helped to perform the calculations, that is, they improved attention to look for verbal clues to solve the operations (Agency/External authority). But, regarding the Focus on goal or on procedure, in the subtraction operation with regrouping they could not explain the procedure and when the team explained it, they could not relate the procedure to the result, that is, they had difficulty in examining the procedure even with the aid of the golden material, presenting difficulties in relation to Bondedness. Regarding the division, they had difficulties and the use of the golden material was essential for them to understand the division based on the distribution of equal amounts. Regarding multiplication, in some operations performed with the 6, 7, 8, 9, the students had difficulties and again the use of the golden material was essential for them to understand what it means to multiply one factor by the other, that is, grouping with equal amounts . Thus, the students had greater difficulty in the multiplicative conceptual field that encompasses division and multiplication operations.

With intervention, there was a significant advance in the understanding of addition and subtraction operations when the App was associated with concrete material. It was found that this integration of didactic resources contributed to improving mental calculation, and it is important that the subtraction algorithm with regrouping is worked first with concrete material so that the students understand the role of orders and classes and quantities that exceed, so it is necessary to regroup and relocate in another order, for example, in the tens. These results also confirmed what Andin, Fransson, Rönnberg and Rudner (2015) found in a research: parietal activation patterns demonstrated greater involvement of the visual and quantitative systems for calculation than language. Hence, the layout of the App (visual aspect) and pieces of concrete material (quantitative aspect) when integrated, substantially improved the understanding of mathematical operations by the students, that is, there is a sensorimotor integration (touch on the smartphone screen and manipulation of the pieces of the golden material). The authors also identified that in exact operations the verbal system is more activated than in approximate mathematical operations and this we noticed when the students had to do the subtraction with regrouping, because in the case of an operation of passing the quantity to the other order, the students had difficulties in regrouping and explaining orally what should be done, that is, the retrieval of arithmetic facts in the cognitive structure is more agile in operations without regrouping, the language-calculation network is easily mobilized because they find more specific activation patterns and more similar ones that have already been assimilated.

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Preparing Preservice Resident Teachers for Equity-Centered Computational Thinking in STEM (STEMeCT) Education

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Abstract: While computational thinking (CT) in science, technology, engineering, and mathematics (STEM) education has been gaining momentum, there is a shortage of qualified teachers, especially in low-income schools that primarily serve minority students. STEM+C3 seeks to ameliorate the problem by establishing an urban teaching residency program that prepares teaching candidates to integrate CT and equity-centered practices. The project aims to understand the impact of the program on teaching residents and their students' perceptions of equity and CT.

Introduction

The integration of computational thinking (CT) in science, technology, engineering, and mathematics (STEM) education has been gaining momentum over the last 15 years (Tang et al., 2020; Weintrop et al., 2016; Wing, 2006). However, there is a shortage of qualified teachers, especially within schools that serve students in high poverty urban or rural and/or in high minority communities (Barth et al., 2016). Moreover, these same students have been marginalized in STEM fields, only making up 13% of the STEM workforce while comprising approximately 38% of the US population (Aish et al., 2018; Anderson, 2015). Nationwide, access to CS education is inequitably distributed with Black, Latino, and Native American students and students eligible for the National School Lunch program having the lowest access (Simoni et al., 2016).

STEM+C3 is an urban teacher residency program at University of California, Los Angeles (UCLA) that seeks to respond to these problems by taking an equity-centered approach in preparing pre-service resident teachers (TR) to integrate CT within their STEM classes in underserved communities. STEM+C3 integrates three critical C's: 1) computational thinking practices; b) computer science principles; and c) community of practice to foster a sustainable and systemic approach for developing equity-centered STEM teachers who understand and leverage CT in their teaching practices. STEM+C3 seeks to integrate these C's through a two-year cohort model. The program supports TRs by integrating CT and CS into their teacher preparation coursework at UCLA and pairing TRs with experienced partner teachers (PT) within a local partner school district who mentor the TRs following a gradual release of responsibility model (Fisher & Frey, 2013). Thus far, the program has recruited three sets of cohorts totaling 39 TRs, including 16 math and 23 science teachers. The TRs participate in a summer professional development (PD) workshop that introduces a framework for embedding CT and equity into STEM, 90 hours of partners in practice PDs that deepen TR understanding of CT by engaging them in cycles of reflection and revision, and a community of practice forum that engages TRs and their respective PTs in sharing knowledge.

STEM+C3 draws on asset-based pedagogies that are culturally relevant (Ladson-Billings, 1995), responsive (Gay, 2002), and sustaining (Paris, 2012) and their application to computational thinking (Kafai et al., 2020). Our program also conceptualizes CT as a tool for underrepresented students to resist marginalization and oppression in and outside of STEM classrooms (Kafai & Proctor, 2022). In brief, our program's approach involves mentoring and training teachers to design lessons and curricula that integrate CT practices and which explicitly value their culturally-relevant ways of knowing and being (Gay, 2002). Figure 1 provides a depiction of the integration of equity and CT within STEM+C3.

Research on the impact of the STEM+C3 is guided by questions at three levels that seek to ascertain: a) the program's impact on supporting TRs becoming equity-centered CT-integrated STEM (STEMeCT) educators; b) what specifically was involved in the development of TRs perceptions, conceptions, and understanding of becoming STEMeCT educators; and c) the impact and extent as well as the ways in which students have responded to TRs STEMeCT instruction. Our data sources include individual, partnered (TR & PT), focus group, and artifact-based interviews, surveys, equitable assessments of CT knowledge, classroom observations, artifacts from professional developments and classrooms, and learning management system data for TR coursework at UCLA.

Figure 1
Computational Thinking for Equity

<table>
<tr><th colspan="2">Computational Thinking for Equity
CT for Equity seeks to empower students to use problem-solving and design skills that are informed by computing to explore, express, critique, and create artifacts about the world around them.</th></tr>
<tr><td>Develop and Use Abstraction
Consider and focus on key components and filter out unnecessary details to make problems easier to solve and includes acknowledging the benefits and consequences of generalizations and or lost details.
Decomposition
Break down a problem of interest into smaller, more manageable components, and the ability to describe this process in detail in order to make decisions, obtain help or find solutions.
Exploring Equity Issues through Computational Thinking and Data
Encourage alternative ways of solving problems. Promote inclusivity and provide universal access to all students, particularly those from underserved and intersectional populations.</td><td>Algorithmic Thinking
Recognize when a solution to a problem can be broken into step-by-step instructions. This set of instructions considers the audience, the purpose, and can be used by someone else or a computer.
Debugging and Evaluating
The ability to identify and correct errors within an algorithm, and ensuring your solution is effective, feasible, and considers the impacts on various identities.
Collaborate Around Computing and Data
Work with others to understand, develop, and design computational artifacts or data visualizations to explore and explain phenomena, solve problems, or develop solutions that matter to students.
Communicating with and About Computing and Data
Describe, explain, and justify observations, patterns, and predictions around computational artifacts and data within the context of the problem as well as communicate applicable ethical considerations.</td></tr>
</table>

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The Narrative Construction of Transformational Science Identities

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Abstract: We report on a program designed to sustain undergraduate and graduate geosciences students' critical identity work in and around geosciences disciplines *and* the prospects of changing them for more equitable futures. We analyze students' culminating narrative artifacts to theorize broader processes of identity development and learning.

Introduction and theoretical framework

Among the natural sciences, the geosciences have suffered from a particularly persistent lack of diversity stemming from issues of access to programs and resources and, crucially, from deep historical and cultural practices within the field's various disciplines (Ormand et al., 2022). To address these issues, a university-based program ("The Program") was specifically designed to engage undergraduate and graduate students in a set of activities that sustain their identity work (Tan et al., 2013) in and around geosciences disciplines *and* prospects of changing them for more equitable and just futures. Here, we analyze students' culminating narrative artifacts to theorize about broader processes of identity development and learning in the sciences.

We draw from sociocultural and sociopolitical theories of learning and frame identities as lenses through which a person positions themself and their actions and through which others position such a person relative to socially and culturally available categories (Varelas et al., 2012). Identity *work* can thus be observed two prominent ways: in (1) in ongoing social interactions, as individuals negotiate, contest, and reify their multiple identities within communities of practice; and (2) in one's own narrative self-elaborations relative to practices and communities (Tan et al., 2013). We also draw from narrative perspectives on sensemaking and changemaking, recognizing that stories told about the geosciences reflect ways of finding meaning and value in the world, and mediate organizing processes for social and cultural change in the discipline. Examining student narratives thus gives us insight into their *experience of becoming* geoscientists, the meaning they see in this process, and what they feel is important for others to know.

Empirical context and method

The Program engages students over the course of two semesters in the authoring of personal narratives that are designed to change people's perceptions of what the geosciences are and who can become a geoscientist. The goal of the program is to show students how their own personal experience affords them a unique perspective to influence the discipline. Students are taught that narratives are "compelling" to an audience due to the way that storytellers establish and resolve conceptual, emotional and values-based tensions, and that narrative sensemaking within the contexts of a story can also pattern and compel certain ways of making sense of the world more broadly. Further, they are taught that counternarratives are a particular kind of narrative where storytellers draw from their own particular experiences to craft stories that stand in tension with status quo interpretations of the world, and which rationalize and compel change for better, more just and equitable futures. Students then set to work developing their own "changemaking (pathway) stories" to be crystallized in a short web-based video (~ 5 minutes) and a written personal profile, a process which involves personal reflection, interviewing (home) community members to better understand their audience and message, and participation in biweekly meetups where iterative drafts of stories are shared for peer feedback. To date, three cohorts of Program participants produced 28 video-based "pathway stories" and associated text-based personal profiles on a public website. These constituted the data corpus for this study and are treated as embedded cases for descriptive and comparative analysis. We took a narrative approach to the data (Czarniawska, 2004), treating stories as artifacts of student sensemaking that may reveal, pattern and contest the way meaning in experience is found and made. Members of the research team initially viewed cases independently, open coding videos and the text of the profile pages and writing short analytic memos. Codes were then compared and refined, a process that revealed that many students told their stories in the general form of a counternarrative, but constructed their narratives from very different kinds of experiences and for very different ends. We then analyzed, discussed and contrasted cases using a shared scheme for coding narrative elements: context, tension, resolution, change project, counternarrative, and lesson.

Analysis and results

For brevity, we present a single case—that of David (pseudonym)—to illustrate our main findings. David was a second-year geology student interested in studying paleontology. He rooted his "pathway" narrative chronologically in a childhood fascination with dinosaurs and youth-oriented science books. In his story, he identifies himself as Hispanic and a Catholic, and says he grew up in Texas where he did all his education and "found" his faith (profile). A dualism between "intellectual" and "faith" was thus established as the central emotional and epistemic tension driving his narrative. While he began to "fall in love" with his faith in middle school, the school "questioned" him about his belief in science. The school believed in a literal interpretation of the bible, and forced him to pit "science and faith against each other" in his own mind (video). Dealing with this was a "struggle" (video). David traces this struggle forward in the context of his schooling, saying that he experienced "the opposite problem" when he entered an "intellectual" culture in high school that "challenged" and "questioned" how he could "believe" in a thing that "doesn't have proof" (video). It wasn't until after a great deal of thinking, research and praying that he found a way to "resolve" the "schism" inside himself dividing faith and science (profile). He realized that belief without proof is "the definition of faith" (video). Not only did he not need to choose between science and faith, but "they rely on each other" and are both necessary to "answer each other's biggest questions" (video). Science and faith both "define" him, and they do different things. "Without a creator," the "mysteries" and "coincidences" in science would never be explained. Faith also instills in him an "appreciation" for nature and a "responsibility" to "learn" about and "take better care" of it (profile). Now he feels his scientific path in paleontology has been "set before" him by God (profile), and he studies geology not just to "discover new dinosaurs," but also to "enact social justice" and apply his learning about the past "to take care of" the present and future planet (change project; video). David draws a key lesson from his experience: While it may at the time have seemed easier "to simply choose a side" in the "struggle between two choices," he needed to have the courage to "swim in the gray" long enough to see that the choice was not "as simple as it seems."

In this narrative, we see David positioning himself as a child fascinated with dinosaurs, a Texan, a Catholic and a serious student. He articulated a formative tension he experienced navigating schooling environments that challenged and pressured him to make a stark choice: faith or science. It was his resistance to this normalizing pressure that caused him discomfort, but ultimately enabled him to understand religious and scientific worldviews as complementary and see how they could make him a more socially and ecologically conscientious scientist. David was not alone in presenting counternarratives built around tensions that were resolved through an eventual realization that one did not need to respect categories or choices received from authorities. Other student narratives drew a similar lesson that younger people could and should take time to hold complexity long enough to understand how to approach academic and professional disciplines in a different way. Having the courage to "swim in the gray" and maintain a critical stance toward received worldviews is directly linked to student's identity and future visions of changemaking.

Looking across student narratives, our analysis reveals the following about the relationship between identity and learning: (i) Developing an identity as a geosciences professional required reconciling past experiences that seemed to "split the self;" (ii) This process required reasoning about the past while also projecting a future identity as a geosciences professional and changemaker, and student narratives reflected both a move towards central participation in geosciences disciplines and towards changemaking in the field; (iii) The process engaged students' multiple identities (e.g., as members of various communities made to intersect through the fashioning of "pathway" narratives) and their articulation around their personal disciplinary interests.

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An Investigation of Feedback in Engineering Design Workshop for Teachers

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Abstract: In this study, we found the nature of teacher educators' feedback used in an engineering design workshop. The findings showed that teacher educators frequently focused their feedback on the participants’ process, and none of them focused on personal evaluation or simple praise, which is common feedback in classrooms. This study suggests the importance of teacher educators reflecting on their feedback during engineering design activities for effective engineering education.

Learning engineering through a teacher workshop

In the United States, the Next Generation Science Standards and several state standards require that elementary students be taught engineering content and practices (National Research Council [NRC], 2013). However, this creates significant challenges for teachers with no experience with learning or teaching engineering. Professional development (PD) can help teachers acquire new knowledge. Especially by alternately wearing a student's and teacher's hat during PD, teachers can better understand how to apply their own learning experiences to their classroom teaching. Additionally, teachers can identify potential difficulties and obstacles that students may encounter, which can help teachers anticipate the type of support their students will need (Sargianis et al., 2012). To support teachers' learning, teacher educators are required to guide teachers on how to implement engineering design instructions in their classrooms and provide productive feedback to their students. By observing teacher educators' feedback, teachers can transfer their learning to their students. Considering the importance of teacher educators' feedback during PD, we developed the following research question: What is the nature of the feedback given by teacher educators during an engineering design workshop?

Methods

This study analyzed video recordings and work products from an engineering design workshop for teachers in rural, low-income elementary schools. The eight participating teachers had an average educational career of 12.75 years, but none of them had experience teaching engineering. Four teacher educators with an average of 13.5 years in teacher education and 10 years in engineering teaching provided the workshops. In the study, teachers were engaged in the engineering design activity named “Save the Penguins” (Schnittka et al., 2010), which asks participants to design a container to keep a penguin-shaped ice cube from melting. Since the workshops were conducted remotely, the videos were recorded and divided into main sessions and breakout room sessions.

The data collected from the workshop were organized and analyzed in three stages. The first step was making event maps (Kelly & Crawford, 1997). Second, transcripts were created by selecting the part where the interaction involved feedback. Last, we extracted the emergent types of feedback based on transcript analysis based on Hattie and Timperley (2007)’s four levels of feedback: task (FT), process (FP), self-regulation (FR), and self (FS). FT focuses on immediate task accomplishment, FP on extending thoughts, FR on self-control and commitment, and FS on simple praise. The study's feedback data was initially coded based on emergent types, and both authors met to discuss and reach a consensus in cases of disagreement. After finalizing feedback types, the data were analyzed using the constant comparative method (Glaser, 1965).

Findings

In the workshop, feedback from teacher educators was presented in various types, from simple status checks to active scaffolding. First, FP was the most frequently observed type of feedback (see Table 1). Teacher educators encouraged teachers to come up with the next plan, suggested some ideas for further exploration, and asked about the expected pitfalls when they applied this activity to their classrooms. This feedback led teachers to come up with strategies to comprehend the tasks and expand their thoughts, which is more effective than at the task level for enhancing deeper learning (Hattie & Timperley, 2007). We also found a connection between teaching experience and the frequency of FP. Walter and Ellen, who have extensive experience in teaching engineering, used the FP much more than other teacher educators. Here, we do not intend to generalize the results, but we infer that more experience as engineering teacher educators might have taught them to use process level of feedback to facilitate teachers' comprehensive learning.

Table 1

The Frequency of Teacher Educators' All Levels of Feedback

	Walter (18*)	Ellen (26*)	Teddy (2*)	Linda (8*)	Total
Task level (FT)	8	4	6	6	24 (34%)
Process level (FP)	21	12	9	3	45 (63%)
Self-regulation level (FR)	1	0	0	1	2 (3%)
Self level (FS)	0	0	0	0	0 (-)
Total	30	16	15	10	71 (100%)

* Years of teaching experience

In addition to FP, FT was also frequently observed, with teacher educators reaffirming information related to the task or pointing out mistakes that teachers were making to prevent misunderstandings about the task. Finally, although infrequently used, teacher educators also addressed teachers' contributions and efforts, mentioning their achievements based on evidence or criteria of engineering design activities, which can be linked to the self-regulation level of feedback. For example, when teachers figured out the way to make the container cheaper, Linda said, "Great, you found a cheap and effective idea!" One of the most important tasks in engineering design activities is making a model in a cost-effective manner. Thus, this type of feedback can be linked to self-regulation level, not self-level, in terms of being distinguished from simple praise. Finally, FS was not provided during workshops, which is uninformative and has a negative effect on learning (Hattie & Marsh, 1995; Hattie & Timperley, 2007).

Conclusion and implications

Even though engineering education has been emphasized in elementary education, most elementary school teachers have little understanding of engineering (NASEM, 2022). Teachers in rural areas often face challenges in accessing high-quality professional development opportunities, including those related to teaching engineering design activities. This study found that teacher educators frequently provide process and task-level feedback to teachers, which can help teachers implement effective engineering design instruction. In it, we also found that the teacher educators with comparatively long experience in teacher education and teaching engineering frequently used the process level of feedback. Task level of feedback was the next frequent type of feedback, and none of the teacher educators used the self level of feedback. Learning and doing engineering through teacher workshops is essential for them to develop their teaching expertise in engineering. Furthermore, teachers' engineering experience during teacher workshops can be connected to classroom practices (Johnson & Gil, 2022; Sargianis et al., 2012), so it is important for them to experience meaningful and effective feedback during engineering workshops. Furthermore, feedback during engineering design activities has a positive effect on the classroom environment as well as relationships between teachers and learners (Burnett, 2010). Therefore, this study suggests that investigating feedback experiences that teachers received in engineering design workshops become a cornerstone for future studies on feedback in engineering education for teachers.

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Designing for Teacher Noticing in College Mathematics

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Abstract: We report on the first phase of a design-based research project aimed at investigating the efficacy of a video-annotation curriculum for college mathematics instructional teams centered on teacher noticing and aimed at supporting the teaching of proof-writing. Teacher noticing involves attending to student thinking and classroom interactions to guide teaching decisions. We discuss our design efforts and share the evolution of the design conjectures that resulted from an interdisciplinary collaboration between mathematics and education scholars.

Introduction and theoretical framing

The transition to upper division proof-intensive math courses can be challenging for college students, with many switching majors within three years (Leu, 2017). Additionally, math classrooms can be marginalizing spaces, particularly for women and students of color (Leyva et al., 2021). Research suggests that student-centered instructional practices can lead to higher learning gains and benefit all students and particularly minoritized students. Noticing in Mathematics for Student Success (NIMS²) is an NSF-funded research project aimed at investigating the efficacy of a video-annotation curriculum for college math instructional teams centered on teacher noticing. Noticing involves attending to and making sense of student mathematical thinking and interactions to inform teaching decisions (Jacobs et al., 2010). This includes ways teachers attend to issues of equity, culture, and power (van Es et al., 2022). While noticing has been examined extensively in K-12 settings, very limited research exists in higher-education contexts. This poster focuses on the project's first design phase and explores the design conjectures and considerations that drove the adaptation of noticing learning activities to the higher education context.

Mode of inquiry

The project is a partnership between the Mathematics Department and the School of Education at a public Hispanic-serving institution on the West coast of the United States. The interdisciplinary team, consisting of both faculty and PhD students, met weekly over the course of the first phase of the project to design the curriculum for instructional teams (including mathematics faculty, teaching assistants, and undergraduate learning assistants) teaching an introduction to proof-writing course. Data sources for the project included field notes from weekly meetings and relevant artifacts, such as conjecture maps outlining the working theory guiding the curriculum design. Artifacts were analyzed to document the design process and decisions.

Findings

Four considerations emerged from the project meetings that guided the design of the 10-hour video-annotation curriculum:

- The need for a proof-writing framework. In meeting discussions, it became clear that a central challenge of the noticing curriculum was to elevate the skills of proof writing (e.g., generating examples to make sense of the statement to be proved, or making use of a definition) from general mathematics content. While an assigned task may focus on functions (mathematics content), students must also access skills that proficient proof writers possess. Thus, we realized we needed a framework for proof writing to unveil potentially hidden aspects of the introduction to proof course.
- Supporting the development of a vision of high-quality mathematics instruction. The curriculum aimed to shift the vision of mathematics instruction at the college level by centering student thinking and participation. However, unlike K-12 teachers, college instructors lack pedagogical training and may feel pressure to cover material rapidly in large lecture courses. To support the enactment of noticing, parameters for high-quality mathematics instruction within the constraints of the college setting were made explicit, considering both lecture-based and group-work contexts. For example, we conjectured that the noticing curriculum would need to make explicit how interactions can be shaped to create opportunities to notice student thinking and responding in ways that support understanding in settings that are typically dominated by teacher-directed instruction. We also decided to make explicit norms for

discursive participation in noticing sessions to support an inquiry stance to student thinking and instructional practice.

- Centering equity. Drawing from research (Leyva et al, 2021) and our personal experiences with university mathematics departments, we recognized from the beginning that we needed to center issues of equity in the design of the noticing curriculum. Through project meetings, we continuously grappled with where and how to elevate this issue. Equitable, quality teaching is multidimensional, addressing student identity and authority as well as reimagining instructional practices (Aguirre et al., 2013; Schoenfeld et al., 2020). We determined that our equity and responsive teaching framework needed to explicitly attend to recognizing students' assets (instead of deficit perspectives) and discuss how implicit bias may impact what instructors attend to and how they interpret student responses. We thus included in the design opportunities for participants to consider how sociocultural and political factors might inform one's noticing. Finally, we decided to prioritize opportunities for instructional team members who have varied expertise and perspectives to collaborate and learn from each other.
- Practical constraints. The final set of design considerations stem from the practical constraints of developing a curriculum for college instructional teams. These included: acquiring video clips that would generate the type of thinking and conversation desired for our noticing tasks and coordinating participant schedules. To meet scheduling demands, the curriculum modules needed to have both face-to-face and online asynchronous components, with asynchronous tasks including opportunities to enact and reflect on learnings in practice.

Discussion and Next Steps

The main aim of the NIMS² project is to adapt a body of work that has been very generative for understanding and improving the competencies of K-12 mathematics teachers to the context of mathematics college teaching and instructors at various levels of their teaching careers. The first exploratory phase of the project was productive in that the interdisciplinary collaboration between education and mathematics scholars was able to surface specific needs and goals that can be integrated into the design of the video-annotation curriculum. A tension that remains is to design tasks and activities that are responsive to and engage productively mathematics department instructional teams while also preserving the complexity of theoretical understandings of high-quality teaching and equitable practices that we draw on from educational research. Ultimately the multiple opportunities to test and iterate the curriculum and revise it based on learning evidence and participant feedback will allow us to adjust and optimize the design.

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Centering Culture in the Clinic: How Healthcare Professionals Learn Through a Trauma-Informed Cultural Competence Training

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Abstract: Inequities in the healthcare system are a persistent issue and disproportionately harm minoritized groups. There are movements in the healthcare community toward providing culturally centered care where healthcare professionals are cognizant of their own and the patients' personal cultures. Our team of university researchers and healthcare professionals co-developed a trauma-informed cultural competence training (TICCT) and investigated how this training shifted the healthcare professionals' interactions with colleagues, care for patients, and self-perceptions.

Introduction

The healthcare community is beginning to address historical inequities in care practices by finding ways to incorporate patients' cultures while recognizing that the healthcare professionals' culture is also present in the relationship (Hammel, 2013). In pursuit of this goal, we, a team of university researchers and healthcare professionals, formed a research practice partnership to co-develop a Trauma Informed Cultural Competence Training (TICCT). We implemented the TICCT with all medical professionals at the Intensive Outpatient Clinic (IOC) over six months using online modules, a mid-course team discussion, and an in-person workshop. The course included modules on developing self-awareness and awareness of others as cultural beings, understanding healthcare inequities, trauma-informed approaches to care, and applied skills. Situated in constructivism, cultural competence, and trauma-informed care, we draw on a range of qualitative data to investigate the research question: How does a TICCT shift healthcare professionals' interactions with colleagues, care for their patients, and self-perceptions? We found key shifts which revealed an interdependence across relations to self, colleagues, and patients in the form of a holistic commitment to TICCT within the context.

Overview of the literature

Cultural competence and trauma-informed care are approaches to healthcare that recognize the history of the healthcare system and the positionality of the healthcare provider. A culturally centered approach to healthcare focuses on insight and intentionality of how a healthcare professional's social location and worldview may differ from others, particularly patients and colleagues, toward the overall goal of learning and applying more culturally responsive care (Hammel, 2013). The core components of cultural competence include awareness of your own and others' culture as well as developing knowledge and skills for effective and respectful cross-cultural interactions (Tehee et al., 2020). Trauma-informed care is an approach rooted in the belief that an individual's current and future decision-making is influenced by their past traumas (Schimmels & Cunningham, 2021). Trauma-informed care considers trauma experienced by both patients and healthcare professionals that might influence their relationship and care.

Research design

Our team of university researchers and healthcare professionals designed the TICCT over Summer 2021 and implemented the first training module at the end of 2021. Over roughly six months, all IOC healthcare professionals (n = 9) completed the online modules, mid-course team discussion, and in-person workshop. All nine members of the IOC team consented to participate in the research, and six members consented to participate in a one-on-one in-depth interview and a follow-up meeting. Here, we focus on the six team members who consented to participating in all aspects of data collection, which included: fieldnotes and recordings of team discussions, course participation data, six interviews approximately one hour in length, and five member-check meetings approximately 30-minutes in length – one participant left their position at the clinic during data collection. Pseudonyms are used for all participants. We developed themes inductively with a grounded open-coding process (Saldaña, 2009) and deductively used three literature-informed areas as thematic categories:

personal, patient, and colleague. In addition to triangulating themes across data, we shared insights and adapted as appropriate to achieve resonance across participants. We then employed an intrinsic case study approach (Stake, 1995) by developing data from each participant as a case, specifically tracing engagement across personal, patient, and colleague categories.

Findings

Through individual and collective engagement with the TICCT, participants reported shifts in practice, which we traced across three spheres: interactions with colleagues, care for their patients, and self-perceptions. First, participants shared extensively that interactions with colleagues shifted through developing deeper understandings of self and others, critical self-inquiry, vulnerability, and discussions of challenging issues at the intersection of health and social wellbeing. Many aspects of the TICCT, such as online discussion posts and in-person activities, generated a shift in work toward becoming a "better team member" (Summer, Interview, 03/29/2022). Second, participants also shared how the TICCT supported their empathy with patients. For example, Angela reflected on how she noticed she was able to "examine from different directions" and had more "openness in going into things with [patients]" (Angela, Interview, 04/14/2022). Lastly, in addition to shifts in interactions with colleagues and care for patients, participants reflected on how they applied their growth in understanding their own personal history and culture, which led to "a different way of orienting to people and the world" (Inez, Interview, 03/23/2022). Tamara further reflected on this personal shift, "it's good to look back on how you were thinking when it first started, and how that has changed, y'know, with learning more" (Interview, 03/28/2022). Finally, participants across the IOC shared different ways in which they internalized the movement toward centering culture beyond their work setting and into their personal lives. Our findings show how group engagement with a trauma-informed cultural competence training guided shifts in practice with their patients and colleagues at work as well as across their personal lives. Moreover, prior to implementing the TICCT, participants shared how the IOC embodied a practice of working as a collective team toward holistic wellbeing, which makes this clinic setting unique compared to individualism and siloed approaches often observed in other healthcare settings.

Discussion: The importance of cultural training & holistic commitments

Though massive health inequities persist across the healthcare system in the United States, there continues to be minimal support for and available training in cultural development, competence, and humility for healthcare workers (Browne et al., 2018; Schimmels & Cunningham, 2021). Our study offers important insights into how healthcare professionals used the tenets of cultural competence and trauma-informed care to develop a deeper understanding and empathy for their colleagues, their patients, and in their personal lives. Participants shared instances of applying the awareness and skills gained from the TICCT across all spheres of their life, which often yielded holistic commitments to feeling more, listening more, and interacting differently. As scholars invite us to center culture in clinical contexts (e.g., Browne et al., 2021; Lekas et al., 2020), this study contributes empirical insights into how healthcare professionals engage with and learn through cultural trainings. The perspectives and stories of the healthcare professionals we shared in this poster demonstrate the potentially transformative nature of centering culture in healthcare contexts, particularly in humanizing not only patients but also the professionals themselves as whole beings with rich cultural identities.

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Using Hierarchical Time Series Clustering to Capture the Trajectories of Epistemic Emotions: The Case of Confusion

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Abstract: This study explored the use of hierarchical time series cluster analysis to group learners based on their epistemic emotional trajectories while rating true or fake news articles. We analyzed one epistemic emotion, confusion, while accounting for the dendrogram shape and cluster validity. Our analysis highlights the dynamic nature of emotions by taking account of the temporal fluctuations of how an emotion is experienced. Such analysis can aid further research on how learners digest complex information.

Introduction

Evaluating the legitimacy of health-related news involves deciphering complex information, and hence can often involve epistemic emotions: emotions elicited when appraising whether new information aligns with one's existing beliefs (Vogl et al., 2021). Such emotions have particular functions. For example, confusion can potentially foster learning as it requires active engagement and cognitive effort for learners to resolve the aversive state (Vogl et al., 2021). To help support individuals to more effectively and reliably navigate the current media landscape filled with information that varies widely in quality, it is crucial to understand the roles of epistemic emotions in health news literacy contexts.

We used a hierarchical time series cluster analysis to explore the types of epistemic emotion trajectories students can experience when evaluating health-related news articles. While prior work that employs cluster analysis to explore learners' emotional profiles exists (Poitras et al., 2019), research accounting for emotions' dynamic nature is scarce, especially in an epistemic context. Our primary research question for this short report was: what are the emotional profile clusters formed for the epistemic emotion confusion?

Methods

Participants and study procedure

The current study used data from 71 undergraduate students (58 female; $M_{\text{age}} = 20.0$; $SD_{\text{age}} = 1.49$) at a North American University. Students participated and data was collected online. $25 electronic gift cards were given as compensation for participants who completed the study. Our participants were from a larger RCT study featuring three conditions: 1) video-based learning group (n=23); 2) text-based learning group (n=24); and 3) control learning group (n=24). The first two groups' learning focused on emotion regulation and media literacy, while the control group focused on space and blackholes.

Post learning, all learners rated the credibility of 12 media vignettes (100-120 words). Six vignettes were factual and from mainstream news sources while six were fake and from non-mainstream sources. After each rating, learners completed the Epistemic Emotions Survey (EES; Pekrun et al., 2017). We hence had 12 time points for each learner. The aim of our larger study required counterbalancing the vignettes. Therefore, the 12 vignettes were presented in a different order for vignette group A (n = 37) than group B (n = 34). This report focuses only on vignette group A.

Hierarchical time series cluster analysis

We used R, with the dtwclust package (v5.5.11; Sarda-Espinosa, 2022), and chose hierarchical clustering due to our small sample size (Meyers et al., 2017). Datapoints were first standardized. Data screening revealed that no data was missing and therefore no participants needed to be dropped. Our analysis produced seven cluster validity indices (CVI): the Silhouette index (SIL), Score Function (SF), Calinski-Harabasz index (CH), Dunn index (D), Davies-Bouldin index (DB), Modified Davies-Bouldin index (DBstar), and COP index. High values for the first four, and low values for the last three supported a better model (Sarda-Espinosa, 2022).

Interpretation of dendrograms

Hierarchical clustering produces dendrograms, which shows how data points merge into clusters. While the CVI can suggest optimal number of clusters, the nature of cluster analyses being exploratory allows researchers to develop their own interpretations based on their expertise (Meyers et al., 2017). We interpreted our dendrograms by first identifying a consensus amongst the CVI. Often the consensus would be two clusters, but in cases where: 1) one cluster was disproportionately small (e.g., 2 vs. 35 members) and 2) CVI showed support for a higher cluster count, we explored results with higher cluster counts. We aimed to identify varied emotional profiles, and hence avoided results with a single cluster containing the vast majority of the participants.

We opted for a six-cluster result (SIL = .21; SF = 8.49e-06; CH = 9.31; DB = .60; DBstar = .72; D = .25; COP = .26) based on improved DB and Dbstar indices from five clusters to six (DB = .80; Dbstar = .85 for five cluster result). Doing so helped us avoid having two clusters where one would only have a single member. While choosing a higher number of clusters can be valid, we opted for the more parsimonious cluster count.

Findings

We identified a dominant cluster (n = 24), which revealed that participants generally experienced low levels of confusion throughout the media rating activity, with the exception of small peaks at the very beginning and in the middle. Our second cluster (n = 9) grouped participants who seemed to steadily experience moderate to high levels of confusion. Lastly, we identified four “clusters” with just one membership that were outliers relative to participants clustered into the first two groups. These participants seemed to exhibit higher levels of confusion than the first two clusters, characterized by rapid fluctuations of self-reported confusion.

We believe our approach can reveal “conventional” trajectories of emotions learners may experience in specific contexts. For example, our analysis shows that 24 learners out of 37 (i.e., 64.86%) tended to experience low levels of confusion with moderate ‘spikes’ or ‘bumps’. A typical learner therefore may find most of the 12 media vignettes not too confusing but may encounter an article occasionally that elicits confusion. Our second cluster suggests that some learners, on the other hand, may experience moderate to high levels of confusion throughout media message rating, though this is less common. Our analysis also revealed outliers, highlighting unique emotional experience trajectories.

Time series analysis from D’Mello & Graesser (2012) suggest that new information that contradicts existing information can lead to confusion and disequilibrium. A state of engagement may be achieved by resolving confusion—if unresolved, frustration, or even boredom may occur. Identifying patterns we can discern from other cluster analyses (for other emotions and both vignette groups) as well as exploring the feasibility of running an analysis that accounts for more than one emotion at a time stand to expand our understanding of how learners assess and understand media messages. Lastly, our time points were not continuous intervals (e.g., emotions measured every second). Therefore, conducting a time-series analysis with a continuous data channel, such as skin conductance or automatic facial expression recognition software, represents another future direction.

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International Society of
the Learning Sciences

Curating Data Sets to Support Students to Create Complex, Investigable Questions About the Impacts of COVID-19

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Abstract: We report on the curation of data sets and design of a tool that allows students to investigate questions using COVID-19 data. Student work from iteration one informed redesign and curation of new data sets to support deeper student thinking. Iteration two resulted in more complex, yet unanswerable, questions. Results reveal opportunities to address the scope of data sets and the tool's limitations, highlighting the importance of iterative design to support students working with data.

Introduction

Engaging with large, publicly available data sets present opportunities for students to explore issues relevant to their lives (Lee et al., 2021). Creating meaning from data sets calls on students to create questions that can be answered with the data available, create and test hypotheses, construct data visualizations, and analyze visualizations to come to a coherent understanding of the data. Curating the right data for students to explore is one challenge in this process (Cherrstrom & Boden, 2020) and involves balancing scope, messiness, and other characteristics of the data (Kjelvik & Schultheis, 2019). Our objective in this study is to explore how the iterative design of a data tool and curation of data sets supported students' meaningful investigations of how different communities were impacted by COVID-19.

Methods

We used a design-based research method (Bell, 2004) to refine the curation of data sets and a data tool (called the Data Explorer, or DE) students used to investigate the data sets. The DE lives within a curricular unit, *Covid-19: Data Science, and Equity.* It was created using an open-source web-based inquiry science environment which is informed by Knowledge Integration pedagogy (Linn, 2011). Students created questions after exploring available data sets and selected a single data set for further investigation. After reviewing their data set, students selected one X and up to three Y variables. The DE then automatically displayed variables in a bar or line graph with labeled axes. Two rounds of iterative refinement of data sets and DE were completed. In the first iteration of the DE (I1) students could explore state or county COVID-19 data sets. Data sets contained COVID-19 cases and population percentages for different racial/ethnic categories across four states or counties. I1 data sets were nine by eight cells. In iteration two (I2) students could choose between four larger data sets on vaccination, job-loss, essential workers, and pre-existing conditions[1]. Data sets also included demographic information such as age, gender, poverty levels and race/ethnicity. The first and second authors created these expanded data sets based on student interest and increased availability of published data. New data sets ranged from 14 by 16 cells (essential workers) to 59 by 16 cells (vaccination).

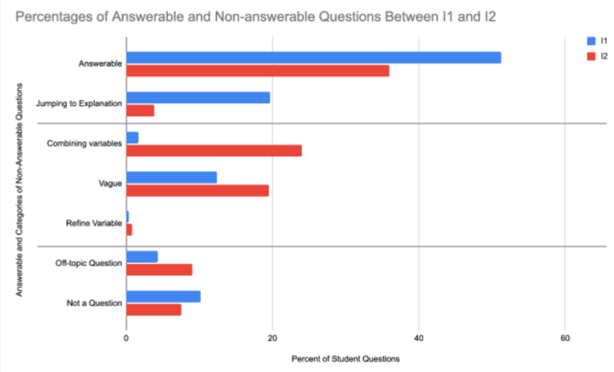
I1 was used in two schools with three teachers (two 8th-grade teachers and one 9th-grade teacher) and their students (N = 403) in fall 2021. I2 was used in fall 2022 by the original ninth-grade teacher and two additional ninth-grade teachers at a different school (N = 227). All schools were located in the same metropolitan area. To assess the effectiveness of curated data sets and the DE the first and second authors analyzed student questions. Questions were categorized as "answerable" or "non-answerable" based on the students' chosen data set. Non-answerable questions were further categorized into the reasons they could not be answered (Figure 1).

Results

Iteration 1 results: In I1, 51.2% of the 234 student generated questions were answerable. Of the remaining non-answerable questions (48.8%), questions that jumped to explaining why trends in the data existed (19.7%) were most common (Figure 1). These questions were unanswerable with the data available. Results suggest that, while a valuable exercise, the data sets used in I1 were too simplistic for students to deeply investigate how different communities were impacted by COVID-19. For I2, the first and second authors sought to broaden the topics of data sets and curate more complex data sets to support students to ask and investigate more complex questions.

Figure 1

Percentages and examples of answerable and non-answerable question types in iterations 1 and 2.



Answerable I1: What is the relationship between the percent of the population and percent of covid cases by race?

Answerable I2: What the difference between covid cases between Latinos in Alameda county and San Francisco?

Jump I1: Why is there so many cases with Hispanic and Latino people in Los Angeles county?

Jump I2: Why does Butte have a high social vulnerability index?

Combine I1: Why is there more cases of Latino people than African Americans in San Francisco county and Santa Clara county?

Combine I2: What's the vaccination rate for the people in poverty?

Vague I1: How do all the races relate to each other?

Vague I2 What is the impact on the economy?

Iteration 2 results: Fewer answerable questions were constructed in I2 (36% out of 133 total questions). However, many non-answerable questions were a result of students attempting to combine two variables together in a data set (24%), something infrequently seen in I1. For example, students attempted to explore how certain risk factors, such as poverty (Figure 1) or having health insurance, affect vaccination or COVID-19 outcomes. A higher percentage of students wrote vague, on-topic questions (19.5%) for data sets they were investigating but did not specify variables. This suggests students had difficulty identifying relevant variables within larger, more complex data sets in I2.

Conclusion

We iteratively curated data sets and designed the DE to support students to investigate large, publicly available, COVID-19 data sets. Results show promise in students' ability to pose complex, relevant questions, but also highlights the need to provide students with additional support to create answerable questions using available data. Results indicate the scope of data sets must be somewhere between the simplistic data sets in I1 and overwhelming data sets in I2. Balancing the complexity, scope, and size of data sets proved challenging (Kjelvik & Schultheis, 2019) and iterating on these data sets to address these issues will be important to better support students. The results also suggest possible improvements to the DE. 24% of students attempted to combine variables in ways the DE could not support. This indicates the DE must be updated to allow for these complex comparisons. We hope that future iterations of the DE (including this new feature and refined data sets) will support students to create meaningful, answerable questions.

Endnotes

(1) Data sets for I1 and I2 were curated from county public health websites, the Center for Disease Control, US Census, U.S. Bureau of Labor Statistics, and the Economic Policy Institute.

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Transforming Learning Data into a Machine Learning Model to Help STEM students Transition to University

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Abstract: Machine Learning (ML) may be a promising tool for predicting student success. Our research aims to predict student performance in specific STEM courses using ML. Self-reported scores on learning strategies, metacognitive awareness, mindset, and misconceptions about the brain were evaluated along with learning analytics to predict grades. The model demonstrated a high correlation between learning attributes and performance with an initial classifier accuracy of 78%. This approach is promising for tailoring our learning strategies for specific courses.

Introduction

Learning is known to be challenging and stressful for incoming undergraduate STEM students especially given the sheer volume of content to be mastered and the limited capacity of the human brain (Wieman, 2007) . The McGill Office of Science Education created the SciLearn program to support incoming undergraduate STEM students with their transition to university-level learning. The program includes a series of workshops, peer collaboration sessions, and special events. The program has been integrated in two large introductory science courses. This study aims to use machine learning to predict student success (Shahiri & Wahidah, 2015; Guleria et al., 2015) in first-year STEM courses. The research question guiding our work is: *How can we leverage attributes that are highly correlated with students' academic success to help early undergraduates become self-regulated learners?*

Machine Learning Methodology

Our methodology involved the normalization of data, correlation of study features, and generation of predictive models (classification and time series) with predicted grades. The system model is divided into three phases *Data Acquisition*, *Modeling*, and *Evaluation.*

Data Acquisition

This phase involves collection of data from various sources (Table 2) for the cohort Fall 2021 & Winter 2021.

Table 2:
Data Attributes and Source (count 400 students)

Data Category	Attributes Collected	Data Source
Demographics (Background)	Background data: Educational background, gender, first-generation, disability etc.	Survey
Learning Inventory Data	Learning Strategies Inventory (LSI), Metacognitive Awareness Inventory (MAI), Mindset and Neuromyths score.	Survey
Progression Data	SciLearn Peer collaboration and lab attendance, grades on assignments(assesments), learning analytics progression data	McGill Learning Management System (LMS)
Atomic Habits Adopted	Atomic Habits (evidence-based strategies: napping, scheduling, notes taking, avoid multitasking and peer learning)	Feedback text McGill LMS

Modeling & Evaluation

Modeling involved data cleaning, normalization, one-hot encoding, feature engineering, analysis, and model training. Four metrics were used to evaluate the performance of our model included 1) *Accuracy*: How many times the ML model was correct overall (Ben-David, 2007; Huang & Ling, 2005) 2) *Recall*: Model's ability to detect positive samples (Baeza-Yates & Ribeiro-Neto, 1999) 3) *Precision*: How good the model is at predicting a specific category (Baeza-Yates & Ribeiro-Neto, 1999) 4) F1-Score: model's balanced ability to both capture positive cases (recall) and be accurate with the cases it does capture (precision).

Results and Key Observations

Correlation Analysis

Pearson correlation coefficient scores were used to understand the relationship between input features and the target category (grades). The analysis have shown a positive correlations of five main attributes; Scilearn lab attendance, internal assesment (recent grades), background, learning profile, and the adoption of atomic habits. While learning profile (LSI, Mindset and MAI attributes), and progression data (assesments and SciLearn lab attendance) have shown the strongest correlation with grades as shown below (see Table 5).

Table 5
High impacting features with the grades

Data Category	Features	Correlation score with Grade
Learning Inventory	LSI	0.81
	Mindset	0.85
	MCAI Knowledge	0.76
	MCAI Regulation	0.72
Progression Data	Assesments	0.89
	Scilearn Lab attendance	0.72

Performance Analysis

Five classification models have been created and tested using five ML techniques, MLR, RF, SVM, EC and DT. Results (Table 4) demonstrate the accuracy and performance measures for each model.

Table 4
Model Comparison

Model	Accuracy	Recall	Precision	F1 Score
Support Vector Classifier	78%	0.73	0.75	0.74
Decision Tree	68%	0.62	0.59	0.60
Random Forest	65.5%	0.60	0.54	0.56
Elastic-net Classifier(EC)	61%	0.45	0.60	0.51
Multinomial Logistic Regression	58.2%	0.41	0.46	0.43

Conclusion and Future Work

This pilot study has limitations, including a small sample size and reliance on self-reported data. Participants in the SciLearn program were self-selected and may not be fully representative of McGill's first-year cohort. Additionally, the courses in which data were collected were taught by instructors known to be excellent teachers, which could affect the machine learning modeling process. However, this research has shown promising initial results, with a high correlation between early learning attributes and grades, and an initial classifier accuracy of 78%. Future research will focus on increasing the sample size, including more time-based features and exploring time-series modeling to improve the accuracy, identifying early markers of success and provide timely guidance.

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Heterogenous Sensemaking: How Multilingual Girls and a Teacher Engaged in Joint Learning

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Abstract: The study explores how heterogeneous sensemaking, student accounts of different ways of encountering, noticing, and wondering about a phenomenon, emerged during joint sensemaking interactions between science teachers and multilingual students, and the diverse resources and repertoires of practices supported by such interactions.

Introduction

In science education, there is an increasing emphasis on promoting robust sensemaking practices among all students and positioning them as active agents in the process of knowledge construction (Berland et al., 2015). Sensemaking arises as students grapple with ideas in order to make sense of a phenomenon or unravel the workings of a design (Odden & Russ, 2019). However, it is also important to recognize that sensemaking is a heterogeneous and culturally embedded practice (Warren et al., 2001) rooted in the ongoing every day and disciplinary activity systems in which youth participate and interact (Kayumova & Sengupta, 2022).

Theoretical framework

We conceptualize science learning environments as activity systems that combine heterogeneous discursive and embodied communication and coordination efforts of teachers and multilingual students as they engage in joint sense- making and problem-solving (Kayumova & Dou, 2022). However, spaces of joint participation can also exacerbate status differences and existing inequities among students, particularly from nondominant backgrounds (Barron, 2000). To this end, teacher-moves play a critical role in supporting or foreclosing heterogeneity that emerges. In this study, we focus on joint sensemaking created by teachers and multilingual students, "the indeterminate processes of learning as a context for deep intellectual activity" as an opportunity to identify heterogeneity inherent within science learning and design work (Vossoughi et al., 2021, p. 18). The study is grounded in longitudinal research aimed at examining how positioning multilingual youth in asset-based terms supports more equitable opportunities to learn (Kayumova & Tippins, 2021).

Methods

The project took place in the Northeastern United States with multilingual youth whose home and community languages are other than the dominant English language. The data was selected from video and audio data, student interviews, documented observations by staff and teachers, extensive field notes, and artifacts collected during the summer 2021 implementation of this program. The program participants were multilingual young people from local middle schools. We coded the selected video footage for students' verbal and nonverbal accounts of noticing, encountering, and wondering about a phenomenon (Rosebery et al., 2010) and teacher moves that supported these diverse instances of joint sense-making, including coordination and communication. Here we present a representative case of a science teacher, Andrew, and three multilingual (Merriam, 1988) girls engaging in joint sensemaking about a water cycle and the formation of vapor.

Findings

Our findings showed that students used multiple resources such as their language, gestures, and everyday experiences to engage in sensemaking. The key repertoires of practice included the way they oriented attention to the process, extended the activity to everyday situations, and tacitly and flexibly coordinated the joint sensemaking communication. To illustrate, here we provide an example of one such moment from an extended collective sensemaking interaction. In this interaction, Andrew, the science teacher, and three multilingual girls are engaging in sensemaking about vapor formation that they notice on a black can. Girls utilized their hand gestures and a combination of English and Brazilian Portuguese to explain how light was absorbed by matter. When girls expressed their understanding verbally using translanguaging between English and Brazilian, Andrew attentively listened and nodded his head in agreement without interrupting. They also used body gestures to explain in further detail how sunlight hits the surface of the can, reflecting or absorbing as necessary. The girls used to point as means to direct Andrew's attention towards the black can and the outside where liquid drops had formed.

Andrew coordinated the communication by inviting all three girls into the conversation by posing a question related to their personal experience, using gestures to communicate his ideas. Thesetypes of communication and coordination support girls' diverse sensemaking repertoires and provide them with opportunities to share their experiences as evidence to support the inquiry. Girls contributed to the sensemaking by sharing examples from their daily lives, adding to the heterogeneous yet collective sensemaking repertoires that emerged among the students and teacher.

Discussion and scholarly significance

This research provides a perspective on the importance of joint sensemaking in creating meaning in science classrooms within teacher-student interactions. Our findings indicated that such interactions not only support disciplinary sensemaking but also allow the emergence of diverse resources and repertoires of practice among students. Such experiences are especially critical for supporting heterogeneous sensemaking repertoires of multilingual youth and transforming the discipline across various activity systems.

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Professional Development for Contextualizing Science Teaching and Learning: A Case From Ethiopia

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Abstract: In this study we present the results of a two-day professional development workshop on contextualizing science teaching and learning. We worked with 19 science teachers, discussing the purposes of science education, learning expectations in their classes, and data-supported low performance of students in national exams. We then asked teachers to work on discipline-based groups and outline the structure of a typical class in their teaching. Finally, they developed learner-centered projects to foster better contextualization of learning. Results show that teachers developed lessons to challenge learners' traditional conceptions about topics.

Introduction

Using context-based approaches in science teaching and making science learning relevant to everyday life of students has received increasing attention in recent decades (de Putter-Smits et al., 2013; Silseth, 2018). The rationale for contextualization relates to addressing a problem of information overload in science education (Gilbert, 2006), motivating students (Bennett et al, 2007) and increasing learner agency. One of the challenges and requirements in contextualizing science education is professional development of teachers. Teachers often teach the way they learned and not many teachers have the competence to make science learning relevant for students' everyday life in a meaningful way. In this paper, we discuss preliminary findings related to how teachers contextualized their lesson plan and developed engaging learning environments following a two-day professional development workshop on the subject. Our research question is "How do teachers contextualize their lesson planning and teaching following professional development for the purpose?"

Contextualizing science teaching and learning

Contextualization of science education could be teacher-centered or learner-centered. In teacher-centered contextualization, teachers often use examples that are familiar to students expecting that such familiar examples will facilitate learners understanding of the topic. Learner-centered activities in contextualization gives students the agency to choose topics, frame contextualization processes, and determine learning and problem-solving strategies (Taylor, 2017). In other words, the role of the educator is to facilitate student-led projects and challenge them progressively based on learners' level of competence and stages of dealing with their learning activity.

Context and methods

In spring 2022, we worked with 19 teachers (9 biology, 5 chemistry and 5 physics teachers) from six secondary schools in Ethiopia and conducted a two-day professional development workshop that focused on discussing the meaning, purposes and ways of contextualizing science education. We started with grouping teachers by subject and asking them to discuss and outline what their typical lesson for a given day looks like. Teachers prepared a list of activities they typically do in a given 50-minute class. We then asked teachers to discuss 1) the purpose of teaching science from their perspective, the extent to which they use their science knowledge in their everyday life, and how much they think students are using their knowledge to address everyday problems. Following the discussions, teachers developed lessons that is relevant for their students to contextualize their learning.

Contextualization for challenging traditional views

Teachers, working in groups, developed lessons that can be applied in their classes. Teachers chose to use issues that are familiar to students and develop learning activities for students to work on. One of the groups on biology teaching chose "traditional medical plants" and their use by the community. Their rationale was that there is considerable use of traditional medicine and medical plants in the community where the school is located. Similarly, physics teachers chose the "rainbow and its formation" for their lesson based on the explanation that students and occasionally members in their community have misconceptions about rainbow where it is considered as "Saint Mary's belt". The teachers want their students to examine how rainbow colors are created and experiment with glasses and paper to create the colors. The following exchange between the three teachers who worked on the rainbow lesson and one of the researchers represents the teachers' reasoning.

> *Researcher: Tell me what your project is about and why you chose "rainbow" for students to work on?*

Teacher A: *The goal of this project is for students to describe and examine the formation of rainbow. Project activities include answering questions such as what is rainbow, what causes rainbow, why rainbow appears with rain and how does a rainbow get its color.*

Teacher B: *Rainbow is a natural phenomenon that students know about. Students and community members don't know much about the concept of diffraction and refraction of light, they have misconceptions. In physics, it is related to single-slit diffraction, properties of wave interference and even ways of creating dim-lights that students use in their house.*

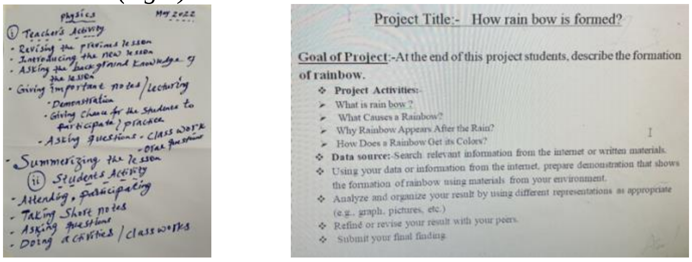
Teacher C: *Rainbow-related misconception is common around churches where it is often related to a promise from supernatural force or St. Mary's belt. Starting from what students know and getting them to experiment the process of creating colors will help them question their views.*

Shifting activity structures

Our second observation from the workshop was that teachers started thinking in terms of ways of engaging students actively in the learning process. Figure 1a presents a typical lesson that teachers reported using in their classes at the beginning of the workshop. Figure 1b is the nature of activities teachers developed for the rainbow project mentioned above. Figure 1a and b represent the shift in the nature of the activities from direct instruction to a more student-focused project where the role of the teacher is not even properly specified.

Figure 1

(a) Typical Activities in Physics Classes (left) and (b) Project Activities on Rainbow Formation (right)



Physics May 2022

(i) Teacher's Activity
- Revising the previous lesson
- Introducing the new lesson
- Asking the background knowledge of the lesson
- Giving important notes/Lecturing
  - Demonstration
  - Giving chance for the students to participate/practice
  - Asking questions - class work
    - oral question
- Summerizing the lesson

(ii) Students Activity
- Attending, participating
- Taking short notes
- Asking questions
- Doing activities/classworks

Project Title:- How rain bow is formed?

Goal of Project:-At the end of this project students, describe the formation of rainbow.

- Project Activities:-
  - What is rain bow ?
  - What Causes a Rainbow?
  - Why Rainbow Appears After the Rain?
  - How Does a Rainbow Get its Colors?
- Data source:-Search relevant information from the internet or written materials.
- Using your data or information from the internet, prepare demonstration that shows the formation of rainbow using materials from your environment.
- Analyze and organize your result by using different representations as appropriate (e.g., graph, pictures, etc.)
- Refine or revise your result with your peers.
- Submit your final finding

Discussions

Contexts can be the foreground that constitute or "animate" the action in that they make the action (e.g., learning) thinkable, possible, desirable, relevant and necessary (Clarke, 2013). The fact that our participating teachers started from topics that students know about (rainbow) and use the phenomenon to challenge learners' understanding in practical ways through experimentation and to teach about discipline related concepts such as "single-slit diffraction" implies contextualization also serves as a way of challenging traditional views. The teachers could have simply lectured about "single-slit diffraction" and give dim lights and rainbow as examples.

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Designing Professional Learning Workshop for Shaping Teachers' Learning Pedagogical Content Knowledge in Computational Thinking

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Abstract: The study focuses on understanding the discourse, interaction, and problem-solving relating to pedagogical content knowledge (PCK) demonstrated by teachers in one professional training workshop on Computational Thinking (CT) and its implementations in classrooms.

Introduction and theoretical framework

While the application of Computational Thinking (CT) to both student's educational experiences and teacher's professional development has been wide (Liu et al., 2022), the discussion on how best to support professional development the process and outcome of such professional development have been scarce (Sengupta et al., 2018). The present study focuses on a single training workshop for teachers in a longitudinal CT professional development project to understand:

1. How did the teachers engage in a professional development workshop featuring design thinking?
2. How did the interactions between teachers and the workshop facilitator shape teachers' pedagogical content knowledge?

Introduction and theoretical framework

Context

The workshop that the present study focused on had two stages: 1. Conceptualizing with teachers the implementation of CT in classrooms through discussion; and 2. Engaging teachers in CT-embedded group projects to experience CT in practice. A facilitator was present throughout, but the teacher participants remained actively engaged. The workshop lasted approximately two hours.

Data sources and analysis

Qualitative observational data was videotaped. One dyad (two teachers) was selected based on their high willingness to implement CT yet both experiencing challenges in doing so. Their self- and other-directed behaviors in workshop were coded, with emergent codes of teacher's engagement pattern presented in Table 1.

Table 1
Code Scheme for Teachers' Engagement Pattern to Instruction

	Positive Engagement	Negative Engagement	Disengagement
Immediate	Eye-Contact or Nodding Answering Questions	Engage in distractions Engage in actions/interactions that are discouraged by the facilitator	Disengaged from the facilitation Ignoring additional instructions
Delayed	Providing additional examples Paraphrasing key concepts	Using key concepts for slight sarcasm	Disengaged from the facilitation

Results

RQ 1. Three levels of engagement patterns in the workshop were identified (i.e., positive engagement, negative engagement, and disengagement) that are either immediate or delayed (Table 1), providing six distinct types. When engaged, the participants showed a moderate level of positive engagement toward the instructions, which aligned with the intention of the facilitator's instructions. However, instances of negative engagement and disengagement were also present, indicating times when the teachers' responses mismatched the instructor's intention or expectation. A notable distinction can be drawn between the two stages of the workshop. In the conceptualizing stage, participants showed mostly positive engagement or disengagement, but both at a mild level, indicating boredom, instead of intense satisfaction or dissatisfaction toward the content. However, during the practical ideation stage where participants were given a CT-embedded group task to complete, the level of engagement drastically increased. Specifically, both immediate and delayed positive engagement were demonstrated up-prompted by the participants, showing an active effort both to communicate and reflect on the CT concepts introduced.

RQ 2. A few features from the teachers' interaction stood out to challenge the effectiveness of the workshop on shaping teachers' knowledge. First, although teachers mentioned key concepts naturally during their group project ("we are *empathizing*", "What type of learning is this? *Kinesthetic* where you would have to touch things?"), these comments were made as social tools to lighten up the mood through humor and sarcasm, instead of for learning and conceptualization means. This speaks to both the challenges for the teachers to internalize new concepts, as well as their misunderstanding of the key points. Second, teachers held near exclusively pessimistic views about their students when providing anecdotal classroom experiences as examples ("my kids would cry". This again shows that teachers found implementing CT in the classroom to be challenging and were reluctant to change. Third, at no point in the workshop did any of the teachers asked follow-up questions or mentioned potential hesitation they may have toward the facilitation, despite them clearly having faced challenges in implementing CT in classrooms in the past. Any question that was raised was about the in-the-moment technical or logistical problems that they have for the workshop, instead of conceptual ones that speak to the core intention of the workshop. This shows that, even if shown positive engagement, the teachers rarely engaged with the concepts at a deep level.

Discussion and scholarly significance

Overall, the findings from the present study support that: 1. Teachers generally positively engaged in the professional development workshop, while 2. Their depth of engagement where relatively shallow. In other words, the discourse, interaction, and problem-solving demonstrated by the teachers showed that the workshop may not have fully prepared them to develop CT-related PCK and implement them in classrooms.

The challenge of integrating CT has long been present, with past research pointing to the technical difficulty of the computing tools as a key factor (Ketelhut et al., 2020). The present study, though, provides an additional layer to this challenge by indicating how the type and depth of engagement from the teacher participants are also critical. This becomes especially poignant given the rapidly changing and ever more diverse world that the teachers today teach in, where computationally literacy and accessibility must coincide.

While the present study was able to identify engagement as a key factor in effective CT professional development projects, future work can be done related to how best to design a project that supports positive and deep engagement from teachers and translates to a successful implementation of CT in classrooms.

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Materiality, Diversity and Inclusive STE(A)m:
A Comparative Exploration of Design Affordances on Youth Making

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Abstract: This study examines how designs and material affordances shape diverse participation, engagement and learning. We conduct an exploratory, comparative analysis that seeks to better understand the implicit affordances and (dis)affordances of digital and physical tools and activities in youth STEM+Arts participation and learner agency. Quantitative and qualitative findings illustrate important nuances in how participants engaged in and expressed computational thinking, collaboration, creativity and self-efficacy. We discuss these findings in light of increasing calls for social justice-oriented and transformative research and practice.

Introduction

While scholarship continues to demonstrate the benefits of diverse making and informal STE(A)M activities for learning, research is increasingly calling into question the implicit biases in the design of technologies, systems and activities, which can have an impact on equitable STEM participation, interest and persistence. Studies have found systemic patterns of inequity (e.g., Scott, Sheridan & Clark, 2015), with critical scholarship increasingly calling for social justice-oriented research and practice (e.g., Gutiérrez, et al, 2019). This study seeks to further address how tools and their material affordances shape diverse learning, engagement and shared meaning making. Our research questions are: How do diverse digital and physical content creation tools shape youth learning and participation? How do these technologies and activities affect learners' self-efficacy and computational thinking?

Methods

We applied multimodal methods (qualitative and quantitative) to conduct an exploratory comparative analysis on two iterations of a workshop designed to support inclusive youth learning of making and integrated design. The 2018 curriculum updated the original bidirectionally responsive curriculum, which focused on three primary content creation tools (Lilypad Arduino, Scratch, and MakeyMakey), while the 2019 curriculum used a newer e-textile microcontroller - the CircuitPlayground Express (CPE) - in place of the Lilypad and MakeyMakey (Richard, Giri & Faimon, 2022). The 2018 participants were aged 14-18, and the 2019 participants were aged 13-15. The 2018 workshop pair is Ebony (Black, female, aged 16) and Priscilla (Latinx and Black, female, aged 14). The 2019 workshop pair is Julio (Latinx, male, aged 13) and Eddie (Latinx, male, aged 14). All are pseudonyms.

The quantitative analysis used pre- and post-survey measures derived from Robinson's computational thinking questionnaire (2015), which established criterion validity (r=.572, n=37, p<.01) and used 5 subscales. Data were analyzed using Wilcoxon matched pairs, given the small sample size and nonnormal distribution (e.g., Wiedermann & von Eye. 2013). The qualitative microanalysis (Derry, et al., 2010) of the video data compared two sets of focal case study student pairs to provide insight into learners' actions and engagement.

Quantitative findings

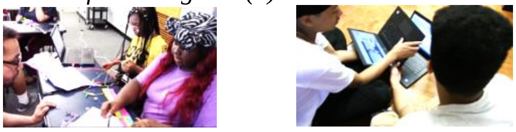
For the 2018 workshop, collaborating, $z = -2.03$, $p = .04$, $r = .59$, abstracting, $z = -1.99$, $p = .046$, $r = .58$, and developing computational artifacts, $z = -2.23$, $p = .026$, $r = .64$, were statistically significant with large effect sizes ($r > .5$). For the 2019 workshop, abstracting, $z = -3.19$, $p < .001$, $r = .58$, and developing computational artifacts, $z = -2.78$, $p < .01$, $r = .51$, were also significant; however, instead of collaborating, connecting computing was highly significant, $z = -2.77$, $p < .01$, $r = .51$. Collaboration items underscore self-efficacy beliefs about working with others to convey ideas, whereas connecting computing emphasizes using technology to shape others' experiences.

Qualitative vignettes

For the 2018 curriculum we focus on how Priscilla and Ebony engaged with Collaboration and Analyzing Problems and Artifacts. This vignette took place about halfway through the creation of their final integrated design project, which is a versatile headband or belt that lights up with the Lilypad Arduino and controls a Scratch catch game, connected by the MakeyMakey. During their creation process Priscilla and Ebony work together to create and troubleshoot their project, describing to the facilitators that "[Priscilla] does the coding" and "[Ebony] does the sewing", but they are "going to work on the Makey Makey together" (*Collaboration*). The process of troubleshooting their connections and the plan for their design took up much of their shared discussions (*Analyzing Problems and Artifacts*), as they talk back and forth with facilitators about including several LEDs along with a tricolor LED. They are purposeful about dividing responsibilities while also working together toward their shared idea and detailed plan. As shown in the background of figure 1a, Priscilla engages in troubleshooting their code via the alligator clip connections between the Lilypad Arduino and the LEDs, as well as writing code for the tricolor LED so it creates the colors they want to use. Meanwhile, because of the complexity of their design, Ebony plans out where she is going to sew the connections (*Collaboration*). Using the tricolor LED added many complexities; while it does not require a ground connection, the other LEDs do, and Ebony and Priscilla had to remember multiple ways of connecting the different material components and work together to finish their project.

Figure 1

Priscilla and Ebony sewing and coding (a); Julio and Eddie recording sounds for their game (b)



(a) (b)

For the 2019 curriculum we focus on how Julio and Eddie engaged in Collaboration and Connecting Computing. Their final project was a negotiated design inspired by the Marvel movies and comics. It used two gloves and the CPE to control the same Scratch fighting game—the Iron Man gauntlet from Avengers *Endgame* and the Infinity Gauntlet from *Infinity Wars*. Because of the affordances in the CPE and because they were intentional in creating two gloves that could control one game, Eddie and Julio engaged in similar parts of the design process though the process itself was not as interdependent, making collaboration more of a concerted effort. While Eddie focused on coding – including creating code to test if they could use two CPEs for one Scratch game (*Analyzing Problems and Artifacts*), Julio focused on the more intricate artistic elements of their glove controllers. Making their projects authentic to and incorporating aspects of the Marvel movies seemed to drive Julio and Eddie's collaboration. They were both intent on collaboratively picking realistic Avengers-themed sounds for their game, choosing to record them (fig. 1b) from the movies through YouTube clips instead of using any built-in Scratch sounds *(Collaboration)*. Later in the workshop they both reflected on what they learned and created, demonstrating awareness of their ability to use computing and design technologies that can affect others *(Connecting Computing)*. When asked if they had ever worked with microcontrollers before, Eddie immediately shook his head and responded: "No… It was easier than I expected. It was really simple." Julio sat in thought for a few moments, then responded emphatically: "I never knew that… I could make a controller out of tape and cloth….[*gestures to the CPE*] I never knew it could grab like something and program it into the computer."

Discussion

The findings help illustrate how diverse tools and activities can scaffold and make different kinds of collaborative, critical and creative possibilities salient for learners. We argue that the findings in this study help to illustrate key nuances for equity and inclusion. For instance, robust understanding of the design of systems and their impact on the world, the ability to articulate ideas and correct complex problems, and effective collaboration are all crucial for critical design literacy and social justice. We plan to investigate this further in future work.

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Connect Two: A Duoethnography Exploring Reconnecting Teacher and Student Relationships After Covid-19

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Abstract: This paper explores experiences of two practitioners returning to their work contexts after COVID shutdowns through a duoethnography methodology. Drawing on the notion of entanglements, this analysis considers themes of disconnection and connection through parallel storytelling. In particular, both researcher-practitioners explore their experiences in the context of social emotional learning (SEL) and noticings of shifts in student and teacher actions post-COVID. Findings suggest themes of disconnection.

Framework

Storytelling has served as the embodiment for not just human connection, but generational connection, for millennia. Storytelling has taken many forms, including cave drawings, cultural dances, chants, music lyrics, but verbal communication provides precision to a basic human need to explain, educate, and enlighten (Anderson, 2010). Recently, Keifert (under review) has proposed storytelling to share lived experiences and reimagine shared futures using the metaphor of entanglements to purposefully understand connection through storytelling and finding commonalities between our stories. When considering individual and collective experiences of disconnection amidst COVID, entanglements may help bring stories together in ways that surface the meaning-making and impacts of COVID on those working within and occupying educational spaces. For the purposes of this paper, entanglements is used as a framework to highlight commonalities and differences between two researcher-practitioners after returning to their school and district roles after COVID shutdowns.

Method

Researchers of the current study implemented a duoethnography method to explore common themes among two social emotional learning practitioner's experiences after returning to school, post-COVID-19 shutdowns. The tenets of duoethnography as described by Breault (2016) include viewing one's life as a curriculum. Through this lens we first examined our lived histories that helped shape our current understanding of and beliefs about SEL.

To facilitate dialogue we engaged in five, 30-minute Zoom sessions and created audio recordings of our conversation. The researchers had dialogue on subjects such as "possible stressors that exacerbate behaviors with students and teachers" and "how SEL can bridge the gap between all stakeholders." These topics were used to drive the conversation. Both participants shared stories from different perspectives. Participant one is a district level coordinator in a large urban school system sharing a view from a systemic lens. Participant two is a campus educator for a mid-sized suburban school system sharing a view from a local, school-level lens. As researchers engaged in dialogue, the themes of teacher and student disconnections began to emerge, and thus were used as guiding questions for further analysis. We utilized the approach of parallel storytelling (Benegas & Gerlach, 2020) in a collaborative Google Document, in which each researcher contributed ideas, stories, and experiences related to guiding questions that supported dialogue. Low inference coding was used to identify common themes in conversation between participants in the transcripts of multiple conversations. By configuring data in a table, themes emerged, and patterns noticed on the topic of teacher and student disconnection being evidenced through differing aspects of the participants' work environments.

Findings

The duoethnography surfaced two primary themes: (1) students struggling with regulating their emotions after COVID shutdown (see Table 1); and (2) teachers experiencing burnout (see Table 2).

Table 1
Students struggling with regulating their emotions after COVID shutdown

Participant 2: Student behavior is probably more difficult right now than it has been since I've been in education. They [students] are struggling to cope with even small things, much less the big things that many of them are dealing with.

Participant 1: I have some campuses that are in the most extravagant neighborhoods, but their students are suffering from depression and having suicidal ideations at an alarming rate. It has quadrupled from what it was prior to the pandemic.

Participant 2: It all is just like, it's like a toxic soup that's been simmering for a while with this pandemic stress which leads to…compounds into this cycle of negativity and stress, and outbursts, behavior outbursts.

Table 2
Teachers experiencing burnout

Participant 1: Teachers are showing increased anxiety and being burned out early in the year as opposed to a time where teacher burnout was closer to STAAR testing time. Their classrooms aren't being managed properly. We have teachers who are so on edge. They are taking all of their days before Thanksgiving, as far as sick days and personal days, just trying to get a handle on their own mental health.

Participant 2: What can we do to decrease the stress and burnout for our teachers? Teachers are struggling to cope with even the small behaviors from students. Typically, things that you would think could be handled in the classroom. It's just too much because so many are just at the end of their coping ability. We're seeing the exact same thing, too... with high teacher absences. They're often quick to anger, assume the worst.

Practitioners noticed that students experienced behavioral outbursts and had increased mental health needs after returning back to school from Covid shutdown. Practitioners noticed that students did not display capacity to self-regulate. Researchers noticed that many teachers experienced emotional dysregulation due to pandemic stresses and currently are struggling when the slightest discomfort happens. Teachers' inability to cope with minute student behaviors emphasizes disconnection with students' needs. Teachers' coping skills have diminished after the Covid-19 shutdown. With both teachers and students in an emotionally dysregulated state, there appears to be a need for an emotional support between them for co-regulation.

Discussion/conclusion

Parallel storytelling revealed practitioner-researcher noticing of students' emotional dysregulation with fewer strategies for managing emotions, and teachers experiencing secondary trauma and burnout. Sharing lived experiences through entanglements and SEL strategies can be methods used for re-imagining a new normal. A shared devastation such as the Covid-19 isolation could serve as a catalyst for reconnection through sharing lived experiences. A structured design, such as those informed by entanglements or SEL instruction, assists those in education to positively make those connections. Students who learn explicit SEL skills through conversation starters or community circles establish valuing their position of belonging to a community of learners. Teachers who have an opportunity to be taught self-reflection and social awareness have safe spaces for students to engage in instruction. Storytelling, as a method of sharing lived experiences, can begin to repair disconnection between teachers and students.

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Exploring Extended Reality for Scaffolding Psychomotor-Intensive Tasks in Complex Real-World Settings

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Abstract: Extended reality (XR) has the potential to leverage newly available multimodal streams of data (e.g., gaze, hand tracking) to accelerate the progression from novice to expert in many fields. By providing adaptive and personalized learning interventions, these advances in XR technology enable a new category of intelligent tutoring systems, which can scaffold psychomotor-intensive tasks in complex real-world settings. We present the preliminary results of two prototypes of XR-based intelligent tutoring systems in the context of advanced manufacturing, primarily focused on demonstrating their ability to scaffold complex tasks. We outline key research questions to move toward adaptive and personalized XR scaffolding.

Introduction

This project seeks to design and understand the affordances of extended reality (XR) technologies for providing intelligent, adaptive, and personalized scaffolding for psychomotor-intensive tasks *in complex real-world settings*, such as advanced manufacturing, with an eye toward supporting novice and differently-abled learners. Skilled performance in these industrial settings is psychomotor in nature, requiring acute spatial perception, reasoning, and coordination of motor skills. Advanced manufacturing is a valuable application area for exploring XR technologies for supporting the learning of novices in psychomotor-intensive tasks such as assembly, maintenance, and inspection that involve careful hand-eye coordination (Moghaddam et al., 2021).

Supporting novice-to-expert skill progression

Advanced manufacturing tasks, such as the operation of a semi-automated metal additive manufacturing process, a computer numerical control machine, or a robotic station, often require operators to engage in psychomotor tasks requiring sophisticated spatial reasoning while carefully and precisely following complex procedures. Operators of these machines must apply a thorough understanding of advanced manufacturing equipment, material properties, and upstream and downstream processes, in addition to developing an awareness of how each of these elements interact together. Leveraging the robust accumulated evidence on the novice-expert gap for complex systems (Hmelo-Silver & Pfeffer, 2004), the goal of the current research is to develop interventions mediated by XR technologies to more inclusively and scalably support the progression of novice-to-expert skill and knowledge development in psychomotor-intensive tasks through just-in-time provision of spatially contextualized learning scaffolding, dynamically tailored to the expertise of individual learners and the real-time setting in which they are acting.

Preliminary results

As part of our iterative, design-based research process, we developed and studied two prototypes, each providing incrementally more sophisticated scaffolding. The first explored the affordances of a simple static (i.e., non-adaptive) AR guide for scaffolding an authentic electromechanical assembly task compared to "business-as-usual" paper instructions. The task involves assembling fuel cell modules of custom-made marine engines, which require following different procedures for each engine model. Seventeen Mechanical and Industrial Engineering students were recruited as participants (6 females, 11 undergrads) and divided into two groups: AR and paper. A questionnaire was used to collect their demographics and related prior experiences to counterbalance the groups. All participants received initial online training on the AR app and hardware (HoloLens 2). Each participant performed three assembly cycles on separate dates using their designated mode of instruction and returned after a few days to perform a final assembly using the opposite mode of instruction. At the end of each session: (1) the experimenters recorded time to completion, number of errors, frequency of help-seeking behavior, and the types of errors and questions, and (2) the participants reported their cognitive load (NASA-TLX), self-efficacy, experience with HoloLens/AR app, and general feedback through structured and open-ended questions.

We found that the number of errors in the AR condition was reduced by 31-84% with negligible reductions in the paper condition (Moghaddam et al., 2021). The task completion times of the two groups are about the same; however, that was partly due to the unfamiliarity of participants with AR and some technical issues. Further, most participants reported absolute independence from AR after two/three cycles, which points to the effectiveness of AR in improving task competency, but also to its decreasing utility as an "assistive tool" for routine tasks once expertise is developed. Further, several participants suggested devising interactive help and voice command systems.

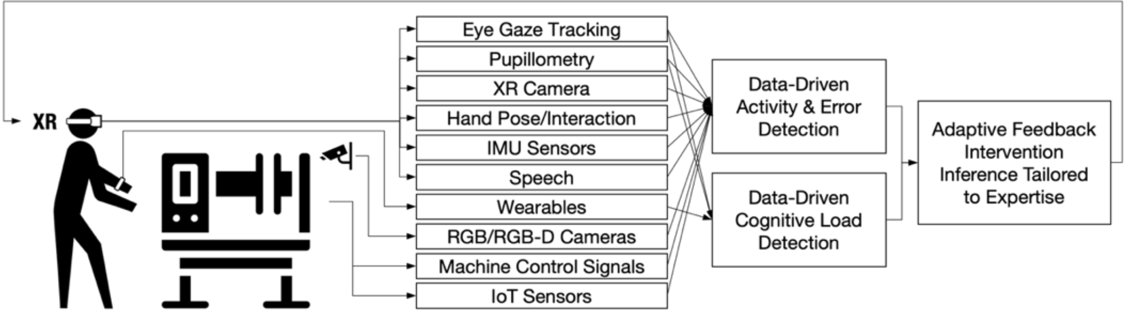
Informed by these results, a second prototype was developed to scaffold the task of setting up and operating an additive manufacturing machine. This version added spatiotemporal alignment of training instructions with the physical equipment and environment in the form of text, 3D animations, videos, and audio cues as well as on-demand access to operations manuals and demo videos via hand gestures and voice commands that allow the user to interact with the app through natural language. Results suggest that users find the spatiotemporal alignment and in particular the 3D animations useful for understanding what they are required to do. While the prototype is modularized—that is, the training modules can be taken in any order—the prototype still follows a step-by-step approach for each module and thus does not adapt to the learner. This would be an important next iteration to consider as some users found it more challenging than others.

Key questions and research agenda

Figure 1 shows a conceptual view of the flow of possible data streams and their combination in formulating adaptive feedback and guidance in real-time to a learner operating in a complex setting such as a manufacturing facility. Our efforts have only just begun to access and integrate the full set of potential inputs available.

Figure 1

Conceptual overview of the possible input to consider for adaptive feedback integrated with XR.



We are now exploring a challenging set of research questions surfaced by the development and application of intelligent XR tutors: (1) *What are the effects of adaptive and personalized XR scaffolding on different dimensions of expertise and the speed of the novice-to-expert development process?* (2) Given the explorations in the previous research question on how to best scaffold psychomotor-intensive, human-machine interaction tasks, *how can we characterize the progression of development from novice to expert for a particular task to advance our theoretical understanding of expertise development and build more robust, generalizable knowledge on what indicators can be used to guide tutoring interventions across a range of tasks and settings?* (3) *How can different streams of user and machine/task data be synthesized to create a context-aware XR system capable of providing just-in-time interventions tailored to the expertise and task context of learners?* Only by accurately detecting the state of work context (e.g., current activity/step, potential errors) and the required human information processing resources can an XR system adapt learning scaffolds to the needs of a learner in real time. New sources of multimodal data captured by XR devices, cameras and sensors, wearables, and machines provide new opportunities to interpret, predict, and guide the behavior of learners through the adaptive scaffolding of XR instructions and feedback.

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Implementing Higher Education Micro-Credentials: Uncovering Challenges to Improve Professional Practice

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Abstract: This study employed a survey to identify challenges faced by professionals who implemented higher education micro-credentials. Inferential statistics were used to determine if amount of experience predicts the challenges of professionals involved in this work. The results of this study have implications for the development of both formal and informal support systems for this growing population of higher education professionals who are tasked with creating micro-credentials.

Introduction

Micro-credentials (MCs) widen the scope of postsecondary learning opportunities; with more options for learners, they are often considered a viable way for institutions to offset declining enrollment and bring new learning opportunities, providing recognition (e.g., assessment, credentials) for learning that is traditionally under recognized (Oliver, 2019). Consequently, there has been an increase of higher education organizations designing MC programs, targeting smaller amounts of curriculum, and avoiding the levels of oversight applied to traditional credentials. However, the increase in micro-credentials offered in higher education is very likely ahead of established good practices for ensuring quality and positive results (Pollard & Vincent, 2022). Importantly, there is not yet basic knowledge about who is implementing MCs in higher education, nor the challenges they identify in this work. Without this knowledge it is not possible to align resources and support (e.g., training, sample curricula) with needs, which is crucial for maximizing the efficacy of professional practice (Caffarella & Zinn, 1999), and for sustaining MC programs long-term (Ahmat, et. al., 2021).

Methods

We employed a quantitative, non-experimental survey design to investigate the identity and perceptions of higher education professionals who have experience working with MCs. We specifically sought to measure time working with MCs because we hypothesized that experience predicts this population’s challenges of working with MCs. Because MCs are different from other credentials (e.g., different curricular design, awarding methods), they entail different processes and procedures, which presents a learning curve for Novice professionals. Therefore, we hypothesized differences between professionals with less than one year experience, and those with one year or more experience. We based these categories on studies of other educational technologies that indicate educators’ attitudes toward the technology changes after a year of practice (Valtonen, et al., 2015).

Data collection

We developed and implemented a survey instrument to better understand the population of professionals with experience working with MCs (e.g., designing, administering, teaching) and to elicit their perceptions in relationship to our hypothesis, $H_0 1$: *There is no significant difference between Novice and Experienced professionals on perceived challenges of working with MCs*. Two items from our survey were used to directly answer the question: *How long have you been working with MCs in higher education?* (Multiple choice); and *What key challenges have you experienced working with MCs? (*Multiple response set). The response options for the multiple response question acted as our dependent variables (DVs): DV1 Financial resources; DV2 Effort/time required for implementing; DV3 Faculty buy-in DV4 Employer buy-in; DV5 Buy-in by leadership; DV6 Student buy-in; DV7 Uncertainty regarding how to design MCs; DV8 Equity of opportunity; DV9 Keeping MCs different than traditional credentials. We received 148 valid survey responses. Participants were categorized into two groups- Novice (less than 1 year experience) (n = 74) and Experienced (1 year or more experience) (n= 68).

Data analysis

The data was analyzed using inferential statistics. Each response option for the question *What challenges have you experienced working with MCs?* was treated as a binary variable (i.e., yes/no) and coded either 1 or 0. Then, we conducted an Independent Samples Test of Proportions to obtain the inferential statistics needed to test our hypothesis.

Results

A test of proportions was conducted for each of the nine variables in the response set- “Challenges of MCs.” Results indicated a significant difference in the proportion of the groups on – DV7: Uncertainty regarding how to design MCs (z= 3.49 p < .001); 39% of Novice and 13% of Experienced practitioners perceived DV7 as a challenge, 95% CI [.12, .40]. Results indicated no significant differences on any of the other variables.

We were not surprised that novice professionals were more frequently uncertain about how to design MCs than experienced professionals; research on other educational technologies (e.g., online courses, games) has shown that amount of experience working with a technology is positively correlated with design-confidence (Northcote, et al., 2015). This finding has implications for the quality MCs, since design of an educational technology influences learning outcomes, including learner satisfaction and persistence (Rienties & Toetenel 2016). If a professional is uncertain about design (e.g., quality principles, processes), they will likely design MCs that are sub-optimal. Although our study does not confirm which specific aspects of designing MCs produce uncertainty for Novice’s, a reasonable solution would be for beginners to learn design principles and strategies from their more experienced counterparts.

While we recognize that a lack of a statistically significant finding is not a finding itself, it should be emphasized that we found no other differences between the two groups regarding their challenges of developing and implementing micro-credentials; eight of the nine challenges investigated in this study were perceived by professionals regardless of amount of experience. This indicates that there are likely several problems of practice (i.e., complex challenges that are common across an occupation) (Norton & Hathaway, 2015), for professionals who develop and implement micro-credentials.

Discussion and conclusion

The needs of implementers of MCs in higher education are critical to the success of these new credentials. Institutional leadership can provide support by properly allocating resources, such as financial resources (e.g., marketing to address stakeholder buy-in), human resources to support the effort and time required to conduct this work, and professional development (PD). Besides institutional support, there is also a clear need for more research in this area. Specifically, further research is needed to determine why some challenges do not cease with increased experience, and what is needed to overcome challenges that could, if not addressed, impact the quality and effectiveness of MCs in higher education.

Lastly, our results indicated there are likely several general problems of practice that apply to all implementers of MCs in higher education, regardless of experience. This is noteworthy, since problems of practice are often the catalyst for the formation of Communities of Practice (CoPs), a type of informal, peer-to-peer support network comprised of individuals who share similar work roles and a common context. Through sharing experiences, members of a CoP use their collective knowledge to generate new ways to address recurring problems (Li, et al., 2009). We recommend that implementers of MCs come together to form CoPs. If effective, CoPs would provide space for these professionals to further develop their expertise and improve professional practice, which, as a result, would lead to large-scale improvements on the quality of higher education MCs.

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Situating Here-And-Now Decisions in More Just Imaginings for Teaching Writing

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Abstract: Drawing on translingual ideologies (Horner et al., 2011) and participatory design-based research (Bang & Vossoughi, 2016), I partnered with a teacher to co-design elementary writing from 2020 to 2022. The teacher's discourses of writing shifted from centering competition and competence to relationships and identities. Further, attending to daily teaching demands *and* translingualism emerged as a mediational tool in our work. These findings have implications for researchers co-designing with teachers to navigate daily dilemmas while imagining futures.

Introduction

With waves of recent 'learning loss' outcries brought on by covid-19, the current moment requires learning designs that resist neoliberal reforms and deficit framings of young people (Philip et al., 2022). Specifically, we need forms of learning that attune to the dailiness of teaching *while* working toward more just pedagogies. Participatory design-based research (PDR) offers generative frameworks for "being-with" teachers while remaining oriented toward aspirational ideologies; PDR names "consequential learning in the here-and-now" as a priority alongside imagining possible futures (Bang & Vossoughi, 2016, p. 174). Writing classrooms can be ripe for the reproduction of deficit ideologies as discourses of appropriateness (Flores & Rosa, 2015) and linguistic competence (Flores & Rosa, 2022) dominate the framing of writing practice (Lane et al., 2021). However, teachers often have little time or mediational resources to distance themselves from school-based dailiness and "see anew" (Gutiérrez & Vossoughi, 2010) to generate novel forms of teaching and learning. For these reasons, I conducted a collaborative design-based research study with a sixth-grade teacher (Mr. Riley, pseudonym) from 2020-2022. We sought to reshape writing activity, focusing on translingual ideologies and resisting deficit frames. In this analysis, I ask: How can a PDR study support shifts in a teacher's writing discourses and build toward more just school writing environments?

Theoretical framework

This work draws on participatory design-based research (Bang & Vossoughi, 2016), which promotes collaborative studies that resist top-down implementations and center deeper participant learning. Our learning focused on translingual language ideologies: these posit that languages, instead of being bound, fixed entities, are always in flux, emerge in hybridity, and are sociocultural phenomena (Horner et al., 2011).

Methods & data sources

Mr. Riley and I met 2-4 times per month for two academic years. I conducted teacher interviews at the beginning, middle, and end of the study. In the second year, I conducted 29 audio-recorded classroom observations. All interviews, meetings, and observations were audio-recorded and transcribed. For the present analysis, I wrote analytic and thematic memos of the three interviews while developing a codebook to identify recurrent themes. This led me to zoom in on salient design meetings that Mr. Riley identified as impactful. I then engaged in inductive and deductive coding of design meetings and the three interviews.

Participants & positionalities

Participants included Mr. Riley, a White male teacher, his sixth-grade class, and myself, a White, female former English teacher. The school's student demographics are reported as 23.6% Asian, 15.5% Black/African-American, 40.5% Hispanic/Latinx, 2.7%, Native Hawaiian/other Pacific Islander, 5.6%, two or more races, 12.1% White, with 73.5% low-income, and 38.1% receiving EL services. I met Mr. Riley through the director of his teacher preparation program, for whom I worked as a teacher coach. We initially spoke about my interests in translingualism, and he shared his desire to improve his writing instruction. Considering our subject positions (Daniels & Varghese, 2020), I aimed to disrupt the linguistic "white listening subject" (Flores & Rosa, 2015) which frames racially and linguistically minoritized young people as linguistically deficient in the name of "competence" (Flores & Rosa, 2022).

Findings

From November 2020 to June 2022, Mr. Riley's reasons for teaching writing evolved from competition and competence to seeing writing as a relational act rooted in students' identities. First, in November 2020, Mr. Riley described learning to write as important in order to be a "communicator" in the world. He emphasized that people get "judged" on how they write when seeking jobs. He also talked about wanting his students to be able to write essays for seventh grade. These goals reflect discourses of competition (to seek jobs) and competence (grade-level preparedness). Later, in September 2021, when asked about goals for his students, he referred to an experience of his class writing outside in a courtyard at the end of the prior year: "there is just like this *vibe* that we had…letting kids experience the joy of writing and being able to identify as writers and not just as students who are checking off a box." He described a "magic in the air," when all students were working on writing as a community. In June 2022, he said, "I think something really strong, powerful happens when you ask kids to write about their lives and then you actually…talk to them about it…kids really open up." He described his experience with teaching writing in 2021-2022 as "the exact opposite" of what it had been before, when he felt "very pressured to teach kids to do a certain thing." Later he added, "I want them to be able to share with the world what they think…what they need for who they are, where they're from…" In this way, Mr. Riley's discourses about reasons for teaching writing shifted from focusing on an academic- and job-centered context to discourses centering community and identity.

Second, situating here-and-now decision making against a backdrop of translingual ideologies allowed for micro-shifts in daily decision-making and set the stage to support shifts in his discourses of teaching writing. In January 2021, we navigated tensions during a design meeting where Mr. Riley expressed concern about sentence structure, and I emphasized flexibility in language use. I alternated between referring to translingual language ideologies ("it matters that they can play with language and be flexible," and "there's multiple opinions around asking kids how it sounds…that can be very…biased…" and "students [should] come away with…agency [to] play with sentence structure") and resisting a stable idea of "competence" (Flores & Rosa, 2022), and providing specific examples of how Mr. Riley might build a lesson around sentence combining (such as how to choose examples and how to plan a remote lesson). Eventually, we co-designed an assessment asking students to use Flipgrid to record themselves talking *about* varieties of sentence combining choices as a way of supporting flexibility and foregrounding student thinking, framing young people as adept language users. Several other design meetings reflected similar tensions and negotiations between immediate concerns and overarching ideologies.

Significance

Decisions in education often get framed as being pragmatic or idealistic, both obscuring what we can imagine and positioning educational actors against each other. However, seeing these perspectives as a kind of epistemic heterogeneity (Rosebery et al., 2010) and designing specifically for it (Taylor, 2020), researchers and teachers can co-design and co-learn in ways that shift both the classroom and research practice.

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Rule Formation in Simulation-Based Discovery Learning

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Abstract: We gave learners a cognitive tool to formulate rules during simulation-based discovery learning about Ohm's law. We selected four cases from a larger sample based on posttest Knowledge Integration scores and used microgenetic analysis to examine different phases of the learning process. Our analysis identified the steps involved in forming distinct rules and tracked shifts in thinking at each stage, including predictions, selective searches, and reasoning processes when interpreting simulation results.

Introduction

This research investigated learners' engineering approaches and regulation of scientific discovery processes as they used a web-based simulation to explore electric circuits and learn Ohm's law. We tracked learners' selective searches among variables, rules they formulated, experimental tests they designed, and ideas they generated about their experiments. Making visible these aspects of inquiry learning allowed characterizing patterns of discovery learning in science. We use microgenetic analysis to dive beneath the surface of scientific discovery to expose detailed operational definitions of different engineering approaches learners use in simulation-based discovery learning.

Theoretical framework

Discovery learning is a self-directed and constructive approach to learning. Prior research has shown that learners do not experiment sufficiently with variations offered by simulations (Chambers et al., 1994). de Jong et al. (1988) identified several challenges associated with simulation-based discovery learning, including the ability to test hypotheses, design experiments, interpret data, and regulate the learning process. Strand-Cary and Klahr (2008) found that explicit instructional approaches were more effective than exploration-based methods in teaching control of variable strategies. These findings suggest that while simulation-based learning can be a valuable tool, specific strategies may be necessary to ensure effective learning outcomes. Bruner et al. (1956) identified different strategies for discovery learning: confirmation redundancy, simultaneous scanning, successive scanning, focus gambling, and conservative focusing. In confirmation redundancy, learners test alterations of the same instance. In simultaneous scanning, learners simultaneously considered all attributes. In successive scanning, participants attended to one attribute at a time. In conservative focusing, learners changed only one attribute on each trial to investigate a single hypothesis. Finally, in focus gambling, learners changed all but one attribute in each trial. This study was our model for investigating learners' strategies for inducing a rule by manipulating variables in a simulation. Wiese and Linn (2021) found that while 99% of 7th grade learners were able to identify at least one underlying rule governing the three computer models provided, only 14% could identify all the underlying rules. This highlights a gap in research concerning rule formation in simulation-based discovery learning. Thus, the present study asks: *How do students' engineering approaches and searching strategies in rule formation impact Knowledge Integration?*

Methods

Undergraduates participated in a 2-hour Zoom session to develop their understanding of Ohm's law through a simulation. Pretests and posttests were conducted to assess their understanding, and their open responses to posttest items were scored using a knowledge integration (KI) rubric. The KI rubric uses the following scores: 0 (blank), 1 (off task), 2 (invalid scientific idea), 3 (partial link), 4 (one valid link), and 5 (multiple valid links). The rubric scores were used to assess how students linked concepts and formed rules during the session. The study used the WISE domain to develop a unit of instruction on electric circuits. The students used a PhET electric circuit simulation to construct circuits and read measurements needed to discover relations involving current, resistance, and voltage. During the investigation phase, students used a rule formation tool to form IF-THEN rules. Sections of the tool labeled IF and THEN allowed learners to specify a hypothesis in terms of a prediction and findings. The prediction and finding areas provided drop-down menus from which students could select values for current and voltage drop. A section of the tool labeled FOR ALL CONSTANT VARIABLES specified control conditions. The study analyzed data from four participants who attained the same very low score on pretest items and tested the same relationships in the exploration phase. These participants displayed particular combinations of KI levels in the posttest for current and for voltage drop. The KI score patterns indicate possible variations in (a) engineering approaches, which we describe as students' comparative selections of variables, and (b) searching strategies for forming rules during simulation learning.

Findings

Case study 1. Student A's posttest showed scientifically invalid ideas (KI level 2) for both voltage drop and current. They used a limited range of variables in their comparative trials, which were restricted to changes in resistance and battery voltage value. Their predictions and findings for voltage drop and current were based on the same rules from previous trials, with no identification of problems. Student A used confirming redundancy in their rule generation, but did not deduce which attributes should be eliminated, resulting in redundant results and no distinct findings.

Case study 2. Student B demonstrated a scientifically invalid idea (KI level 2) and a partial link (KI level 3) in their posttest. They made discoveries about voltage drop by changing the number of bulbs in their trials, but did not test other variables. Their predictions were mostly based on previous rules. They verified more predictions and falsified others for voltage drop, but did not falsify any for current. They did not identify any problems in formulating their rules, but used successive scanning to test a single hypothesis about voltage drop. Their engineering approaches and searching strategy limited them to make a partial link about voltage drop and an invalid idea about current.

Case study 3. Student C had a partial link (KI level 3) and 1 valid link (KI level 4) in their posttest. They tested multiple variables to measure current and voltage drop. Their trials show changes in bulbs, resistance, and ammeter placement. Their predictions were either based solely on prior rules or aimed at filling any gaps within those rules. They verified some predictions and falsified others for current, but did not falsify any for voltage drop. They used successive scanning and focus gambling strategies equally. Their engineering approaches, predictions, and utilization of focus gambling resulted in a higher KI level for current (KI level 4) compared to voltage drop. They needed more trials to confirm findings generated by a focus ambling strategy.

Case study 4. Student D demonstrated a high level of knowledge integration (KI) in their posttest, providing multiple valid links (KI level 5) and one valid link (KI level 4). They conducted extensive trials to measure current and voltage drop, testing the most variables compared to their peers. Their searching strategies show they filled more gaps in their predictions and falsified more experiments. Unlike their peers, Student D identified problems in their experiments and used both successive scanning and conservative focusing to make discoveries. Student D employed conservative focusing when identifying a problem in a circuit and systematically tested the most crucial variables by altering only one attribute at a time. By honing in on voltage drop, Student D effectively avoided getting lost in extraneous details and remained focused on the fundamental principles underlying the circuit.

Conclusion

Describing how learners engaged in discovery learning with scaffolded rule formation helps identify searching strategies (i.e., focus gambling, etc.) that can be used to identify engineering approaches (i.e., planning and carrying out investigations). This will help intervene more effectively to guide students during simulation-based discovery learning. Clarifying the specific operations related to rule formation and concept attainment from simulation-based discovery learning will aid in developing a classification system of cognitive engineering approaches.

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From Every Angle: Group In/Equity Behaviors

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Abstract: We set out to develop a reliable coding scheme for relatively quick (compared to some qualitative coding schemes) analysis of equity in collaborative small groups by modifying a previous coding system (Slattery & Hutchison, 2018). In this poster, we describe the coding scheme and argue it can generate useful across-group comparisons, identify which group members have fair access to learning resources and positive positional identities, and show how group members affect peers' fair access.

Introduction

Many science educators and researchers consider group work a key element of an effective STEM learning environment (Esmonde, 2009; O'Donnell & Hmelo-Silver, 2013), but inequitable group dynamics can undercut the benefits of collaboration and reduce fair access to learning opportunities for some students. Describing the dynamics of inequity in groups is a necessary step toward understanding how to mitigate it. There are numerous methodologies for characterizing and analyzing group in/equity (i.e. Esmonde, 2009; Engle et al, 2014, Langer-Osuna, 2016). These coding schemes are labor intensive and limit the amount of data that can be analyzed. We are interested in schemes that would take less time and allow for analyzing larger amounts of data.

Theoretically, we begin from Esmonde's (2009) definition of equity. She argues a small group is equitable when all students in it have fair access to learning resources and positional identities as "knowers and doers" of STEM. Thus, an effective coding system for researching group in/equity must reflect who has access to resources and positional identities and the factors that affect an individual's access. Shah and Lewis (2019), building on Esmonde's definition, identify two important facets of an equitable group: participatory equity and relational equity. Participatory equity describes when the classroom has a "fair distribution of both participation opportunities and participation itself" (p. 249). It is by participating in the group's discourse that students access both learning resources and positive identities. The second facet, relational equity, occurs when students care about their peers' learning and respect the contributions all students put forth (Boaler, 2008).

Group in/equity behaviors

We started with a previously developed system (Slattery and Huchison, 2018) that codes discourse behaviors as attenuating or amplifying inequity. We felt two important revisions were necessary. First, the existing scheme fails to capture the positive impact off-task behavior can have on participatory equity (Langer-Osuna et al, 2018). Then, it does not track who behaviors were directed toward. So we added a code to note the potential inequity attenuating impact of social interactions, and we tracked the participants who engaged in the behavior and to whom the behavior is directed.

Group in/equity behavior coding then consists of two components: behavior/function and direction. These indicate the significance of a student's behavior and the student or students the behavior impacts. To assign behavior/function, the researcher examines each utterance or action, and labels it using one or more of the nine behavior coding categories (see Table 1 on the next page). To code direction, the researcher identifies the participant(s) at whom a behavior is directed. For example, whose idea was ignored or encouraged.

Discussion

To both refine and test our coding scheme, we analyzed a series of roughly 30-minute video segments of three collaborative small groups. A research team had collected the video during small group activities where college-aged students learned about climate change in an inquiry learning format. (Franklin et al, 2018)

Because in/equity is not a binary designation, groups are not simply equitable or inequitable, but rather one episode is more or less equitable than another episode. Behavior code counts provide a way to make relative, across group comparisons and could also identify differences within a single group's episodes on different days. Further, the direction code can provide insight into the dynamics of a single group by identifying repeated patterns of behaviors between group members that attenuate or amplify inequity and pinpoint who repeatedly initiates and receives in/equity behaviors.

While our intent in this poster is describing the coding scheme, it bears noting we found it reasonably straightforward to use consistently across trained coders. Our percent agreement among three coders was 88% before reconciling. We believe this coding scheme has the potential to provide insight into understanding the in/equity impact of things like activity type, group composition, teacher intervention, and other factors that might impact participatory and relational equity in collaborative small groups.

Table 1
Group In/Equity Behaviors and their impact on equity

Behavior	Description	Effect
Social Bonding	Any socially related statement or action that elicits a positive response from another member or members of the group	Attenuates Inequity
Encouraging/ Energizing	Statements or actions that promote the ideas or statements of another student	Attenuates Inequity
Orienting/ Clarifying	Statements or questions that attempt to clarify/understand an idea or action in the group	Attenuates Inequity
Gatekeeping	Attempts to get any/all members of the group to participate in the discussion or activity	Attenuates Inequity
Forwarding	Taking a leadership role in moving the group towards completion of the task at hand	Attenuates Inequity
Ignoring	Not verbally engaging or acknowledging the ideas or attempts to contribute of another member of the group	Amplifies Inequity
Overtalking/ Aggressing	Talking louder while another student is talking, making harsh comments or tone of voice toward another student	Amplifies Inequity
Individual Blocking	Any action or statement that prevents another student from contributing their ideas to the group	Amplifies Inequity
Derailing/ Group Blocking	Statements or actions that cause the group to become off task or lose focus on the task	Amplifies Inequity

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Friends or Feedback? – Computer Science Students' Goals and Their Intention to Use a Feedback-Tool

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Abstract: A lack of technology acceptance might hinder students from using educational technology. The UTAUT-model specifies performance expectancy, effort expectancy and facilitating conditions as relevant factors that influence the intention to use (ITU) a technology. Little is known about learner characteristics that influence ITU. We investigated the effects of different achievement goals of *N*=155 computer science students on their ITU of a feedback tool and learning outcome.

Aims and theoretical background

Digital technologies offer great promise for student learning. Students are more likely to engage in higher-order activities when technologies are implemented in class compared to when no technology is used, and such activities are also associated with a higher learning outcome (Wekerle et al., 2022). A key factor influencing the use of digital tools is students' technology acceptance (Venkatesh et al., 2003). A well-established model that focuses on the acceptance and use of digital tools is the Unified Theory of Acceptance and Use of Technology (UTAUT; Venkatesh et al., 2003). According to this model, *performance expectancy* (PE) and *effort expectancy* (EE) are decisive for the *intention to use* (ITU) digital tools, which in turn predicts the actual use of the tool. PE describes the user's perception that using the tool will help him or her achieve performance benefits. For students, for instance, this might refer to the belief that the use of a tool will promote his or her learning. EE, in contrast, describes the perception of how much easiness is associated with the use of the tool. For example, this might be a student's perception of whether the tool has an intuitive user interface. Further, facilitating conditions (FC) describe the user's perception of the extent to which there is a supportive infrastructure for the use of the tool (Venkatesh et al., 2003), which is also assumed to impact ITU. While these relationships have been supported empirically in many studies, it is still unclear what influence learner characteristics have on the use of tools and how these relate to student performance, particularly when it comes to educational technology. In this realm, we focus on achievement goals as a motivational construct that might influence the ITU (Hullemann et al., 2010).

There are many types of achievement goals that might influence learners' behavior (Daumiller, 2019). For the ITU of a peer feedback tool, especially the following three kinds of achievement goals seem to be relevant: learning approach goals (LAG, i.e., the goal of students to learn as much as possible), appearance approach goals (AAG, i.e., the goal of being perceived as competent by others) and relational goals (RG, i.e., the individual's striving to build close relationships with other students). Research suggests that learning-related goals, such as LAG, are particularly beneficial for learning and positively associated with learning outcomes. However, for AAG, studies often show positive, negative, or null effects on learning outcomes (Hackel et al., 2016). Positive effects on the behavioral level may also be assumed for RG and are associated with positive outcomes (Daumiller et al., 2019). The aim of this study was therefore to investigate the effects of different goals on ITU of a digital peer feedback tool of computer science students.

Based on UTAUT, the core connections that PE, EE and FC predict the ITU of the feedback tool were first assumed. In addition, since feedback tools provide learning opportunities that also involve interactions with peers, we assumed that LAG, AAG and RG positively predict the ITU of the digital peer feedback tool. Furthermore, we assumed that ITU of the tool also predicts students' performance.

Method

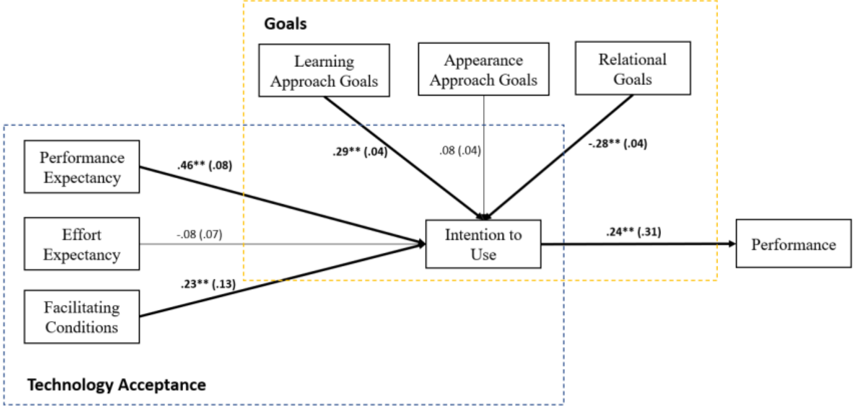
A total of *N*=155 computer science students took part in the study. They were first introduced to a digital feedback tool called "getFeedback!" in a lecture and then carried out a test task. After that, they answered items to measure PE (3 items, e.g., "Using getFeedback! increased my productivity", Cronbach's α=.81), EE (4 items, "I found getFeedback! easy to use", Cronbach's α=.90), FC (4 items, "I have the resources necessary to use getFeedback!", Cronbach's α=.52), ITU (4 items, "I think I will use getFeedback! this semester", Cronbach's α=.91; Venkatesh et al., 2003) and LAG (4 Items, "[When using the tool getFeedback!] …I want to constantly improve my competences", Cronbach's α=.93), AAG (4 items, "...I want to be perceived as competent", Cronbach's α=.80) and RG (4 items, "...my main concern is to have a friendly relationship with students" Cronbach's α=.93; Daumiller et al., 2019). One week later, the students worked on their tasks and then gave each other feedback. In order to examine the connection between feedback performance and ITU, students evaluated the feedback messages of each other. Due to the small sample size, the mean values of the scales were treated as manifest variables and a manifest path model was calculated.

Findings and conclusions

A manifest path model showed a good fit to the data, df = 13, $\chi 2$ = 7.85, p = .25, RMSEA = .005, CFI = .980, TLI = .96, SRMR = .033. PE (β=.46), FC (β=.23) and LAG (β=.29) significantly predicted students' ITU the feedback tool (p<.05). There was no significant effect for EE (β=–.08) and AAG (β=.08) on ITU. Surprisingly, however, there was a significant negative effect of RG (β=–.28) on ITU (p<.001). In addition, performance was significantly predicted by ITU (β=.24) Thus, the assumptions of the UTAUT for the prediction of intention by PE and FC could be confirmed. When interpreting the effects of FC, the insufficient reliability should be considered. In addition, ITU was significantly predicted by LAG. For AAG, in contrast, no significant associations with ITU were found. This might indicate that learning goals may also have effects on the use of digital peer feedback tools probably because students with learning goals regard working with the peer feedback tool as a learning opportunity. An explanation for the missing effect of appearance goals might be that, on the one hand, students with this primary goal might not want to help other students in order to perform best themselves. On the other hand, they might want to demonstrate their competencies. Hence, the two effects may cancel each other out (Daumiller et al., 2019). The negative effect of relational goals might indicate that digital interactions are associated with the fear of negatively influencing social relationships. Investigating the link between goals and technology acceptance further might therefore be a promising avenue for future research.

Figure 1

Results of path modeling the effects of PE, EE, FC, LAG, AAG, RG and ITU on Performance



Note. Presented are the standardized coefficients and standard errors in parentheses. *p < .05, **p < .001.

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Authority-Sharing in Nature: Critically Examining Power in Field Trip Programs

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Abstract: This qualitative design-based research-practice partnership studies justice-centered practices towards consequential informal STEM learning and program design, focusing on authority sharing to understand how to reimagine and restructure power dynamics in nature-based field trip programming. Findings offer a lens for disrupting injustice in informal learning.

Introduction

We explore what supporting justice in ISL looks like in daily practice and design with educational leadership teams. Centering justice in on-the-ground enactment, we seek to contribute to emerging understandings of daily justice-centered design and enactment, insights on strategies for building institutional capacity to advance justice in ISL. We focus on three interconnected components of *authority sharing*: a) offering youth opportunities to be an expert/authority, b) decentering adults, and b) supporting new and hybrid forms of expertise. Working in justice requires integrative, cross-cutting, and critically connected actions across multiple areas and scales of activity (Ayers et al., 2008). In ISL, programs can be shifted in-the-moment, over time, at individual scales, and at institution scales (Penuel, 2017). In learning from and participating in the concrete and consequential efforts that particular institutions are engaging, we seek to strategize together towards more multidimensionally impactful transformation, generating knowledge for the field grounded in a research-practice partnership.

Justice-centered informal STEM learning

Informal STEM learning (ISL) settings can help disrupt systemic underrepresentation in science, technology, engineering and mathematics (STEM) (Philip & Azevedo, 2017). However, while informal STEM programs and practices may be made accessible to a wide range of audiences, the learning experiences themselves may welcome some participants while excluding others. Models that position educators as sole decision makers for learners carry implicit assumptions that center information-and-skill delivery and absorption, even within inquiry and practice-based models. STEM programs are called to leverage the experiences and practices youth and their families and communities offer towards more meaningful learning (Dawson, 2014; Feinstein, 2017). Informal learning leaders play an important role in this shift. We seek to offer lenses to guide informal learning structures towards justice outcomes of rethinking what counts as STEM, what it means to participate in STEM, and who gets to lead in STEM.

A focus on daily informal educator practice and design

Informal education leaders' daily "practices" refer to (a) the process of designing structures, programs, and activities and (b) pedagogical approaches to interactions with youth in-the-moment. Core Equitable Practices are pedagogical practices that support learning in empowering ways. When educators engage in these practices, they position themselves with youth as co-learners, co-disruptors, and co-creators in STEM. As a part of educator daily practice, we argue that Core Equitable Practices can a) welcome and legitimize youth's lives, b) disrupt power relations that marginalized low-income youth, youth of Color, and girls, and c) support new individual and collective participation forms, agency and identity (yestem.org; Greenberg et al., 2023). We seek approaches that directly address issues of justice at the individual and collective level through disrupting/transforming power, valuing youth along with their communities, and supporting STEM-agentic lives (supporting the ability of youth to use STEM as a tool for greater agency in whatever they desire to focus on in life). These patterns of practices can form an integral part of informal learning leaders' and designers' everyday practices (Peercy et al., 2022).

A centering of justice necessitates an ethical and political choice as educators. Our term "core equitable practices," draws from prior work in "core practices," a practice-based framework of teaching emphasizing daily action shaped by context (Kloser, 2014). Such practice happens in relation to systems of power (Peercy et al., 2022). To build capacity for justice-oriented informal learning, core equitable practices need to be studied further to understand how they can make visible, disrupt, and transform daily injustices in informal spaces.

Area of focus: Authority sharing

In exploring the core equitable practice of *authority sharing*, we seek to enhance understandings about implementation of a justice lens through daily practice in informal STEM education (including any tensions/challenges and possibilities for follow-up research questions). Typically, in learning environments, the educator is seen as an expert authority (Wrong, 2002) who decides what knowledge is important and how youth can demonstrate competency in taking up that knowledge. Adults hold expertise, but youth also bring valuable experiences to learning spaces. When we move beyond a binary of adult versus youth-centered learning, authority is shared. This helps to position youth knowledge and practice as valuable. It can also help de-center White, Western, masculine-lens epistemologies. When new, more egalitarian authority structures are created, whose knowledge and experiences matter (and how and why) is expanded. Adults can restructure authority in informal learning spaces through assigning roles (both implicitly and directly), valuing input/participation, and acknowledging expertise and effort. Authority Sharing involves supporting youth in using their expertise to educate others, drawing from the stance that youth have powerful ideas and experiences that matter in learning and doing STEM. Beyond giving youth the opportunity to be authorities, adults can embrace new forms of authority that bridge/merge and/or challenge traditional forms.

Context, methodology, & methods

Across more than 5 years of iterative and interdisciplinary research, we generated a set of 9 core equitable practices, including the practice we study here, *authority sharing* (Greenberg et al., 2023). We are now partnering with leadership in critical participatory design-based research (Getenet, 2019) using Summer 2022 data from 32 graduate student educators' actions and perspectives, informed by 3 institutional leaders and 4 university research partners. Data include interviews, researcher notes, focus groups, informal dialogue with educators, photos of teaching, and participant-observation. Our process of co-analyzing that data is described in our poster.

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International Society of
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Predicting Students’ Collaborative Interdisciplinary Problem Solving

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Abstract: Empirical evidence on what predicts students’ perceived collaborative interdisciplinary problem solving (CIPS) is limited. This study responded to this gap by building a multiple linear regression model to predict CIPS using 375 surveys collected from 71 undergraduates over eight weeks in an interdisciplinary digital literacy course. Motivating goal-directed affect positively predicted students’ CIPS, while anxiety was a negative predictor, indicating the importance of optimizing students’ motivation and emotions to facilitate their interdisciplinary learning.

Introduction

Addressing real-world problems requires technical skills and competencies to collaborate with others and navigate diverse knowledge landscapes. A promising way to cultivate these skills and competencies is by incorporating real-life, workplace, and societal issues into classrooms via interdisciplinary learning (Hains-Wesson & Ji, 2020). Accumulating evidence suggests the benefits of interdisciplinary learning, such as promoting learners’ organization of knowledge; facilitating critical thinking, metacognitive skills, and collaboration; and supporting the application of knowledge and skills to real-world issues or problems (Ivanitskaya et al., 2002).

Dealing with multiple disciplines simultaneously and communicating with group members from other disciplines may make interdisciplinary tasks difficult (Abbonizio & Ho, 2020). Cognitive theories typically view learning as an active goal-oriented process (Schuell, 1986), suggesting the importance of motivating goal-direct affect in learning. Growing research recognizes that epistemic emotions influence and are influenced by students’ motivations, social interactions, and cognitive processes (Pekrun et al., 2017). This study examined how these constructs contribute to students’ collaborative interdisciplinary problem-solving (CIPS).

Methods

This study was conducted in a digital literacy course that covered eight topics, such as Computational Thinking and Quantitative Reasoning. The participants were 71 undergraduate students (33 females, $Mean_{age}$=20.33 years old) from a public university in Asia. They came from ten different schools across Business, Sciences, Engineering, Humanities and Social Sciences. Four to six students from different schools were placed into a group to facilitate their interdisciplinary learning. A flipped classroom learning approach was employed: each week before the class, students were instructed to watch an hour-long video and take a short test; in class, they had 90 minutes to participate in CIPS activities, present their work, and fill in a weekly survey on their perceived difficulty of the activities, motivating goal-directed affect (five items adapted from the Positive and Negative Affect Scale, Cronbach’s alpha=0.94, Watson et al., 2018), epistemic emotions (seven items to measure discrete emotions adapted from the Epistemically Related Emotions Scale, Pekrun et al., 2017), and CIPS (adapted from the Integration subscale in Cole et al., 2018, Cronbach’s alpha=0.94). We conducted multiple linear regressions using all the other independent variables to predict CIPS.

Results

Table 1 shows how the key variables predict students’ CIPS. Among these variables, one unit increase in motivating goal-directed affect contributes to a 0.49 increase in CIPS, while one increase in anxiety leads to a 0.15 decrease in CIPS. Students’ perceived task difficulty, motivating goal-directed affect and various epistemic emotions explained 31.0% of their CIPS.

Table 1
Regression results using collaborative interdisciplinary problem-solving as the dependent variable

Predictor	*b*	*b* 95% CI	sr^2	sr^2 95% CI	Fit

		[LL, UL]		[LL, UL]	
(Intercept)	3.97**	[3.38, 4.57]			
Difficulty	-0.04	[-0.12, 0.04]	.00	[-.01, .01]	
Motivating goal-directed affect	0.49**	[0.30, 0.68]	.05	[.01, .09]	
Surprise	-0.04	[-0.17, 0.09]	.00	[-.00, .00]	
Curiosity	0.15	[-0.00, 0.30]	.01	[-.01, .02]	
Confusion	-0.08	[-0.21, 0.05]	.00	[-.01, .01]	
Anxiety	-0.15*	[-0.29, -0.01]	.01	[-.01, .02]	
Joy	0.05	[-0.09, 0.20]	.00	[-.00, .01]	
Frustration	0.05	[-0.10, 0.21]	.00	[-.00, .01]	
Boredom	-0.04	[-0.17, 0.08]	.00	[-.00, .01]	
					R^2 = .310** 95% CI[.22,.37]

Note. * indicates $p < .05$. ** indicates $p < .01$.

Discussion and conclusion

This exploratory study found that a significant amount of variance in collaborative interdisciplinary problem-solving can be explained by (1) motivating goal-directed affect and (2) anxiety. We posit two possible reasons for this pattern of results. First, motivating goal-directed affect and anxiety might be influential variables that buffer the effects of conditions, perceived difficulty and epistemic emotions. This result implies that external conditions (e.g., nature of activity or difficulties encountered) may be less significant than the internal motivating state in learning. Indeed, Gill and colleagues (2021) found that the task was of secondary importance compared to the quality of interaction between motivated students in interdisciplinary learning. Anxiety was negatively predictive of collaborative interdisciplinary problem-solving. This result corroborates Saito and colleagues (2018), where greater learner anxiety predicts worse performance and limits the learner's opportunities to engage actively in the classroom (Yashima et al., 2016). Second, another possible reason is the self-selection bias of the current participant pool, which represented only approximately 35% of the classes sampled. The voluntary participants may be more motivated than the typical student population, resulting in a greater contribution of motivating goal-directed affect in the regression model than expected.

Some limitations of the current study should be noted. Firstly, we collected multiple observations from a single student, resulting in a nested data structure that was not accounted for in the regression analysis. Second, we used a single item to measure perceived difficulty and discrete epistemic emotions. Although research (e.g., Fisher et al., 2016) suggests robust psychometric properties of single-item measurements may replace multi-item counterparts, future studies could be strengthened with multiple-item measurements of these constructs.

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Can AI Help Teachers Write Higher Quality Feedback? Lessons Learned From Using the GPT-3 Engine in a Makerspace Course

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Abstract: We explore how a cutting-edge language model, GPT-3, can be used to augment and assist periodic feedback writing in a makerspace course. Personalized messages were generated using student data then edited and combined with human instructor feedback. We discuss the lessons learned: namely, AI did well in summarizing work and positive encouragements, yet could write off-target feedback for struggling students. An initial interview with an instructor revealed that future iterations must consider ways to formalize and manage human expert roles.

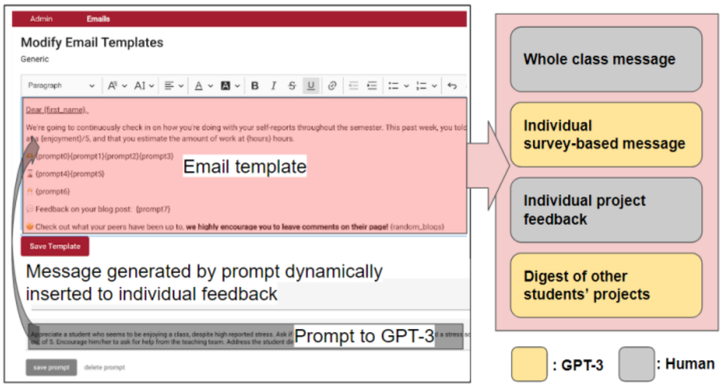
Introduction and setting

Could AI technologies augment periodic feedback, a standard practice in many learning environments? We study how this might be done in one context less explored but ripe for automated data-based feedback systems: a makerspace, a physical project-based learning environment where students monitoring can be a challenging task. Our context is a semester-long course on digital fabrication at a graduate school of education in the U.S., where students (n = 19) applied standard makerspace tools for a personal project. For many, the course is not only a chance to learn a new skillset, but to revisit their identities and perspectives on learning. Yet, we also saw students who quietly struggle to keep up. While instructors reaching out could help these students, this requires keeping tabs on multiple data sources and writing time-consuming feedback. Our study tests whether AI could assist this instructor responsibility, with the current paper focusing on results of our explorations on what tasks AI could and could not do well in an educational context, as well as lessons learned on supporting AI-human partnership.

A platform for developing a human-AI partnership: Preliminary findings

Our platform used GPT-3, a cutting-edge generative AI model that can generate humanlike speech with a high level of sophistication and naturalness. During an exploratory phase, we fed various blog posts written by students to GPT-3 to identify when and how the system might be used in a project-based environment. Our explorations led us to believe GPT-3 may provide the starting point of a helpful feedback: it was able to 1) use supportive language to appreciate projects (e.g., imaginative, impressed); 2) recognize the work put in (e.g., I appreciate the effort, I'm impressed); and 3) value students' strategies (e.g., you did a great job of staying organized throughout the process). Based on our explorations, we developed a writing platform seen in Figure 1. The system is shown on left, while on right is the structure of the periodic feedback sent out.

Figure 1
Interface for generating feedback through human-AI collaboration & feedback structure



Dear {first_name},

We're going to continuously check in on how you're doing with your self-reports throughout the semester. This past week, you told

a {enjoyment}/5, and that you estimate the amount of work at {hours} hours.

{prompt0}{prompt1}{prompt2}{prompt3}

{prompt4}{prompt5}

{prompt6}

Feedback on your blog post: {prompt7}

Check out what your peers have been up to. **we highly encourage you to leave comments on their page!** {random_blogs}

Appreciate a student who seems to be enjoying a class, despite high reported stress. Ask if

of 5. Encourage him/her to ask for help from the teaching team. Address the student di

How can GPT-3 be used in project-based learning contexts?

Our platform used GPT-3 for two tasks: generating encouraging messages for students and summarizing student blog posts on their weekly projects. Again, GPT-3 showed clear value in summarizing student reflections of their own work. The machine-generated summaries were concise and accurate, giving instructors overviews on how student work was progressing. They were also close enough to natural speech to directly add to emails, making it easier to encourage peer engagement. GPT-3 also performed acceptably in writing congratulatory messages. However, we noticed that feedback was often insensitive for struggling students. One prompt (“Write a supportive message to a student with {*stress* (*high)} and {*enjoyment* (*low)}.”) may result in messages of varying quality:

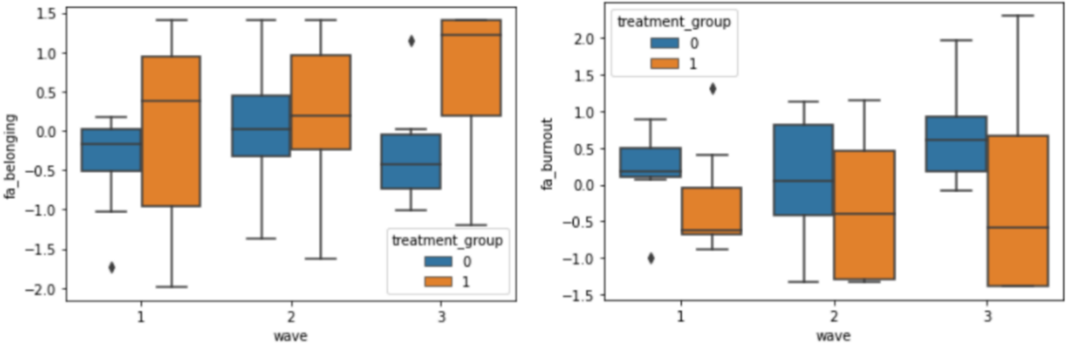
> **Message 1**: We're sorry to hear that you're not enjoying the class and that you're feeling so stressed. Can you tell us more about what's making you feel this way? We want to make sure we're doing everything we can to support you. Are there any specific things we can do to help you feel more comfortable and successful in the class?
> **Message 2**: We think that you're not enjoying the class and that you're feeling slightly stressed. I encourage you to reach out to the teaching team for help.

While the first message is not perfect, the second message is too short to reasonably expect any effect, and the term “slightly” depreciates the level of reported stress. While further tinkering with the prompt could result in better feedback, this may defeat the purpose of making the process easier for human instructors.

Below, we show a descriptive graph of self-reported levels of belonging and burnout for students who did and did not receive the AI-augmented areas of the feedback (i.e., yellow boxes in figure 1). Students who received augmented feedback (orange) seem to report higher belonging and lower burnout, but further analyses on the final data will test these differences statistically and explore the effects with student interviews.

Figure 2

Descriptive trend of student belonging and burnout with and without the AI-augmented feedback



There were also two lessons learned from involving instructors with the platform. One, we quickly realized that human input was an indispensable, limited resource. The makerspace facilitator we interviewed noted that this seemed to add a layer of complexity to writing feedback. While the learning curve may be justifiable for a larger class - for instance, this may make feedback possible in a course with 100+ students -, we acknowledge that these concerns hit a pain point for future iterations. Second, the facilitator noted that for instructors to put trust in these messages, a basic understanding of how AI worked and where it failed was necessary. Conversely, our interviewee also pointed out that other facilitators might be too trusting of the output, and neglect to thoughtfully edit AI feedback. This is a central tension: how do we prompt users to think deeply about the quality of their feedback, but at the same time lessen workload? These questions will be guiding our next iteration efforts.

Conclusion

To sum up, the design and implementation of an AI-augmented feedback system revealed that GPT-3 is helpful in summarizing written products and writing words of encouragement, yet can write off-target feedback for struggling learners. An instructor interview also revealed that we need to consider resource constraints and ways to build trust in AI. In future work, we hope to build system-side quality safeguards, e.g., automatically ‘flag’ sub-par or repetitive messages. We also hope to include existing richer data sources in the input, such as open-ended student feedback, and in particular the camera-based location data from the makerspace, an objective measure of work patterns inside the space. These additional inputs are hoped to increase the accuracy and relevance of AI-generated feedback. On the other end of the pipeline, we also hope to seek advice from students and instructors about effective feedback in different scenarios, to create better prompts for GPT-3. Throughout these improvements, we aim to continuously engage instructors and learners in an iterative co-design process.

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Textile Technology: Learning With and From Materials

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Abstract: Understanding the roles of agency in learning can be expanded by taking up a posthumanist stance and examining material conversations in creative spaces—such as in this participant observation study set in a university textile technology art class. Using video/audio records, artifacts, and field notes, we categorize being, doing, and becoming agency of materials and the learning opportunities they offer in ecoprinting and computer/machine embroidery. Learning with becoming materials may depend more heavily on iteration.

Introduction and purpose

Materials hold energy from their pasts that speak to how we can—or should—use them to create artifacts and learn in the process. We consider the agency of materials as members of a university course on textile technology and examine traversals across materials, exploring artefact creation as joint projects involving shared agency, guided by a research question: How might we learn from and with materials through negotiations of agency?

Theoretical framework

Our work is guided by theory on agency and its role in learning. To this, we bring a posthumanist stance that positions materials as learning partners. Agency has long been treated unproblematically as making decisions, constrained by structures (Giddens, 1984). We take a situative approach to agency (Svihla et al., 2021) in which decisions unfold interactionally and vary in their consequentiality. We also take up a posthumanist view of material, extending classic descriptions of design as a conversation *with* materials (Schön, 1992). By treating materials as living and having the capacity to engage in joint projects, we center "withness" (Shotter, 2006) in which materials are worthy of respect. *Being* materials exert covert and potentially coercive influence or implicit background structure on the design landscape. *Doing* materials are ones that are selected specifically for a particular role and meet a specific need that is negotiated between designer and material. *Becoming* materials are those that are agentively repurposed by the designer as part of an interactional relationship between maker and material (Gravel & Svihla, 2020). We conjecture that becoming material conversations offer fertile grounds for both negotiating agency and learning.

Methodology

We used participant observation to investigate materials as partners in learning, alongside students as co-investigators (DeWalt & DeWalt, 2010). Students engaged in an ecoprinting process (Ratnayaka & Haar, 2022) and used Snap-based TurtleStitch to produce machine-embroidered designs (Wolz et al., 2019). The course, at a large southwestern US university, centers on textile art. The study team includes the course instructor, two learning scientists-as-observers, three graduate students, and two undergraduate students. We collected data through video/audio recording, artifacts, and field notes. We used discourse and interaction analysis to attend to ways members negotiated agency with materials.

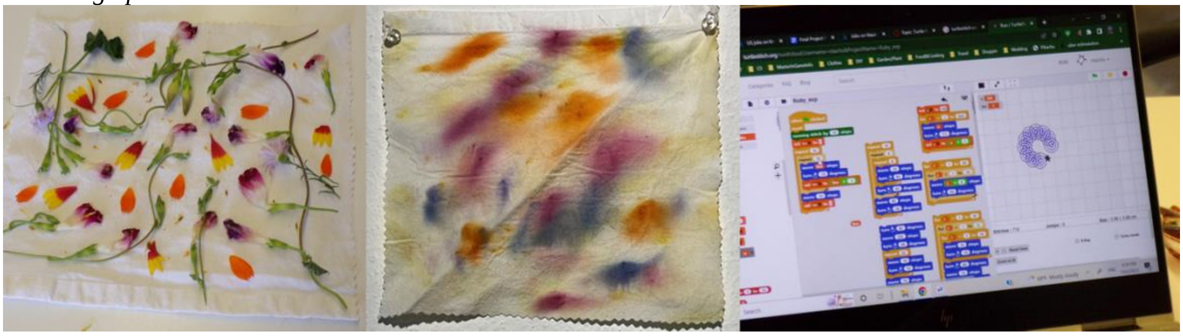
Results and discussion

In ecoprinting, the dowel around which we wrapped the fabric and the steamer pot were being materials; their absence would be noticeable, but their presence was little remarked upon. The fabric and plastic were doing materials, selected for their dependable behaviors. We negotiated agency with the plants, as a becoming material, willing to contribute, yet surprising us. For instance, eucalyptus, a plant we sought for its ability to make distinct orange or brown prints, produced pale yellows. Plants withheld their capacities from us, requiring us to interact with them to discover what they could become. The water held more consequential agency than we anticipated. It seemed like a being material, present as damp, as steam, a backdrop. Yet through our material explorations, we were surprised by its roles in shaping the final print (Figure 1).

In TurtleStitch, the computer itself, browser window, and program were being materials. The individual code blocks, embroidery machine, and thread were doing materials. Created code blocks and the editable values of existing blocks were becoming materials, producing unexpected results for us as inexperienced programmers. Although the preview on screen provided feedback, its translation to fabric was slow. Here, the embroidery machine held more consequential agency than expected, as a computer-drawn line running over itself hundreds of times is acceptable, but doing so even a few times with thread can break thread, needle, or tear fabric.

Across both, we experienced surprise in the transition between working with materials and the product that resulted. The time between code and rendered preview was shorter than the steambath of ecoprinting, but in both, the materials offered little ongoing feedback about how they would behave in final form. In lieu of ongoing feedback in ecoprinting, members gathered to review one another's designs both during designing and when unrolling final designs, sometimes making edits to their own yet-to-be-steamed design. In reflecting on their process, work, and material agency, members noted that they had plans or had implemented additional designs, at least partially in response to the unexpected ways certain materials behaved.

Figure 1
Examples of student work, left to right: preparation for ecoprinting; the completed ecoprint; TurtleStitch code and design preview



Implications

Our analysis foregrounds the negotiated nature of agency between designer and materials, providing insight into roles different materials play in designing and learning. Though the materials differed across ecoprinting and computer embroidery, both included *becoming* materials that had consequential agency, manifested as surprise. Our status as newcomers with the particular materials positioned some as becoming materials, but in the hands of an expert, the same materials might be being materials. Thus, as we learn, our relationship to the materials changes. Our ongoing research builds on this to consider ways we can support learner agency, such as anticipating deliberate, iterative work and reflecting on varied negotiations with different forms of material agency.

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Joint Media Engagement as a Resource for Family Learning: Catalysts and Transmedia Connections

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Abstract: With an abundance of information sources available, families are learning in novel ways. To understand how family-based collaborative learning moments emerge in everyday life we collected and analyzed caregiver narratives of a recent knowledge-building occasion. Learning stories were analyzed to understand their origins, affective qualities, technologies used, and forms of joint media engagement. We find digital tools are leveraged to address immediate needs for information and problem-solving as well as support established interests, connections, and bonding.

Background

In the U.S., young children's time spent on mobile devices tripled between 2013 and 2017, from an average of 15 to 48 minutes daily. During the pandemic, screen time increased dramatically when children spent more time at home, with a recent international meta-analysis estimating an average increase of an additional 84 minutes daily (Madigan et al., 2022). As conversations around digital media and young children evolve from quantifying "screen time" to considerations of content and context, learning sciences research has an important role in providing insights about everyday learning relevant to caregivers, educators, and designers. In this project, we explore how digital media resources can serve as powerful learning tools when adults and children use them as catalysts for collaborative exchanges around personally meaningful content. Digitally anchored activities shared with parents, siblings, grandparents, and extended family can generate questions, explanations, and extended conversations that build connections to real-world experiences and support the development of language and literacy. Digital tools also allow for the co-creation of artifacts that offer opportunities to reflect on original content. Ethnographic studies have shown that these forms of joint media engagement (JME) can be a powerful mechanism for fostering cultural knowledge, coordinating activities between home and school, and co-developing interests that evolve over time (Barron & Levinson, 2017; Takeuchi & Stevens, 2011). In addition to these benefits, learning together can be a source of bonding and shared enjoyment. Given the potential of leveraging technology for learning, it is essential to understand the conditions that catalyze generative moments in the context of daily life. We contribute to this agenda by sharing findings from a study of parents and children learning together. We report qualitative analysis of collaborative learning narratives reported by caregivers. Two questions organized this analysis. (1) What motivates learning together (origins, purpose, content)? (2) What sources of enjoyment and challenge do caregivers articulate?

Methods

This project uses a remote research tool, dscout, as an experimental method to conduct qualitative research with remote participants. We captured instances of parents and children learning together from 50 diverse families in the service of better conceptualizing child-driven contemporary learning ecologies. Families each had at least one child between the ages of 7-10. The gender balance is approximately 55% male. In our sample, 50% of families reported household incomes below the national median for families in the United States ($75,000). Participants answered a series of questions using short videos, photographs, responses to multiple/choice and rating queries. This poster focuses on caregivers' reports of using technology to learn with their child. Data for each entry included a 2-minute video (and transcription) of the caregiver describing and reflecting on the learning moment.

Findings

Our coding system includes seven primary dimensions: learning catalysts; focal content; mode of joint engagement; learning partner roles as guides and learners; media resources; affect; and sources of enjoyment/challenge. Examples of learning together ranged in content and form. Each transcribed caregiver video-response was coded for the primary four themes below (see Table 1). Learning together promoted bonding and collective positive affect across the sample. Due to space limitations, Table 1 highlights one subcode and example for four major themes.

Table 1
Selected Codes for Family Learning

Topic	Code	Example
Affect	**Joint positive affect**: Caregiver and child share positive emotions from an activity	Gardening is my passion and it was fun to share it with them and see the delight on their faces when I told them in a few years we will have a tree and may even get apples.
JME	**Conversational anchoring**: Digital artifacts support joint understanding of a concept, activity, or place	We went on NASA's website and we were learning about the different layers of Earth's atmosphere. So we got to learn all about the various layers of the atmosphere as it went through.
Media resources	**Video sharing platforms:** Use of platforms like YouTube or TikTok	So we did the counting, then I put it on a TV because we have a smart TV, so it does YouTube. We sat there and we did all the dances.
Catalyst	**Life Challenge:** Joint learning is motivated by an immediate or possible future challenge related to health, well-being, repairs, communication, or finances	So my kids were fighting again and freaking out. I was telling them that they needed to figure out some coping mechanisms to help them deal with their emotions so that you don't take them out on each other. He was like, “Whoa! Like what?” So, I said, Hey, let's Google it. And so we went to the Internet to find coping mechanisms for him.

Here is one learning moment example from a mother, Brianna and her nine-year-old child learning together.

> We actually found a book on Epic about owls, and we learned the different things about how owls are, the difference between the owls and how they live, how they eat, how they expand, how they travel. We worked together to do some more research and looking at pictures and videos and listening to the different sounds these owls make. We learned together, and it was just about bonding, building, and learning together.

In this case, the parent and child collaborated to search the online Epic reading database for a book to learn about a topic of interest, owls. The form of joint media engagement, collaborative interest-driven search, leveraged the internet to find videos, photos, and audio to enrich their understanding of how owls live. Holistic learning occurs here through reading, visualizing, listening, and discussing the topic. By building knowledge together, Brianna and her daughter bonded, and she appreciated her daughter’s research skills, setting the stage for expanding this practice elsewhere.

Implications and future directions

With countless ways to interact with information today, how can we best support families? This project analyzes instances of child-caregiver driven collaborative learning to understand catalysts of inquiry, productive JME co-learning practices, preferred media resources, and to conceptualize affective and epistemic benefits. Future design work can leverage these insights for co-designing family reflection tools that surface productive JME and shared joy, as a metacognitive and meta-emotional resource for making choices about how to spend valuable time together.

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Dialogic Coaching Routines to Develop Teachers' Adaptive Expertise in Video-Based Coaching

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Abstract: Instructional coaching that builds teachers' integrated knowledge of dialogic teaching concepts and practices is essential for achieving ambitious education reform goals. An enduring challenge, however, is that relatively little research has focused in-depth on the processes that facilitate teacher learning in coaching contexts. Here, we illustrate a 'dialogic coaching' approach that connects the learning processes needed to develop teachers' adaptive expertise for dialogic teaching to an interactional framework for coach-teacher joint reflection.

Introduction

Instructional coaching is a widely used form of teacher professional development to advance dialogic teaching approaches. Historically, however, coaching as it normally occurs is often misaligned with learning theory that emphasizes joint participation in the core processes that underlie a complex task (e.g., facilitating a classroom discussion). Our presentation illustrates a 'dialogic coaching' approach that emphasizes eliciting and scaffolding teachers' pedagogical inquiry and reasoning processes to connect dialogic teaching concepts to their own practice.

Theoretical framework

Effective professional development requires integrating professional learning activities in robust, theory-driven frameworks of teacher learning and change processes. Here, we draw on an adaptive expertise research (Hatano & Inagaki, 1986) to identify three interrelated pedagogical thinking and reasoning processes needed to support teachers' learning of dialogic teaching: *problematizing* teaching-learning situations to negotiate a shared problem space; *weighing* alternative scenarios to resolve problems; and iterative linking between teaching specifics and abstractions (i.e., *instantiating* and *generalizing*). (Walsh, 2021). We highlight these pedagogical reasoning processes in specific because they closely align with the nature and demands of dialogic teaching. Specifically, as an approach that fundamentally hinges on responding to students' developing thinking and ideas, teachers must learn to flexibly reason through alternative ways of interpreting and responding to pedagogical scenarios and dilemmas (i.e., *problematizing* and *weighing*) and build integrated knoweldge by iteratively connecting specific lesson interactions to broader pedagogical concepts and aims (i.e., *instantiating* and *generalizing).* Together, these processes can destabilize routine ways of thinking and acting in the classroom and enable more productive decision-making.

Illustrative exemplar

In this section, we draw on excerpts of coach-teacher dialogue from a larger study of a successful video-based coaching program (Correnti et al., 2021). In the following, the coach and teacher discuss a video clip where the teacher had asked students to explain the meaning of the idiom "You can't feed hope with food," with the goal of having students infer the larger meaning using text details. Our aim is to highlight how coaching interactions can elicit and scaffold the pedagogical reasoning processes needed for adaptive teaching expertise described above.

Problematizing: Developing a clarified conception of the problem space

Table 1
Excerpt 1

Turn	Quote (coach= C; teacher=T)
1	C: You began by asking: "What is the author talking about?" *What is the pattern of the conversation and how did this impact your learning goal for students?*
2	T: My goal was for the students to make the connection that there wasn't any food, water, or schools—the things Salva hoped for—so there wasn't anything to 'feed hope.' *The pattern I noticed was students guessing and then I would try to explain why it wasn't quite right.* **[instantiating]**
3	C: I thought we could look again and *see if you think that at any point the balance of talk is not in the students' court.* **[generalizing]** […video plays…]

4	T: I probably shouldn't have started the conversation with 'you can't feed hope with food,' *because the students spent so much time trying to figure out what that meant…I think I beat the dead horse for so long that…the meaning got lost…*
5	C: What did you notice the students saying?
6	T: Keyla said there wasn't enough to eat. The government didn't have money to give to the camp…*so, they were saying all the things about the camp that made it unrealistic or made it difficult to hope.* **[instantiating]**
7	C: Let's look at a couple of talk moves that might be useful *when kids are throwing out a lot of details, but they are not getting that big message in the text.* **[generalizing]**

The coach begins by inviting the teacher's thinking about the link between her pedagogy and student learning (T1), prompting the teacher to offer an initial formulation of the problem space (i.e., that students were 'guessing' and she was 'explaining') (T2). The coach then suggests a slight reframe focused on student participation linked to a broader aim (T3). After viewing the clip, the teacher offers a new framing of the problem space (T4) to which the coach responds by orienting the teacher to student's expressed thinking in that moment to draw attention to the fact that students were providing many important details (T5). The teacher then offers a strong inference based on specific evidence (T6), providing the basis for a more sophisticated formulation of the problem space, i.e., that the pedagogical problem was not that the interaction had 'gone on too long', but that teacher facilitation was needed to help students infer larger meanings from multiple text details (T7).

Generating and weighing alternatives: Refining and resolving the problem space

Table 2
Excerpt 2

Turn	Quote (coach= C; teacher=T)
10	C: If students are throwing out these various details, how might you use talk moves *to help pull these details together so that they could start to see them as a unified piece?* **[instantiating + weighing]**
11	T: Well maybe, "What is the basis for that conclusion?" Or, "I hear you saying… "What do you think…?" Or even, something like, *"Okay. Given what Keyla and Vanessa just said and what we just read about, what do you think the author is trying to tell us?"* **[instantiating]**
12	C: I think that this would help them get to *the 'so what' of that portion of the text so that they can collaboratively build toward the big ideas. It is important for students to know details, but it is also important for them to help each other put those details together to interpret the larger message.* **[generalizing + weighing]**

Once the problem space is identified, the coach invites the teacher to propose specific talk moves that might be useful for similar future situations. The teacher offers several specific alternatives given students' expressed thinking, ending with *'what is the author trying to tell us'* (T11). The coach affirms this alternative and connects her explanation to a general principle of dialogic teaching (T10). This connecting of specifics to general principles is critical for developing more integrated knowledge and transfer insights to future lessons. As such, it is central to adaptive teaching expertise—the ability to choose talk moves to achieve dialogic teaching goals in practice.

Discussion and implications

This poster provides insight into how dialogic coaching interactions can support teachers' development of adaptive teaching expertise through problematizing and iterative linking of teaching specifics and abstractions, contributing insight into the 'black box' of teachers' professional learning conversations.

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Can AI Disrupt Disinformation? Assisting Learners in Identifying Fake News Through an AI-Powered Platform Informed by Inoculation Theory

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Abstract: The recent increase in the spread of disinformation poses dangerous implications for society. This project draws on inoculation theory to design and test an interactive platform based on Large Language Models – Aide – that uses language modeling to educate users on common textual strategies employed in pieces of disinformation. Preliminary user experiences with Aide suggest an influence on learners' disinformation sense-making processes.

Introduction and theoretical framework

Disinformation is a central concern in today's world. While the origin and definition of disinformation are widely debated, we draw upon the definition of disinformation as any information whose primary function is to mislead individuals (Fallis, 2015). This study is inspired by the epidemiological theory of inoculation as a response to disinformation, and builds on research proposing that preemptive exposure to controlled doses of disinformation can offer "cognitive resistance" against future disinformation (van der Linden, 2022). The platform developed to "inoculate" learners in this study, Aide, utilizes artificial intelligence (AI) to help users identify misleading tactics employed in pieces of disinformation. Previously, AI models that identify different textual features present in disinformation have been developed for social media moderation (Zhuk et al., 2018). However, there is still a gap in the application of AI and Large Language Models in teaching and learning about disinformation. Through a progression of interactions with Aide, users observe how the platform detects these textual features, namely unwarranted correlations, overgeneralizations, and emotional triggers. The team chose this set of strategies following related work (e.g., Roozenbeek & van der Linden, 2019). Aide emphasizes the methods and processes for determining the validity of information, rather than solely confirming or denying a learner's preconception of it. This study builds on previous work by the researchers (Russo, Blikstein & Penalva, 2021; Russo & Blikstein, 2022) to investigate how Aide's use bolsters learners' ability to identify common strategies in disinformation campaigns and assists in developing critical mental models that can be applied to daily information consumption. We present preliminary findings related to learners' ability to identify textual features of disinformation, and their stated tendency to apply similar strategies in real life.

Methods

Aide has been designed as a mobile app implementing a JavaScript-based interface in connection with OpenAI's API for GPT-3, "a third-generation, autoregressive language model that uses deep learning to produce human-like text" (Floridi & Chiriatti, 2020). We hypothesized that an AI agent's linguistic analysis would allow learners to critically reflect upon disinformation by serving as a resource outside of learners' social bubbles. A convenience sample of 4 international graduate students in the US majoring in education (22-26 years of age) was recruited to test the application. They were individually interviewed and recorded for approximately one hour on Zoom, and had their screen recorded for observation of their interaction with the app. We examined how interaction with the prototype was associated with verbal expressions that denoted reflection and/or learning, such as when users' manifest analytical approach to identifying disinformation tactics mirrored that of Aide. Prior to user testing, participants received a brief explanation of Aide's functionality. Researchers then asked about participants' media consumption and sensemaking processes when encountering news articles. For the majority of the interview, participants interacted with the prototype utilizing think-aloud strategies. Finally, participants shared their impressions and ideas on how to improve Aide for future use. Researchers took notes during the interviews and watched the recordings to identify evidence of learning as they interacted with Aide.

Results

We found preliminary evidence of learning and effectiveness of the prototype during the user testing. Prior to interacting with Aide, only one out of four participants could define disinformation. Although we understand that a memorized definition is not the most appropriate way to assess one's learning, that provides us with a point of reference for familiarity with the topic. After approximately 20 minutes of interaction with Aide, 3 out of 4 participants seemed to recognize general patterns of disinformation explored in the prototype, such as "unwarranted correlations" and "overgeneralizations." It is intriguing to notice that by minute 20, participants had already (1) briefly discussed forms that disinformation could take, (2) seen Aide's evaluation for a news headline, and (3) were evaluating a news story by themselves, following Aide's heuristics. Also, the participant who spent most of the test interacting with Aide (53% of total interaction time) came up with concrete pattern recognition such as "conspiracy theory" and "emotional trigger."

We also noticed a tendency to assimilate patterns. Learners stated that the strategies evidenced by Aide could help them read the news more critically in the future. More specifically, one participant said that Aide "tells me what to do with disinformation." Another participant stated that she wanted "to imitate what Aide does. Because Aide provided two strategies of disinformation, I want to do something similar." Although this insight is encouraging to develop further the prototype, it also signals the need for attention to excessive reliability on a Large Language Model-based system: although one participant alerted against the embedded biases that the prototype itself has, other participants were enthusiastic about the idea of "outsourcing" criticality in consuming the news. For example, one learner said that she wants "Aide to decide for me whether the news is trustworthy or not." Despite the preliminary nature of this data, this also serves as a warning as to how much further we can go in relying on AI systems to make decisions on our behalf.

Discussion and future directions

Although the tests conducted in the current research are limited, they show Aide's potential as an effective implementation of the inoculation strategy against disinformation. Participants showed engagement and enthusiasm in using Aide as a tool to identify disinformation patterns on a day-to-day basis. The study hereafter needs more explicit instruction and design elements that make the overall journey more explicit, as well as the tasks expected from the user at all stages. Data collected so far leads the team to conjecture that visibility of those steps tends to promote effective learning and enhanced engagement.

In conclusion, the initial research phase indicated that interaction with Aide inspires users to adopt critical sense-making processes toward disinformation. In particular, preliminary results suggest that Aide influences learners to express disposition in detecting textual features commonly employed in disinformation. Following this, we will focus on testing that enables further insight into how Aide serves as a scaffolding tool. In the next phase of data collection, we will analyze how learners approach news prior to, during, and post their interaction with Aide, identifying evidence of learning associated with interaction with the platform. We understand that one particularly important aspect of Aide needs further consideration from the research team: its reliance on a commercial API to access an AI linguistic model. As most AI solutions, OpenAI's API has biases and its algorithms are not accessible to researchers and end-users.

Despite the limitations, we conjecture that this research can lead to insight into novel ways to employ technology in the learning process and teaching approach towards disinformation in the K-12 context, ultimately leading to the reduction of disinformation spread. In contrast to the harm brought about by AI, we expect to contribute to harnessing its potential to impact positive change in education and society.

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International Society of the Learning Sciences

Envisioning a Sociopolical Framework for Care Within Teacher Education

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Abstract: The purpose of this qualitative study was to envision a framework for how to authentically care for students, particularly within a COVID sociopolitical context. Our research question examined: What could a framework of sociopolitical care look like? This research utilized Noddings' (1998, 2012) care theory, critical theories, and indigenous pedagogy to envision care that centers the student within a broader relational community.

Major issues addressed

Noddings' (1988) care framework has provided meaningful guidance for educators seeking to care for their students. In it, she argues for a reframing of the aims of education around care, modeling, dialogue, practice, and confirmation. However, for reasons surfaced by the twin pandemics of the COVID-19 and systemic and institutionalized racism, the limits of Noddings' ethic of care has come into full relief. While Noddings is careful to create some space for student agency in how she conceptualizes care, the process of caring is initiated by the teacher and is focused on a unidirectional relationship whereby the teacher cares for the student.

In this paper, we explore the construct of care within Teacher Education, focusing on the role of care in the early months learning during the early months of the COVID-19 Pandemic. Previous work examined how the context of the COVID-19 pandemic impacted how we consider and define the elements of care (Smith, Sutton, & Tierney, 2022). Through our examination of literature and our data, we identified the need to adopt a framework for sociopolitical care that centers issues of equity, power, positionality, and the cultures, relationships, and communities often marginalized in normative frameworks of care. Doing so, we also identified the need to disrupt conventional views of who is acting and who is being acted upon in relationships of care. Our research question, "What could a framework of sociopolitical care look like?", is an initial attempt to explore these issues.

Potential significance

This study highlights the need for teachers to listen to the expressed needs of their students, particularly as those needs relate to the sociopolitical context of the time. Demonstrating care for students should not be a simple show of values, which could be detrimental in promoting imbalanced power dynamics (Noddings, 2012) or deficit models of students, perpetuating racist thinking (Matias & Zembylas, 2014). Rather, care entails co-construction of learning between the teacher and the student, revisioning Noddings' (1988) framework to be more inclusive and racially conscious.

Theoretical perspectives

Research studies that focus on critical care for students utilize a variety of terminology in their understanding of care and advocacy for students. Rector-Aranda (2018) calls for teacher education programs to integrate *critically compassionate intellectualism* (CCI), which combines critical pedagogy, authentic caring, and social justice curriculum. Roberts (2010) calls for *culturally relevant critical teacher care* (CRCTC), which integrates tenets of culturally sustaining pedagogy (Paris & Alim, 2017) and critical race theory. This framework entails a focus on students' voices, counternarratives, and student futures, in addition to a consideration of political and ideological thinking, especially related to race and power (Roberts, 2010). In addition, we consider the relationship between indigenous pedagogy and culturally sustaining pedagogy (McCarthy & Lee, 2014). Hanson et al. (2000) recognize that responsible teaching needs to be recognized as both cultural and political, specifically recognizing histories of colonial violence. These critical perspectives related to care can contribute to a revisioning of Noddings' (1988) framework to be more inclusive and racially conscious.

Methodological approaches & data sources

The research question was addressed in 10 virtual working meetings with the researchers. Researchers in this study recognized gaps in the data related to the sociopolitical context of care needed to authentically teach and learn in teacher education. Thus, we have developed the proposed theoretical revision to relational pedagogies to help guide our own practice and to encourage like-minded educators in their own practice. Our positionality within this work is as three white-identifying researchers. In this work, we do not presume to be embodying indigenous pedagogy. Instead, the framework presented is influenced by indigenous perspectives, as well as sociopolitical and sociocultural perspectives, theories of power, and our own lived experiences as teacher educators.

Major findings: Revisioned practice of care framework

Drawing from indigenous perspectives and pedagogies (Castagno & Brayboy, 2008; Holmes & Gonzalez, 2017; Sabzalian, 2019) to rethink care, we propose an extension of Noddings' care framework that centers students within a larger ecosystem of community. We argue that acts of care are more than the actions of an individual teacher to an individual student; authentic caring involves a collaborative process between students, students and teachers, students and the community, and teachers and the community. We propose that care results from co-constructed structures of support, built by students, community members, and educators so that care becomes a fundamentally de-settled and de-colonized process that reflects the values, norms, traditions, and epistemologies of students' communities.

Indigenous theories of co-constructed, de-settled, and decolonized practice, both with and by a community, emerge most powerfully in the work of Indigenous scholars, many of whom are cited above. Underlying Indigenous ways of approaching education are several interconnected and overlapping shifts that we believe should be used to rethink an ethic of care in classrooms and schools. The first includes a shift from an individualistic ethos, which tacitly asserts that care is an act of an individual teacher to an individual student, to an ethos that sees students as part of larger communities who may instill different norms, values, and epistemologies than those espoused by the White, middle class school system. The second includes a shift from thinking of schools and the process of educating children as separate from communities; instead, education is nested within communities and thus accountable to them. The third, and perhaps most important shift, argues that an ethic of care should only be defined as care if it has been co-constructed by teachers, students, and the community. When schools are repositioned as places that are part of a larger ecosystem of families, cultures, and communities, it also demands educators to think of care as a co-constructed, collaborative process embarked upon by the ecosystem of support the student and school is situated within. In particular, the teacher education classroom can draw from the same principles of co-constructed, de-settled, and decolonized community by co-constructing a caring teacher education classroom space with students and making space for them to bring in their myriad identities and lived experiences. In this revisioned *Practice of Care*, we flatten the hierarchy typically present between teacher candidates and teacher educators in part by de-centering the teacher educator and centering student experience, identities, local community strengths, and the sociopolitical context.

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Exploratory Case Study of Collaborative Practices in Flexible Learning Spaces

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Abstract: Flexible learning spaces are considered to support active learning pedagogies with flexible furniture, plenty of writeable surfaces, multiple projectors or display screens and other technology. This study uses a case study methodology to investigate collaborative practices in two flexible learning spaces in a higher education institution. Findings suggest that flexible learning spaces allow participants to share mediating artifacts and provide a horizon of observation that can support students' shared understanding and work.

Introduction

Higher education is being called upon to adopt contemporary technologies and pedagogies to address 21st century skills like innovation and collaboration. One response is the increased focus on designing and integrating flexible learning spaces with flexible furniture, writeable surfaces, and enhanced technology aids to support student centered learning. Flexible learning spaces have been studied for their impact on academic performance, instructor and student behavior, focusing mostly on utility functions and perceptions of space regarding teaching, learning and technology (Gordy et al, 2020). Much of the empirical research around learning spaces has focused on data related to feedback, students' perceptions, and satisfaction surveys. However, research that focuses on students' in-class collaborative actions and their interrelations to space and its elements is underreported in the literature. This study uses a case study methodology to focus on the collaborative practices within a flexible classroom. Our research questions engage specifically with physical artifacts in the classroom, which we narrowed via ongoing analyses to one element, a portable whiteboard, and its affordances for collaboration. Our main research questions are: (1) How do students interact with physical artifacts in the classroom to support collaboration? and, (2) What triggers students to engage with the physical artifacts in the classroom?

Theoretical framework

To frame this study we primarily draw upon Distributed Cognition, where cognitive processes are distributed across members, distributed across time and help to coordinate between humans and resources and systems in the environment (Hollan et al., 2000). The DiCoT (Distributed Cognition for Teamwork) framework (Blandford & Furniss, 2006) is used as the framework for describing the collaborative activity of the small groups in this study. Of the three themes in the DiCoT framework (physical layout, information layout, and design and use of artifacts), we focused on the physical layout and artifact themes and chose two principles from each of the two themes- Situation Awareness, Horizon of Observation, Mediating Artifacts and Scaffolding.

Context and methods

This research was conducted in two flexible learning spaces on a university campus within the northeastern United States. Data from one space was selected for presentation. The space has movable and adjustable chairs and tables, multiple projectors, and whiteboards–both portable and wall-mounted. The class analyzed was a 200 level undergraduate Physics course with 21 students where most class time was spent solving worksheets in groups.

We used an exploratory case study methodology and collected video and audio recordings and field notes. Initially whole classroom recordings were used and over time these recordings became more group focused. The video recordings and field notes were reviewed together to identify three episodes described in the findings. Verbal (speech, hums) and non-verbal (gestures, movement, use of artifacts) interactions in each of these episodes were transcribed using guidance of interaction analysis (Jordan & Henderson, 1995). Each turn of verbal or non-verbal participation is coded into active social (discussion), passive social (explaining, nonverbal participation), and physical (interaction with artifacts) (Vujovic et al, 2021).

Findings

Three episodes of collaborative activity using a physical element of the classroom as a shared artifact, i.e., a portable whiteboard, will be illustrated in the poster using figures and tables. One of the episodes is illustrated here as an example (Figure 1). At the start of this episode four students are seated around two square tables working together on the problems in their worksheet and request help from the TA. The TA asks one of the students to write out the solution on the portable whiteboard as they solve the problem again. As seen in the script, students gesture to the whiteboard and engage in active and passive social talk as they reason through the problem.

Figure 1
Left: Screenshot of classroom, Right: Interaction between students and TA in with codes

Actor	Verbal	Nonverbal	Code
G1.TA	And this one is the	Gestures to shared artifact	Active social
G1.S3	Yeah, fifteen minus zero and fifteen minus (unclear). Ahaa! I get it, I get it"		Active social
G1.S1	They're not even		Active social
G1.S3	No because they have to (unclear)	Gestures to shared artifact	Active social
G1.S2	Oh		Passive social
G1.TA	There you go		Passive social

Discussion

The episodes were chosen for illustrating the use of the whiteboard in performing the task and three key themes emerged: whiteboard as mediating artifact, horizon of observation, and triggers for whiteboard use. In all three episodes the whiteboard was brought into coordination to help solve worksheet problems. Based on episode data we found that the mediating artifact could support shared work such as in episodes 1 and 3 where the shared whiteboard artifact allowed students to engage both actively (by writing or gesturing toward the whiteboard) or more passively by looking at the whiteboard content as part of the activity. The whiteboard also helped make student cognitive work visible, by providing a reference point and a clear representation of the group thinking. A key affordance of the flexible space specially the whiteboard was that all students could see and hear each other's talk and gestures and view the progress of the problem solution on the whiteboard. We noted that in all selected episodes, whiteboard use was triggered by either the instructor or TA and was aimed specifically at encouraging students to make their thinking visible. The instructor and TA themselves used the whiteboard to explicate their thinking. In another episode with little student interaction, we noted that the professor answered student questions by turning draw and explain answers on the whiteboard. Such modeling reinforced the mediating nature of the artifact and its role in coordinating multiple perspectives over a horizon of observation.

Conclusion and limitations

We used this exploratory case study to examine how flexible learning spaces and the whiteboard as an artifact impacted students' engagement in collaborative activity. Our initial findings suggest that flexible classrooms and artifacts can support coordination of collaborative work by making by visible students' cognitive process and affording a joint horizon of observation. Such arrangements allow for active cognitive engagement by students which is supportive of learning and suggests that cognition is affected by how individuals adapt to their environment and the artifacts. Data and interpretations are limited by the focus on the whiteboard in this study; a deeper analysis of collaborative work would include a broader range of artifacts and actions. Multimodal approaches that examine different forms of media and artifacts would provide additional nuanced insights.

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Ubiratan D'ambrosio and Ethnomathematics: Contributions to the Learning Sciences

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Abstract: In this work, we bring an overview of research on the life and work of Ubiratan D'Ambrosio and Ethnomathematics as a research program and as a reference for valuing the culture of peoples and their ways of conceiving mathematical knowledge, overcoming the Eurocentric view predominant to decolonize knowledge. Starting from an exposition on the main aspects of Ethnomathematics, we propose a reflection for the field of Learning Sciences in the world with the purpose of giving visibility to the production of knowledge in different sociocultural contexts.

Introduction

In this work, we bring a brief report on the life of Ubiratan D'ambrosio (brazilian researcher and Ethnomathematics, a research area permeated by crucial issues such as Critical Mathematics Education and Social Justice, for that, we will use D'Ambrosio's works on the subject, and in this way , we seek to preserve our identity as Brazilian researchers, valuing our context, our culture and our way of conceiving knowledge mathematical. Although Mathematics has been built by different peoples throughout the history of mankind, with the process of formalizing its language, the Eurocentric view of operating with Mathematics prevailed, and the ways in which different peoples deal with mathematical knowledge, suffered a process of denial, rejection and acculturation, promoting a process of mischaracterization of the corpus of the various mathematics that circulated around the world. These different mathematics gradually disappeared, becoming invisible and treated as something out of use, a process that is a legacy of colonization and forms of oppression of the native peoples of the territories. The different forms of knowledge were erased and gained a “unique” version, somewhat depersonalized, but which serves the structures of power and domination policy, economic, social and mainly cultural. The different mathematics could coexist and integrate, which is what is expected when one thinks of human diversity on the planet, but what was seen was a movement to eliminate knowledge, impoverishing the collection of knowledge in the history of Humanity. And why is one mathematics useful and the others not, if the logical mechanisms of reasoning involved in the social practices in which Mathematics circulates follow a line with different forms? To propose a “unique” Mathematics, with rules, symbologies, theorems, notations, would be to crush the spontaneous and creative manifestations of human thought, to belittle Mathematics itself as a corpus constructed throughout history by different ethnicities. Thus, starting from these initial notes, we bring the trajectory of Ubiratan D'Ambrosio and Ethnomathematics in the sense of bringing reflections to the field of Learning Sciences worldwide in order to give visibility to the production of knowledge in different contexts sociocultural and decolonize knowlegdes.

Ubiratan d´ambrosio and ethnomathematics: A citizen of the world understanding the different mathematics of the world

Ubiratan D'Ambrosio was born on December 8, 1932 in the city of São Paulo, Brazil. He was of Italian descent and in 1951 went to study Mathematics at the University of São Paulo, one of the main Brazilian universities. He taught in basic education and after completing his graduation in Mathematics he became a professor in higher education. When he was a student he loved to read books in the library of the University of São Paulo and through them he got to know other cultures and other knowledge. In 1964, Ubiratan moved to the United States and became a research associate in the Department of Mathematics at Brown University, in Providence, Rhode Island. He then landed a tenured teaching position at the State University of New York at Buffalo. He served as a professor in undergraduate and graduate courses in mathematics. In 1970, he went to work on a project of the United Nations Educational, Scientific and Cultural Organization (UNESCO) that was being implemented in the Republic of Mali, in Africa, to train doctors in mathematics. There, he goes on to observe how African people deal with Mathematics in their social practices and how they conceive mathematical knowledge. Ubiratan observes a richness in the construction of Mathematics of these peoples and begins to reflect that there is no only one Mathematics, but there are several Mathematics and several ways of dealing with Mathematics that exist in the world and that still resist.

Thus, at this time, questions and criticisms began about the teaching of Mathematics, which had a perspective that disregarded different cultures, did not focus on the student's protagonism or on their prior knowledge and on different contexts, nor on the reality and experiences of students.The technicist teaching, based on training, repetition of procedures, which was an inheritance of the modern mathematics movement, began to be questioned. Ubiratan returns to Brazil in 1972 and goes to work at UNICAMP (State University of Campinas). From his readings, experiences and research, he conceives Ethnomathematics as a program, explaining that: “The Ethnomathematics Program is conceptually designed as a program of broad investigation of the evolution of ideas, practices and knowledge of the human species in different cultural environments. Essentially, it implies an analysis of how groups of human beings generated forms, styles, arts and techniques of doing and knowing, of learning and explaining, how they deal with situations and solve the problems of their daily lives, of their natural and sociocultural environment.” (Ubiratan, 2018, p. 191-192)

The word ethnomathematics was created by D'Ambrósio from the adaptation of three Greek radicals: ethno, mathema and tica. The radical “ethno” refers to culture, people; “mathema” is related to the act of understanding, way of doing; and the term “tica” means technique. D'Ambrosio explains that Ethnomathematics is transdisciplinary, transcultural and recognizes specific cognitive strategies of a culture to deal with reality and build knowledge in the context of that culture. Thus, Brazilian Indians and Quilombolas, among other groups, build their mathematical knowledge considering their social practices and cultural elements. An example is the construction of ocas (houses of Brazilian Indians). The construction of ocas by the Guarani Tambeopé Indians, fo example, is sustainable, made with elements taken from nature and the dimensions are not standardized, but determined by the number and height of the people who will live in the space, that is, the material to be built, the way of measure space, the construction technique does not follow conventional architectural techniques or traditional geometry. The geometry used by the Brazilian Indians to building ocas is linked to space, context, culture, indians and their characteristics and is not related to the formal geometric conception. The geometry of the Brazilian Indians is a set of knowledge that emerged from living with nature and the forest. In this way, the different mathematics that are born with these groups and constitute the corpus of Ethnomathematics have peculiar logics, symbologies and languages, which are different from the predominant Eurocentric mathematics in the school, that is, Ethnomathematics implies "a study of the cultural evolution of humanity in its broad sense, based on the cultural dynamics that can be seen in mathematical manifestations” (D'Ambrosio, 2005, p. 102). This way, ethnomathematics seeks to understand the production of knowledge as a collective construction, developed through dialogical relations between individuals and the socio-cultural context, giving new meaning to mathematics from the point of view of a social practice and as such it has peculiarities that do not may restrict themselves to standardizing ways of dealing with mathematical knowledge, which stifle the learning process because students see only one way of working with mathematics in the school. In 2021, Ubiratan D'Ambrosio passed away leaving a legacy for World Mathematics Education with his studies on transdisciplinarity, history of mathematics, ethnomathematics, mathematical modeling and teacher training. He won several international awards such as the Felix Klein Medal and formed several Brazilian researchers, having as a greater meaning of existence, respect for human beings and their diversity of thinking.

Future reflections on ethnomathematics for the field of learning sciences

Ethnomathematics gives voices to different peoples, gives citizens of the world the opportunity to express their ways of reasoning, of building knowledge, of giving protagonism to everyone so that they manifest their creativity in the way they conceive mathematics and its understanding. Ethnomathematics is the place of respect and sharing in which everyone is important with their uniqueness: “I think, I exist. I am a human being in the world. I understand Mathematics in a different way than you, but we can learn from each other. I'm Brazilian, I'm Latino, I speak Portuguese, I'm indigenous, I live in a tribe, I'm black, I live in a quilombo, my way of doing math with mathematics is different from yours, but it's also right. I build an Oca, a home for Brazilian indigenous peoples, using my geometry, it's different from yours, but my architecture is just as beautiful as yours. I'm a child from the periphery, I learned to count by selling candy in traffic. My way of counting is different from what the teacher teaches at school, but it’s also right.” Thus, with these words, it is hoped that the Learning Sciences will open space for the different peoples that are part of this great research community to express their knowledge and transform the classrooms of their countries, allowing children of different ethnicities to express how they conceive mathematical knowledge and other knowledge and create their own ways of doing mathematics, restoring the cultural dignity of peoples, breaking down the walls of oppression and domination, decolonizing knowledge and opening up space for dialogue.

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Theorizing and Modeling Teachers’ Knowledge of Noticing

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Abstract: Efforts to improve science education offer a vision of science teaching requiring teachers to notice the productive resources in students’ thinking and allow these resources to drive learning. However, we do not yet understand the complex teacher knowledge involved in the practice of teacher noticing. This research reports on in-progress theory-building work and presents a conceptual model of teachers’ *knowledge of noticing*—a special kind of teacher knowledge that matters for science teaching.

Overview

Efforts to improve science education emphasize that an important shift needs to take place in what teachers attend to in the science classroom—shifting attention away from content as a body of correct information and towards content as disciplinary ideas and reasoning (Coffey et al., 2011). Teachers “need to understand what initial ideas students bring to school and how they best may develop an understanding” (p. 256) of phenomena in the world (NRC, 2012). This requires teachers to continuously notice the substance in students’ thinking and allow this substance to drive students’ learning. However, while the field supports this shift in what teachers attend to, it does not yet understand the complex teacher knowledge involved in the practice of teacher noticing, and therefore it does not know the true extent of making this practice learnable (Grossman et al., 2009; Sherin et al., 2011). As such, this research decomposes the practice of noticing by unpacking the knowledge pieces elementary teachers draw on when noticing students’ thinking across the work of teaching science (in lesson planning, in teaching, and in assessing learning). Specifically, this research reports on in-progress theory-building work and offers up for scholarly discussion a conceptual model of teachers’ *knowledge of noticing*.

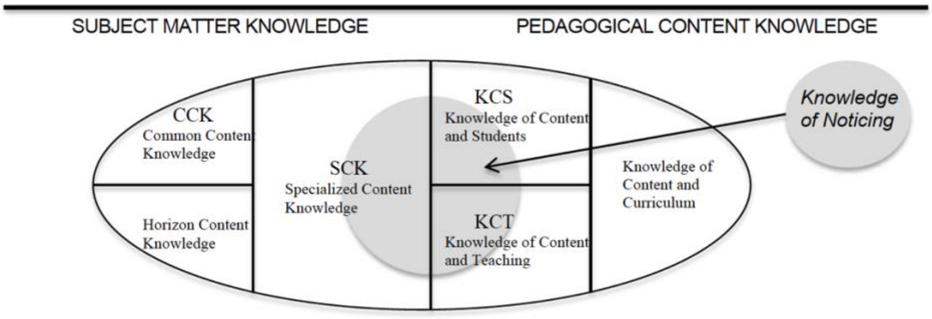
Motivation for theorizing teachers’ *knowledge of noticing*

There has been limited research examining what within students’ thinking teachers notice (i.e., the productive pieces within a students’ idea) and the teacher knowledge base noticing draws on. It seems this is an important missing piece in research on teacher noticing, one that requires us to unpack the knowledge involved in this practice. Discussing teacher noticing as a process absent its knowledge base limits its usefulness as a construct in understanding teacher practice. As such, we need a practice-based theory (Ball & Bass, 2003) of teachers’ *knowledge of noticing* for the purposes of making the practice of noticing the disciplinary substance in students’ thinking both learnable (Grossman et al., 2009; Sherin et al., 2011) and useful to teachers in ways that support authentic disciplinary learning for their students.

Building a conceptual model of teachers’ *knowledge of noticing*

Figure 1

Conceptual model showing where teachers’ knowledge of noticing lies on Ball, Thames, and Phelp’s (2008) map of teacher content knowledge



An investigation of elementary teachers’ noticing practice across the work of teaching science provides the empirical basis for developing a conceptual model of teachers’ *knowledge of noticing*. I have identified the teacher knowledge pieces evident in the empirical data and have mapped those pieces onto Ball and colleagues’ (2008) model of content knowledge for teaching (Figure 1). As a result of this mapping, a *knowledge of noticing* model has begun to emerge. For example, the shaded area on Figure 1 shows where the knowledge pieces identified from the empirical investigation mostly populated on the map of teacher content knowledge. From this initial representation, a picture of teachers' *knowledge of noticing* presents itself as an amalgamation of Ball and colleagues' specialized content knowledge (SCK), knowledge of content and students (KCS), and knowledge of content and teaching (KCT). (Table 1 lists and briefly describes these three categories of knowledge applied to the domain of science teaching.) Also emerging from this representation is the idea that teachers' knowledge in use while engaged in noticing is more than a grouping of these three types of knowledge. It seems to involve a special category of teacher knowledge active at the junctures of these domains—what I have named teachers' *knowledge of noticing*. This theory building work is on-going and further analysis of teacher noticing data will test whether this new category of teacher knowledge is indeed unique.

Table 1

Three domains of content knowledge for teaching (Ball et al., 2008) adapted to reflect science teacher knowledge

SCK: scientific knowledge and skill unique to teaching; disciplinary knowledge "not typically needed for purposes other than teaching" and "in its decompressed or unpacked form" (p. 400).
KCS: knowledge that combines knowing about students and knowing about science; knowledge that involves "specific [disciplinary] understanding" interacting with "familiarity with students and their disciplinary thinking" (p. 401).
KCT: knowledge that combines knowing about teaching and knowing about science; knowledge that involves "specific [disciplinary] understanding" interacting with "an understanding of pedagogical issues that affect student learning" (p. 401).

Potential contribution

Two reasons further motivate the model building work of this research, one theoretical and the other practical. First theoretically, as Schulman (1986), Schoenfeld (2008) and other scholars have argued, a model of teaching has explanatory power for understanding what drives teaching practice. Second, a model of teachers' knowledge can be leveraged in teachers' learning. This model building work is in service to both contributing to our theoretical understanding of teachers' knowledge in use surrounding their noticing practice and to informing teacher learning and knowledge construction around this practice. The research presented will report on the progress of this theory-building work and offer up for scholarly discussion a conceptual model of elementary teachers' *knowledge of noticing* the disciplinary substance in students' thinking.

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How do Good Practices Emerge in Vocational High Schools? Lessons From Eleven Cases

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Abstract: Good educational practices are those that are valued by communities. With the intention of understanding them and knowing the elements they have in common, 11 cases were analyzed from the theoretical perspective of the Activity Theory, finding 10 common characteristics. The aim is to provide knowledge for educational improvement in secondary vocational education, while sharing the results to inspire the emergence of such practices in other institutions.

Introduction

Chilean secondary education is divided into two cycles. The first cycle is common to all students and the second cycle is differentiated. In the second cycle, students can choose between two educational paths: scientific-humanistic or vocational (Agencia de Calidad de la Educación, 2016). The vocational path is popular among students from the most vulnerable socio-economic sectors of society (Larrañaga, Cabezas & Dussaillant, 2013), as it aims to provide comprehensive training in a specialization that facilitates the transition from school to work and integration into the labor market (Servat, 2017; Sevilla, 2010). This type of education is crucial for improving productivity and the economic and social development of the country (Ministerio de Educación & UNESCO, 2018), as well as facilitating the social mobility of the students who follow it (Servat, 2017). However, one of the main challenges is the adequacy of the training, which requires the adaptation of the training to the needs of each institution (MINEDUC, 2018).

In order to understand how school leaders address these challenges, good educational practices developed in their organizations have been examined from an AT theoretical perspective. From AT, it is understood that activity is composed of a set of essential elements: subjects, objects, mediators, rules, community and work organization, elements that constitute what is called an activity system (Engeström, 2015). A set of actions then constitutes an activity, while an activity sustained over time constitutes a practice. A practice is not an isolated and individual phenomenon, but a systemic activity that takes place in collective and relational contexts that have been developed over time (Engeström, 2015). A practice is created by a community, with a set of rules and an organization, where there are subjects who have a shared sense of purpose (an object) that they approach collectively with the help of mediators. Each practice is understood as a set of relations between subjects and their purposes in their specific social situation (Hojman et al., 2022).

Based on the above, we can understand a good practice as an initiative that develops something that the educational community considers valuable, while good leadership practices seek to improve the management and/or organization of schools, have an impact on student learning and the overall results of the institution, and have continuity over time (Hojman et al., 2022). It is then possible to understand good practice as complex, historically and culturally situated, and to understand how it is created, sustained, and transformed over time.

Methodology

The study conducted is qualitative, exploratory and located in a dialectical epistemology to capture the richness, depth and quality of what is produced (Creswell and Creswell, 2018). To this end, paradigmatic cases were selected through purposive sampling, which is a common selection for studies that seek to analyze values, rituals or meanings (Creswell and Creswell, 2018).

The first step was an open call, in which institutions belonging to the network of the Center for Innovation for Educational Leadership (CILED) of the Universidad del Desarrollo were formally invited to participate in a project that would allow them to share their practices with other institutions through the publication of a book. Schools interested in participating filled out a Google Forms form in which a member of the institution described the good leadership practice they wished to share. Once the call for entries was closed, a blind evaluation process was conducted in which a committee reviewed each case and prepared a report that was then reviewed by the project director, who formalized the selection of eleven practices. Some of the inclusion criteria were: to be vocational high schools, to have a consolidated practice for more than one year, and to have some method to evaluate the practice.

For the data collection, the researchers were supported by a guide with the main thematic categories to be explored, as well as guiding questions for each category. This guide was organized to understand each of the relevant elements of the activity according to AT, so that, for example, the category of subjects sought to understand how the subjects who were part of this practice were organized. At the end of the information gathering process, an integrative analysis of all the cases was carried out, which allowed to have a guiding vision of the relevant elements for the continuous improvement of leadership in TVET.

The members of the institution were selected based on whether they were employees of the selected institution, whether they were over 18 years of age, and whether they had a relationship with the practice. Informed consent was obtained from both the institution and the participants at the beginning of the fieldwork process.

The main objective was to understand the good practices of leadership in secondary vocational education, together with their emergence and history. The specific objectives were to understand the relationships in each practice based on activity theory; to describe the protagonists (subjects) of the good leadership practices by understanding their relationships in practice; to understand the meaning (object) that the actors of the good leadership practices attribute to their practices; to describe the mediators involved in the good leadership practices; and to describe the trajectories (including the conformation of the communities, their rules and their social organization) of the good leadership practices.

Findings and analysis

The practices were studied in depth using the case study methodology, which aims to achieve a complex and deep understanding by studying the experiences of individuals, groups or contexts, also taking into account less concrete elements such as relationships or projects (Creswell and Creswell, 2018). This analysis was made from the AT, exploring how the theory allowed the understanding of each element of the practice and, based on this, what were the common elements that emerged between them.

Considering the above, after the analysis process, it was possible to find the following common elements between practices: (1) students are at the center of the practice, since they not only participate, but also have a leading role in its development; (2) Community collaboration and participation are key aspects. They allow for the development of the activity and its stability over time; (3) because the practice arises in response to a shared need among members of the community, there are clear and shared meanings for all participants; (4) There are different types of leadership involved, depending on the institution, the level of development of the practice, and the skills of the institution's team; (5) networks are created with the community, providing greater opportunities for support, resources, and external observers; (6) It is a practice that develops gradually over time, and as it is established, it generates cultural changes; (7) It allows for the translation of theoretical learning into practice through the development of learning activities that contribute to students' learning and development of competencies; (8) it emerges from the school community itself, based on the needs identified by them; (9) although there are resources that are fundamental to the development, they are seen as tools that support the shared value of the practice; (10) All practices systematically improve from year to year by having a system that records and evaluates experience and learning.

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Problem-Solving or Solved Problems: Constricting Design Challenges in High-School Engineering Education to Avoid (Disruptive) Failures

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Abstract: We investigate how high-school engineering teachers anticipate and deal with disruptive and productive failures in students' design challenges. This study involved a six-week participatory design process with two teachers, revealing that teachers often make design challenges too prescriptive in order to prevent disruptive failures, which can hinder opportunities for productive failures. We discuss the implications of failure mitigation and suggest opportunities to better support teachers, including the design of an intelligent system.

Introduction

High school engineering courses provide students with hands-on, open-ended design challenges that require the application of various learning objectives such as practicing the Engineering Design Process (EDP) and iterating on their prototypes, which can lead to both productive and disruptive failures. *Productive failures* (Kapur 2008) force students to revisit their documentation and engineering knowledge to engage more deeply with the problem, and though they may cause deviations from the original curriculum plan, they are beneficial to the overall learning. On the other hand, some deviations from the teacher's plan may not have pedagogical value, such as students ignoring the tasks at hand. We refer to those deviations as *disruptive failures*. These dimensions lead to a significant cognitive and pedagogical load for teachers in planning and executing design challenges. This paper aims to investigate the following questions: (1) What disruptive and productive failures are high-school engineering teachers anticipating that students will face in solving design challenges? (2) How are they actively trying to prevent and help students recover from disruptive failures, specifically?

As part of a larger endeavor geared towards designing intelligent educational supports for high-school engineering teachers, we conducted a six-week participatory design (PD) process with two teachers with diverse backgrounds and teaching experiences. For this paper, we focus on two research activities from the PD process focused on student failures, and teachers' prevention and recovery strategies. Our findings suggest that teachers dedicate significant efforts to preventing disruptive failures by constricting design challenges that limit or eliminate the opportunity for students to learn from productive failures, and highlight the need for technological tools for teachers to effectively plan for and prevent disruptive failures while supporting productive ones.

Design challenges and productive failures

Engineering education faces challenges in designing authentic and open-ended design challenges that provide hands-on opportunities for students to apply engineering practices and grapple with real-life situations. Moore et al. (2022) found that, in practice, design challenges are often formulated in ways that restrict the possible solution space, reduce creativity and inventiveness, and undermine students' engineering identity. Promoting ill-structured problem-solving is crucial to prepare students for engineering professions and their challenges (Trueman, 2014). More importantly, Kapur's (2008) productive failure theory contends that problem-solving activities should be designed for students to reach an impasse and generate opportunities for students to explore the affordances and constraints of the problem before consolidating their learning through comparisons and organization of student-generated solutions into canonical solutions (here, analogous to the *evaluation* and *presentation* phases of the EDP). Kapur explains that this structure leads to better performance on both ill- and well-structured problems and increased creativity and transfer of learning. While previous studies focus on implementing productive failure in problem-solving and corroborating its benefits, we use productive failure theory as a pedagogical lens to understand current design challenge formulations focusing on whether those formulations offer opportunities for students to productively fail.

Methods

This study took place in summer 2022 as part of a teacher professional development internship program hosted at a major university in the Southeastern U.S. We selected two teacher interns with different backgrounds and experiences, Macie and Stanley (pseudonyms), to co-design a task model of their students' activities and challenges to serve as the basis for prototype development of an artificial intelligence-enabled system. Over the six weeks of the program, the teachers participated in eleven participatory design *research blocks*, sessions ranging from two to four consecutive hours dedicated to research activities designed to elicit teachers' tacit knowledge (Moreno et al., 2021) of engineering education and the practical constraints they face. Audio recordings and photos were taken, and all artifacts, including written reflections, curricula designs, presentation slides, flow charts, and task models were collected. For the purposes of this analysis, we focus on two activities, spanning three research blocks: (1) one synchronous research block consisting of a discussion of design challenges, focused on eliciting teachers' practices and priorities when creating and/or choosing design challenges, including the breakdown of the components and properties they consider, and (2) two asynchronous research blocks consisting of a Miro board-based flow chart design activity, asking teachers to document the anticipated obstacles and recovery strategies when students start building the physical prototype – a challenging step according to previous discussions with the teachers. We used Braun and Clarke's (2006) theoretical thematic analysis to qualitatively code the design challenge discussion transcript and the flow charts for mentions of student failures (disruptive or productive) and the strategies teachers use to prevent or repair them.

Findings and discussion

In the design challenge discussion, the total number of failure references is not important since the discussion was free-flowing. However, from the Miro flow chart activity, we extracted a total of 31 digital sticky notes referencing failures. All failures were inductively categorized into three classes: (1) failures related to classroom practices (i.e., students' behavior problems in the classroom such as not following classroom rules or being off-task), (2) failures in engaging with the EDP (i.e., students trying to circumvent completing the steps and/or substeps of the process, such as documentation, reflection, sketching, and planning), and (3) failures tied to design challenges (e.g. failures around the design requirements, materials, tools, and prototype construction such as inadequate materials, improper use of tools, etc.). Within these groupings, failures related to the EDP were documented most frequently (n = 14), with lack of student planning as the most common failure (n = 9).

Across all categories, we found that most failures were disruptive in some way, such as students challenging classroom authority, actively trying to circumvent using the EDP or playing around with materials without learning from the activity. Only three failures were identified by the research team as potential productive failures. Two were categorized as EDP failures: (1) teams not having a plan to handle failed prototypes, and (2) students' building process not going as planned. One was a design challenge failure: student's prototype not working according to the design challenge requirements.

Both teachers described common strategies for mitigating, preventing, or safeguarding against the above failures. We arranged Macie and Stanley's strategies into four categories: (1) adding rules and restrictions to the design challenge (e.g., requiring the use of all EDP steps, limiting materials usage) (2) reflecting and making changes along the process, (3) using extrinsic and intrinsic motivational approaches (e.g., including students' interests in the design brief, giving prizes for documentation), and (4) using outside resources for help (e.g., other teachers' materials posted online, outside curricula such as Project Lead the Way).

Our research surfaced that, in anticipation of failures which are mostly disruptive, teachers constrain the design challenges to become even more prescriptive. These restrictions could preclude productive failures (Kapur, 2008) from happening, which, our research found, are rarely occurring as is. Such a narrow and evident set of solutions could even eliminate the need for and utility of the EDP, ultimately resulting in a lack of understanding of its actual value, and of opportunities for students to apply their inventiveness and cultivate their engineering identities. In their development and implementation of design challenges, teachers need to balance open-endedness, open exploration, and opportunities for productive failures while ensuring that their students achieve the various learning outcomes that will lead to success in the engineering pathway. We need to find ways to support teachers in preventing disruptive failures in order to redirect scaffolding and restrictions towards the appropriate aspects (e.g., supporting students in applying analytical skills and the EDP steps).

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Situated Networks of Learning and Development: Shared Attention in Student Co-Design of Learning Environments

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Abstract: This paper reports on student co-design of Situated Networks of Learning and Development. Situated Networks of Learning and Development are systems of nodes that represent the subject matter and experiences required to meaningfully engage in a situated learning environment and a particular content domain. This study examines data from student co-design of Situated Networks of three university courses connected to a single-subject credential program in a teacher education program in the United States. Results indicate that the co-designed Situated Networks increased the intentionality of the design, captured activities and markers of success, and served as an organizational mechanic, allowing for highly tailored and customized learning experience for the community that creates it.

Major issues addressed

Student co-design is the process in which students participate as an integral part of the design of learning programs and curriculum in order to integrate student perspectives and experiences. The process of co-design creates an opportunity to accurately reflect and be responsive to the needs, identities, and histories of learners and the uniqueness of the community being designed in and for and, at the same time, co-design has the possibility to challenge implicit hierarchical structures and inequities embedded in curriculum design and products, redistributing power, and supporting the agency of learners (Bang & Vossoughi, 2016; Iversen, Smith, & Dindler, 2017; Tierney, Horstman, & Tzou, 2021). This paper reports on student co-design of digital technology using Situated Networks of Learning and Development. In our work we define Situated Networks of Learning and Development as systems of nodes that represent the subject matter and experiences required to meaningfully engage in a situated learning environment and a particular content domain (Horstman, Tierney, & Tzou, 2020). One promise of representations of situated networks is how they mark the combined social, emotional, and academic achievements that learners accomplish (Horstman, Tierney, & Tzou, 2020) and create visible trajectories for learners to follow (Pinkard, Barron, & Martin, 2008). Taken together, individual learning objectives can create a pathway that, when followed, indicate what participants have learned, but also indicating membership of a learning community, having achieved valued practices and rites of passage.

Potential significance

In our study, the specialized use of digital tools for designing a technology captured the thinking of the design group, creating narratives of thinking over time. The Situated Networks used in our research on co-design captured co-design activity, forcing specific moments of design space to be recognized. As representations of learning and development, the design team reflected on their next steps, specifically on how to emphasize elements that support equity within the learning environment. As such, the co-designed Situated Network: 1) Acted as conceptual maps of learning and development for shared reflection and redirection - increasing the intentionality of the design by the community that has created it; 2) Captured activities and markers of successful completion but within the larger context of a learning trajectory; and 3) Served as an organizational mechanic, allowing for highly tailored and customized learning experience for the community that creates it. This study broadens and reframes understandings of student co-design, specifically attuning to tools aimed to processes of shared attention amongst designers. Emerging findings indicate how shared attention guide the value of the co-design as a metacognitive process for learners, an assessment tool of learning for instructors, and an evaluation tool for programs.

Theoretical perspectives

Our approach focused on the co-design of a digital technology as a construct for organizing and sequencing a learning program. We leverage technology as a mechanism to involve students in the design process as collaborators, creating representations of the thinking of the design group over time. In this way, technological tools, and the design practices for creating them, have the potential to make visible and prioritizes the needs of the community (Horstman, Tierney, & Tzou, 2020). Co-design of situated networks creates a unique opportunity that reflects values associated with sociocultural models of program design - being responsive to the uniqueness of the community the technology serves, and redistributing power and promoting equitable participation, enabling the agency of learners (Collins & Bilge, 2016; National Research Council, 2000).

Methodological approaches & data sources

This study examines data from student co-design of Situated Networks of three university courses connected to a single-subject credential program in a teacher education program in the United States. Data includes video recordings of virtual design sessions for the co-design revision of three university education courses (19 sessions total). The three design teams (21 students total, plus 2 facilitators) created Situated Networks of Learning and Development, then iterated on that design to center equity within course frameworks. In addition, student co-design participants were interviewed following their participation in the design process. First, we examined Situated Networks as a design tool for mapping developmental trajectories and, second, the co-design of the Situated Networks with students in the credential program in order to identify learning and engagement in and across courses. The videos were analyzed and coded for using a previously developed coding scheme (Tierney, Horstman, & Tzou, 2021) that focused on negotiation of design content, as well as identified learning and development. We then analyzed interviews for perspectives on the design process and individual learning that occurred through co-design. Memos and associated vignettes of data were generated around emerging themes.

Major findings

Co-design teams were asked to design Situated Networks of Learning and Development of courses they had previously taken. The Situated Networks that were designed were made up of individual Learning Objectives: Authentic requirements of a situated learning environment. Specific goals, expertise, and subject matter is defined within the community. The Learning Objectives were then purposefully clustered into Nodes that embody groups of learning objectives with defined relationships in and among those learning objectives and can embody granular to broad sets of experiences and criteria to be met.

By involving students to be an integral part of designing the digital badge systems, they introduced concepts more directly linked to their experiences and development in and across the university courses. One key element of this process was how student participants drew links between existing course content and issues of race, equity, and inclusivity. This suggests the value of combining co-design and digital badges as a design tool to integrate development and engagement more deeply into learning environments. The sequence of topics identified by the group represented not only the agreed-upon priorities of the community, but also shows how the group views and interprets the relationship between topics. For participants, the artifact of the Situated Network created a vantage point from which both the learners and educators can reflect on how they've represented the hierarchy and relationships of the content itself. The Situated Networks demonstrate how the participants interpreted and prioritized learning content and activities. In this way, the Situated Networks provided a tool for design participants to reflect, individually and as a group, on what they learned. Further, the Situated Networks helped reify the design process across time.

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A Case Study: Design Cycle for a Meaningful Maker-Based Learning Approach

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Abstract: Carrying out activities involving maker-based education has been implemented in educational institutions that aim to propose a student-centered teaching and learning process. This work presents an approach for teaching Design concepts to K-12 students, during the development of ergonomic design projects. The methodology used is the Design Cycle of the International Baccalaureate Middle Years Programme, which underlines the importance of identifying an opportunity to solve a real world problem through the use of design thinking.

Introduction

Different studies show the importance of the teaching and learning process being active and meaningful. A research carried out by Michael (2006) presents evidence from learning sciences, cognitive science and educational psychology supporting student-led learning. In his work, the author points out some elements that underline the value of active construction of meaning for the student, the difference between learning facts (*"what" - as declarative knowledge*) and learning to do something *("how" - as procedural knowledge*), as well as the voice of an educational process that is facilitated by the articulation of coordination, whether for oneself, colleagues and teachers.

Hands-on activities, mediated by New Information and Communication Technologies (NICTs) have the potential to help students achieve goals for active learning, which can be stimulated by their involvement in interdisciplinary projects (Halverson; Sheridan, 2014). This approach allows students to lead their academic training and develop important skills for professionals in this millennium, as it enables the connection between areas of knowledge to solve real problems, based on the development of artifacts that positively impact the world around him/her.

To collaborate with this discussion, this article presents the work developed in the Design subject of the Middle Years Program (MYP), in American School of Rio de Janeiro, a Brazilian international school. The institution has an International Baccalaureate (IB) curriculum, a child-centered educational approach that teaches life skills. Within the eight subject groups currently offered in the MYP - *Language acquisition, Language & literature, Individuals & societies, Sciences, Mathematics, Arts, Physical & health education and Design* - there is not only an emphasis on the acquisition of knowledge by the student, but also on "understanding concepts, mastering skills and developing attitudes that can lead to thoughtful and appropriate action" (Daly et al. 2012).

Theoretical foundation

The inclusion of the Design subject in basic education has been increasingly explored in educational institutions worldwide. When a design-based learning approach is used in the classroom, students develop skills related to problem solving, decision making and collaborative work (Hsu, Purzer & Cardella, 2011).

In the MYP, for example, Design is a subject that provides students with the opportunity to learn about a multidisciplinary learning strategy, enabling the integration of different areas of knowledge. It provides an educational path in which the student is a co-author of their educational process, and not just a receiver of information. The importance of teaching and learning by disruptive methodologies has been discussed over the last few years by educators, school managers and authors of educational public policies, concerned with the connection between school education and the real world.

This approach is also highlighted by the learning theory of Seymour Papert, Constructionism. Based on Piaget's Constructivism as a reference, Papert (1996) states that the teacher's role is to provide conditions for invention, instead of providing already consolidated knowledge. The emphasis on stimulating creativity and the search for innovative solutions is a counterpoint to exercises with standardized answers, which lead students to reproduce something they memorized during an expository class.

Thus, in the MYP Design subject, the development of projects is guided by the Design Cycle.

The Cycle is a variation of the *design thinking process* and consists of four criterion (with four strands each): Criterion A - Inquiring and Analyzing, Criterion B - Developing Ideas, Criterion C - Creating the Solution, and Criterion D - Testing and Evaluation. The four criterions don't necessarily need to be completed in order, and in fact it's recommended to backtrack and skip when necessary.

Methods

This work is supported by an experience with twenty (20) 7th-grade students, who developed design projects with a focus on Ergonomics. They were presented with the task of identifying the needs of a client in their household and developing an ergonomic, sustainable design invention for them.

For the **provocation step**, students began the unit with a provocation. In this challenge, they were divided into groups of 3-4 and presented with five (5) story cards with client prompts; an elderly man, a baby, an astronaut, an athlete, and a high school student. Groups were tasked with designing a chair for each of the clients based upon the physical needs presented in the prompt.

During **inquiring and analysis step (Criterion A)**, the MYP takes an inquiry-based approach to learning. Students began this project with a presented statement of inquiry: “Through scientific and technical innovation, humans can adapt their everyday environment by developing solutions utilizing ergonomics and invention”. The statement of inquiry serves as the central idea of the unit from which students develop conceptual, factual, and debatable lines of inquiry to help guide their learning. Students concluded their Inquiry and Analysis with the development of a design brief.

The **developing ideas step (Criterion B)**, once students generated their *“How might we…?”* questions, they were then tasked with establishing design specifications using the relevant research provided in their design brief. Students applied this information to “Building a Box” which aids students in visually understanding the constraints and limitations of their solution, as well as taking into consideration elements of the design.

Once the “box” was established, students began their brainstorming process. Lessons on visual brainstorming and ideation were presented in class addressing sketching for industrial design and the SCAMPER (1) technique for idea generation. In industrial design sketching, creative thinking and the visual communication of ideas encourage students to create multiple iterations of a design, as well as communicate the various functions that the designs may have.

Then, during **creating the solution step (Criterion C)**, they began prototyping their solution. Students learned the difference between low-fidelity and high-fidelity prototypes, their intent, and the materials used to create both. As this project only required a low-fidelity prototype, students continued to develop their skills with hand tools and Dremels to create their solutions. Although low-fidelity, each prototype was required to function as intended and must have met the success criteria established in the design specifications.

Finally for **testing, evaluating and feedback step (Criterion D)**, completion of the prototype, as well as general creation, presented opportunities for testing, feedback, and improvement of the design. Students assessed the success of their designs using the success criteria established in their design specifications.

Conclusions

The aim of the IB programme is to develop globally-minded people who recognize their common humanity and shared responsibility for the planet. But this is a worldwide necessity. In the same way, education has the role of developing individuals who are questioners, researchers, who communicate and have principles, with an open mind, risk-takers, but are balanced and careful with others.

When a student develops a project for another person, be it their family, school or neighborhood environment, they begin to develop an outward look, which will impact the world in which they live.

The next step of this study is to expand the use of the Design Cycle through the implementation of interdisciplinary design units and projects that are directly connected with other subjects such as social studies, sciences, or mathematics, for example, to promote interdisciplinary teaching and learning scholarly activities. The results of this new research will be published in the future.

Endnotes

(1) SCAMPER technique: SCAMPER is the acronym for: (S) Substitute, (C) Combine, (A) Adapt, (M) Modify, (P) Put to another use, (E) Eliminate and (R) Reverse

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Co-Designing Without Content Knowledge: How Teachers Navigate Co-Design of an Artificial Intelligence Curriculum

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Abstract: Currently, co-design is gaining traction as a transformative process to develop AI curriculum for k12 classrooms that simultaneously addresses teachers' lack of AI content knowledge by doubling as professional development. This study details how teachers navigate co-designing a robust AI curriculum when they do not possess the AI content knowledge. Our findings suggest features of co-design may disengage teachers from content knowledge to focus on pedagogy and their own learning goals for students. This work seeks to better understand middle school teachers' assets and knowledge gaps in the context of co-design to help inform the evolving efforts to integrate AI content across the k12 curriculum.

Introduction and background

Co-design, as a form of participatory design, is increasingly valued and adopted by the learning sciences' community as a powerful tool to create educational innovations in real contexts while increasing teachers' agency (Roschelle et al., 2006; Severance et al., 2016) and the likelihood of teachers implementing innovations in their contexts. This poster examines how teachers' content, pedagogical, and technological knowledge (TPACK; Koehler & Mishra, 2009) informs their engagement in co-designing an AI curriculum for middle school students–in other words, a curriculum in which teachers have little to no content knowledge. Due to space constraints, we narrow our focus to teacher orientation toward AI content knowledge.

The importance of this work emerges in relation to an educational landscape under pressure to integrate AI content across the k12 curriculum. As AI's impact on the micro and macro scales become impossible to ignore, education researchers are sounding the alarm: students need to be taught the skills and knowledge necessary to understand the technical and social dimensions of AI to navigate our AI-powered world (Zhang & Aslan, 2021). Currently, co-design is gaining traction as a transformative process to develop AI curriculum for k12 classrooms that simultaneously addresses teachers' lack of AI content knowledge by doubling as professional development (Voogt et al., 2016). This study aims to fill the substantial gap in understanding how teachers navigate co-designing a robust AI curriculum when they do not possess the AI content knowledge.

Methods

We present findings from the first design-implementation-iteration cycle of a larger design-based research study developing responsible AI curricula for Middle Schoolers. In particular, this paper examines the co-design process between researchers and middle school CS and technology teachers who will implement the co-designed curriculum in their classrooms. We investigate the overarching research question: How do teachers navigate co-design of an AI curriculum? Given the unique nature of AI as a nascent subject matter that our partner teachers, like the general public, lacked expertise in, our question may be broadened: How do teachers navigate co-design of nascent subject areas where they are not content experts?

Co-design: Participants and process

We recruited two middle school teachers, Lily and Willow, each responsible for teaching Middle School technology courses involving coding and app development. We organized a total of 6 co-design sessions on Zoom over 3 months–the end of January through the end of April. Sessions lasted two hours on weekdays after school. The core focus of the co-design sessions was to develop a four-week-long socio-technical AI literacy unit organized around the machine learning pipeline and its sources of bias (Suresh & Guttag, 2021), with a concerted focus on image classification and computer vision technology. Each session contained 3 activities, each typically focusing on one of two tasks: activity building–developing individual lesson plans–or curriculum building–tending to the sequence, structure, and flow of activities across time. Co-design activities were structured to: 1) begin with an introduction of the activity's purpose and review of relevant AI concepts and/or pedagogical reasoning, 2) walk through the research team's preliminary iteration of the activity or curriculum flow, and 3) elicit teachers' ideas and questions through whole group discussions.

Data sources and analytic approach

To investigate how teachers navigated co-designing an AI curriculum, we center our attention on data generated specifically during co-design activities. All six co-design sessions over Zoom were recorded and later transcribed. In order to answer our research question, we used the TPACK framework (Koehler & Mishra, 2009) to guide analysis of how Lily and Willow navigated activities laden with AI content. Results demonstrate how teachers negotiated and expressed their content, pedagogical, and technological knowledge while co-designing in an unfamiliar content domain. We view our findings in light of co-design being a process that empowers and supports teachers' agency (Roschelle et al., 2006; Severance et al., 2016). That is to say, the special kind of agency afforded teachers through codesign may help explain how: a) these teachers oriented themselves to the curriculum and the goals they had in mind for themselves and their students that informed their choices navigating co-design.

Key finding & conclusion

Our participating teachers were not AI experts; even Willow, who recently graduated with a computer science degree, claimed no special expertise in AI. During our first session, we asked our participants what they thought their students knew about AI. After Lily explained why she thought her students didn't know much at all, she proceeded to focus on the knowledge gap for teachers: "[Teachers are] familiar with apps in the sense of they know that an app is different than a web page. They understand algorithms. They understand that you're telling a machine, the computer, what to do. But I don't think they've done the next steps. They haven't put those together to AI. They've heard of AI. They just don't understand what it is."

After reviewing AI content and walking through activities or curriculum flow, our participants consistently never had questions about the AI concepts. As co-designers without expertise in AI, teachers' reluctance to discuss the content may signal an understanding of their role like a consultant, contributing where they have the most expertise: matters of pedagogy and classroom culture. As co-design is intended to support teacher agency, it's reasonable to expect teachers to opt to position themselves in a role that empowers them to navigate the co-design process comfortably and confidently.

Willow's navigational choices appeared to parallel Lily. After being presented with a plethora of AI concepts during the first co-design activity in Session 2 , Willow's remarks revolved around the "visual aspect" of using the ML pipeline and the structure and flow of the curriculum, navigating around questions or comments about the content itself. Lily reiterated Willow's key points: "I think I'm kind of mirroring the same thing that Willow had said. The model really worked for me. I could see it flow maybe in my visual head here. But I think the students really need visual, along with everything else." Throughout the sessions, Willow and Lily appear to be in alignment in terms of their role: scrutinizing and highlighting pedagogical elements which are untethered from the AI content.

As efforts to bring AI content into schools evolve and multiply, better understanding middle school CS and technology teachers' assets and knowledge gaps and their relationship to co-design seems crucial to successfully integrate AI content into the k12 curriculum. We hope this work sparks vigorous discussion of the essential role teachers play as schools, institutions, and nations rush to support students' AI literacy in the classroom.

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Proposing the Multimodal Learning Analytics Platform for Social Emotional Learning

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Abstract: We present an ongoing effort to create an integrated data to knowledge platform that focuses on multimodal learning analytics for social emotional learning research. A key feature of the platform is the ability to extract and analyze multimodal data from video streams with various computer vision algorithms, curated to be applicable to a range of learning scenarios including individual or dyadic work, and co-located learning in an open learning environment.

Introduction

Social-emotional learning (SEL) continues to receive high political and scholarly interest, bolstered by a rising recognition that there are reverberating personal and social implications to helping students develop social emotional competence, or "the capacity to integrate cognition, affect, and behaviors, to achieve specified social tasks and positive developmental outcomes" (Elias, Kress, & Neft, 2003, p. 1023). Emerging approaches of using fine-grained multimodal sensor data (e.g., joint location, facial expressions) for measuring social emotional aspects bring real-time SEL support for teachers and learners into the realm of possibility. However, in past computational SEL research, the methods for data processing and feature engineering have tended to vary, even for similar data and features (Di Mitri et al., 2018). There is a need in the field to build towards a shared set of methods in the data to knowledge pipeline - the set of choices to make to collect data, create metrics, measure constructs, and connect metrics with constructs.

The platform introduced in the current paper attempts to meet this need. The goal of the Multimodal Learning Analytics Platform for Social Emotional Learning (MMLA-SEL) is to provide accessible ways for researchers to create multimodal proxies of social-emotional learning from videos, a common data source in education research. In addition to making multimodal analytics more financially and technically accessible, focusing on videos as a common data source makes it significantly easier to create comparable metrics across settings. In the present paper, we argue for the necessity of this toolkit and discuss current and upcoming features.

Tools and cumulative science

Despite heightened interest, several issues slow down the take-up of multimodal SEL research. Research-grade sensors can be expensive, and collecting and cleaning multimodal data require high technical expertise. As multimodal data is collected with different sensors, the processing steps needed to separate signal from noise also tend to vary, with different groups "reinventing the wheel" in different ways. When post-processed data looks different, metrics created using this data naturally become non-comparable. For instance, a recent meta-review by Horvers and colleagues (2021) finds that one metric, "mean electrodermal activity," had in fact been calculated on data at different stages of the processing pipeline (e.g., raw, denoised, decomposed). Finally, the field of SEL itself also suffers from what some call "conceptual clutter" (Jones et al., 2016), where constructs overlap, are measured in different ways, and terms fall in and out of favor. Partly due to this, the field has measured complex constructs with varying or researcher-designed tools.

Why is this an issue? First, the high financial and technical burden of existing approaches inhibit the participation of content experts and practitioners that could contribute to theory and practice relevance. Second, having to continuously re-invent the wheel for data processing results in a net loss of resources that may have been devoted to next-step analyses and research. Third, knowledge cumulation in the computational social sciences tends to rely on replication studies or quantitative meta-reviews that report the effectiveness of certain feature sets or methodologies in explaining a construct. When both metrics and constructs with similar terms vary on what they mean, it becomes difficult to create accurate summaries that subsequent work could launch off of. The field has expanded rapidly, and now seems to have reached a stage where converging upon a common set of tools for all steps of the data to construct pipeline – data collection, processing, featurization, construct operationalization – is necessary to yield cumulative, robust, and replicable findings.

Features of MMLA-SEL

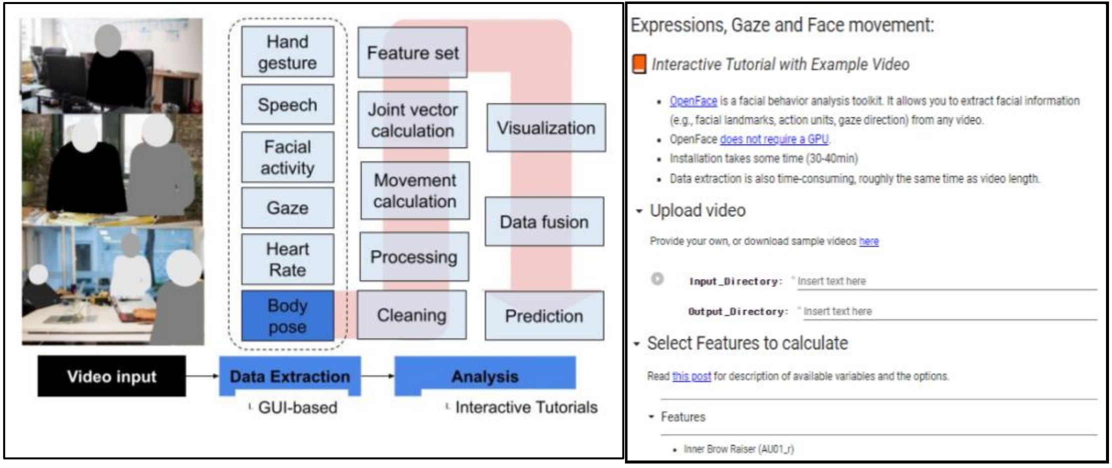
Given this need in the field, our proposed platform focuses on the area of SEL to curate a set of tools that could be used to collect, process, and featurize data in an integrated pipeline. Additional features like forums, data repositories, and interactive meta-review visualizations are hoped to encourage users to be a part of the cumulative knowledge-building process.

The platform expands upon an existing toolkit that can extract data such as heart rate, gaze, facial expressions, hand pose, and body pose from videos collected with typical laptop webcams (see https://mmla.gse.harvard.edu/, Schneider, Hassan, & Sung, 2022). Data extraction is done through a graphic user interface and requires no programming experience, and as calculations happen on the browser, sensitive video data does not leave the user's PC. Current development focuses on expanding the toolkit so that it can collect new types of data (e.g., speech to text), and data on different scenarios: front-facing single learner, collaborating dyads, and multi-angle video streams for 3D tracking in an open learning space.

The data extracted through the GUI interface can then be processed and featurized with interactive computing notebooks. Users can input data and change settings with drop-down menus to create metrics drawn from prior research. For instance, following one particular pipeline, a user can create metrics such as kinetic energy, bounding volume (i.e., openness of pose), prevalence of certain poses (e.g., hand crossed, hand raised), similarity of movement, and head proximity from videos of dyads, as shown in the lefthand diagram in figure 1. An example of a notebook tutorial is shown on the right.

Figure 1

On left, a data extraction and analysis pipeline; on right, a sample notebook tutorial



Expressions, Gaze and Face movement:

Interactive Tutorial with Example Video

- OpenFace is a facial behavior analysis toolkit. It allows you to extract facial information (e.g., facial landmarks, action units, gaze direction) from any video.
- OpenFace does not require a GPU.
- Installation takes some time (30-40min)
- Data extraction is also time-consuming, roughly the same time as video length.

Upload video

Provide your own, or download sample videos here

Input_Directory: " Insert text here

Output_Directory: " Insert text here

Select Features to calculate

Read this post for description of available variables and the options.

Features

- Inner Brow Raiser (AU01_r)

Finally, users can consult documentation, forums, and dynamic meta-review visualizations on the platform to guide their research design. Current work focuses on expanding an existing visualization focusing on collaboration to cover a representative set of constructs in SEL. At the same time, we plan to add a functionality to allow researchers to propose an update to the graph with their own research results. Another goal is to foster a forum for multimodal SEL research, and host data repositories where researchers can upload anonymized data and be cited when others conduct new or replication studies. Using iterative prototypes, we hope to engage the research community to gain insight on the needs, conditions, concerns, and goals that potential users may have at all stages of the development process.

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Comparing the Pedagogical Strategies of Teachers Who Co-Designed Units to Support Students' Theory Building

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Abstract: Co-design is a collaborative approach intertwining individuals' unique perspectives resulting in a product that holds creative stakes for all parties. In this paper, we focus on two teachers who co-designed a unit to engage students in theory-building practices and explore similarities and differences in strategies. Through preliminary analysis of classroom video data, we identified six pedagogical strategies teachers enacted including *technology use, lesson introduction, whole-class discussion facilitation, monitoring, addressing questions,* and *wrapping up the lesson*.

Introduction

Co-design is an approach to collaboratively creating innovative interventions with researchers and teachers that addresses both practical and theoretical aspects of learning (Roschelle et al., 2006). The value of co-design in these cases is the recognition of the classroom context and teachers' needs while creating interventions, as research shows that teachers' contexts and practices are highly influential in the adoption of learning innovations (Penuel et al., 2007). Yet, how these designs are taken up in context may vary from teacher to teacher, as they have different pedagogical strategies and classroom norms that affect how they teach collaborative lessons (Kaendler et al., 2015). In this study, we describe two teachers' pedagogical strategies during a lesson they created together. We argue that units co-designed with the teachers who implement them are often operationalized differently in practice. We explore teachers' pedagogical strategies to understand how teachers enact innovative units and identify potential strategies that we can intentionally build on in future design iterations.

Theoretical and empirical foundations

Pedagogical strategies are the moves that teachers enact to support learning in their classrooms (Leat & Higgins, 2002). Teachers take up different strategies to support interactions during collaborative activities that differ based on their experiences, beliefs, and goals (Kaendler et al., 2015). Pedagogical strategies, such as monitoring or intervening, are important for collaborative learning because the quality of these strategies can impact groups' interactions (Hoffman & Mercer, 2016). However, research shows that pedagogical strategies that support productive collaborative learning require intentionality and training (Kaendler et al., 2015). This becomes more challenging when teachers are implementing interventions that are new to them. The focus of our co-design was to create a unit that incorporated students' ideas within the teachers' existing curricula, therefore, there was no explicit emphasis on how they might use different pedagogical strategies to support groups' collaboration. Therefore, we ask the research question, *how do teachers who co-design a series of classroom units together enact different pedagogical strategies in their implementations of those units?*

Methods

This study focuses on data from the implementation of a one week-long lesson, implemented by two 8th grade science teachers, Katie and Rebecca. In the lesson, "can crush," students dropped a bottle filled with variable amounts of water (mass) from varying heights, watching as it crushed an empty aluminum pop can on the floor. They recorded the height of the can, post-crush, and compared the amount of can-crush with the initial drop height and amount of water in the bottle. Following each investigation, students responded to questions asking them to make sense of and model the relationships between the initial height/mass of the dropped objects, and the outcomes they resulted in. A total of 60 students consented and participated in the study across both classrooms. We collected video data of the groups and the teachers' interactions during the lesson. To analyze the data, the video data was reviewed and described through content logging (Mayring, 2014). Content logs were compartmentalized into time intervals of two minutes; we then conducted thematic analysis and identified six pedagogical strategies (Braun & Clarke, 2012).

Findings

Although six pedagogical strategies were identified in both classrooms, Katie and Rebecca operationalized them differently during the lesson. For instance, *technology use* in Katie's class was limited and students only used their Chromebooks to take a quiz at the beginning of class and used paper-and-pencil to document progress for the remainder of class; *technology use* in Rebecca's class differed drastically as students used their Chromebooks to work on and document their progress for the entire class period. We summarized the similarities and differences of the six pedagogical strategies used by Katie and Rebecca during the "can crush" activity (see Table 1).

Table 1
Pedagogical strategies by teacher.

Strategies	Strategy Definition	Katie's Strategy Examples	Rebecca's Strategy Examples
Technology Use	How teachers used technology	Students used paper-and-pencil worksheets	Students used Chromebooks to fill out worksheets imported from Canvas and Google Docs
Lesson introduction	How the teachers introduced the lesson	Less direct instruction, but scaffolded with information from past lessons	Gave highly structured instructions in the beginning
Whole-Class Discussions	Class discussion before and after lesson	Students raised their hands to answer questions	Called on students randomly, but with some hand raising
Monitoring strategies	How teachers observed students' progress	Silently observed student progress	Monitored student progress, gave reminders about documenting experiment
Addressing questions	How teachers responded to students questions	Provided direct clarifying responses to questions	Prompted students to ask group members about their answers
Wrap strategies	How teachers concluded their class	Structured wrap-up with lesson goal and clean-up	Left the class with questions to think about the next day

Discussion

In this study, we explore how two teachers who co-designed a unit together implemented that unit using different pedagogical practices. Six themes were identified that we classified as pedagogical strategies including how Rebecca and Katie *used technology*, *introduced the lesson*, *engaged in whole class discussions*, *monitored*, *addressed questions*, and *wrapped up the lesson*. While Katie and Rebecca co-designed the unit together, they both have their unique classroom norms and teaching strategies, which informed how they supported students' collaborative theory building, mirroring findings in the literature (Kaendler et al., 2015). We emphasize that there is no right or wrong way to enact these pedagogical strategies, rather we are exploring the range of strategies to inform how we might iterate on this unit in the future. As a design-based research project engaging in co-design, we will leverage Katie and Rebecca's pedagogical strategies that emerged in the unit, as well as their post-implementation interviews to iterate on them and create new strategies to support groups in the classroom.

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Beyond Disinformation: An Agent-Based Modeling and Curriculum for the Post-Truth World

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Abstract: We propose an Agent-Based modeling approach to research and instruction on disinformation that can both reproduce the interplay between individuals' actions and effects at a larger scale and visualize complex systems at work. Our design is composed of a curriculum framework and four research-informed NetLogo models, the latter being the focus of this poster. Implications include design heuristics for instruction to combat disinformation.

Introduction and related work

Education takes a central role in the debate on disinformation—false information created and spread with the intention to cause harm (Wardle & Derakhshan, 2017). We use a series of computational models in NetLogo (Wilensky, 1999), a constructionism-inspired, agent-based modeling (ABM) environment, to address the learning needs of our audience and guide further research. By manipulating the behavior of agents, learners can generate hypotheses and test them. This approach also allows the visualization of the cumulative effects of small changes over time, or non-linear changes. In contrast to direct instruction, working with NetLogo allows learners to see changes in the models' behavior as they try out what-if scenarios by exploring the model's parameters.

This paper is part of a larger research project that investigates learning and cognitive processes in operation at both individual and system-level (e.g., Russo & Blikstein, 2022). Here, we report on the design of a curriculum unit that employs ABM for the instruction about disinformation, its causes, and implications for society. The set of models in our design affords the visualization of effects caused by *different types of agents* who are interconnected through *different types of networks* and are exposed to messages that are themselves subject to different *types of treatment*. From unit 1 on, each model and set of activities incorporate concepts gradually, making abstract concepts concrete and interconnected. In the past, only a few other Agent-Based models address related topics (e.g., Sobkowicz & Sobkowicz, 2021; Johnson, 2021), and the approach is employed with relative infrequency for educational purposes when it comes to disinformation. We propose that our design addresses a gap in current educational interventions for disinformation: many educational interventions and research up to now adopt a media literacy lens, whereas we propose an ABM approach.

Design

Disinformation Spread is a software-embedded curriculum designed to encourage reflection on the factors that affect belief in and the spread of disinformation and is based on two existing NetLogo models (Rand & Wilensky, 2008; Stonedahl & Wilensky, 2008). The curriculum includes 4-units through which learners experiment with computational models and discuss the factors underlying the phenomenon they depict. During class/workshop meetings, learners are presented with different factors at play in disinformation, especially those with political motivations, represented by variables in the software interface. This paper focuses on the set of NetLogo models that are part of the curriculum.

The models build on one another, from the most simplistic one (unit 1) to the most complex (unit 4). In addition to the standard "setup," "go," and "go-once" buttons, all 4 models have a few common interface and code components. Those components include:

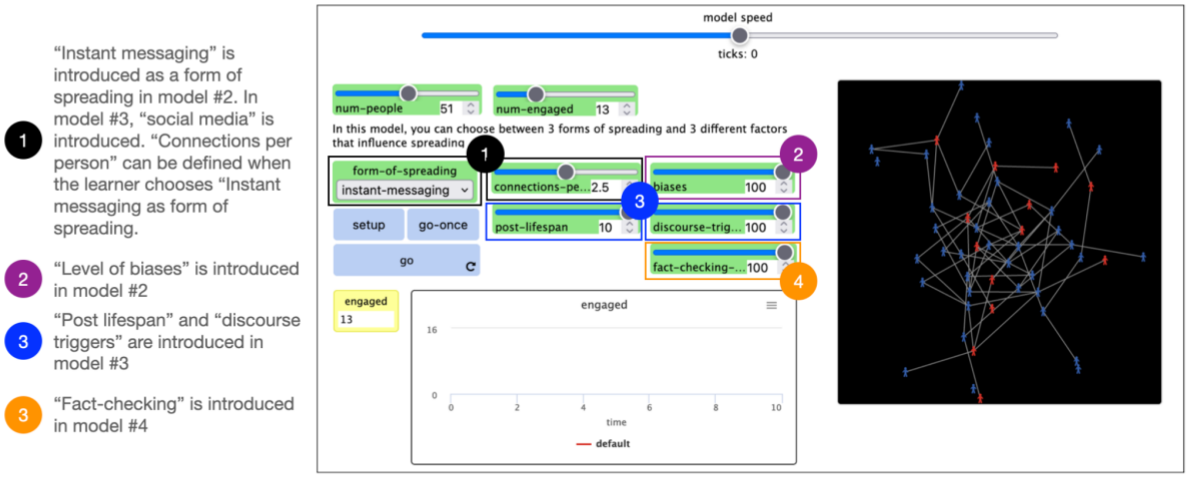
- Variable '*number of people'* (num-people:) represents the number of people in the system;
- Variable '*number of engaged people'* (num-engaged:) represents the number of people who believe in a piece of disinformation and can, therefore, communicate that to other people in the system. These agents appear in red (Table 1);
- An "Engagement vs. Time" a line chart represents the total number of people engaged across time;
- An "Engaged" monitor displays the number of people engaged as the model runs.

Disinformation Spread is designed as a facilitated activity that requires an educator to guide learners in a workshop-like setting. Participating students can experiment with the models and define values for variables in ways that potentially represent their understandings of disinformation. By the end of the unit, it is expected that students will have developed a deeper comprehension of how disinformation spreads and what strategies can be employed at a personal level to address the issue, as well as an awareness of systemic components of the problem.

Disinformation Spread relies on a constructionist approach by inviting the learners to express and debug their mental models using a computational interface, specifically by creating models that express their views on the topic. For preliminary testing data, see Russo, Lei and Blikstein (in press).

Figure 1

Features highlighted in model #4, showing which feature is introduced in each of the previous models



① "Instant messaging" is introduced as a form of spreading in model #2. In model #3, "social media" is introduced. "Connections per person" can be defined when the learner chooses "Instant messaging as form of spreading.

② "Level of biases" is introduced in model #2

③ "Post lifespan" and "discourse triggers" are introduced in model #3

③ "Fact-checking" is introduced in model #4

In this model, you can choose between 3 forms of spreading and 3 different factors that influence spreading

Design critique, conclusion, and discussion

This project proposes an under-explored approach to researching and addressing disinformation through a curriculum based on a series of agent-based models. Existing research in this space tends to focus on media literacy and critical thinking skills (focus on individuals) or on the broader, societal-level understanding of disinformation (see NAMLE, 2019). We understand that this project addresses the interaction between those two dimensions—the individual (micro level) and the society (macro level), an affordance that is typical of ABM. With that in mind, we attempt to explore three characteristics of that approach: offering the learner the opportunity to (i) grasp the effects of individual agents in the system; (ii) make sense of phenomena through visualizations that represent interactions over time; and (iii) to adopt a perspective that brings them closer to scientific epistemology through hypothesis generation, observation, and experimentation. We plan to fine-tune the parameters in the models and add new ones, which will likely afford deeper conversation about their representations and implications. We expect that this work can contribute to the current discussion about disinformation and to our understanding of its causes and implications, both at an individual and at a systems-level.

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“The Focus Came in Handy for Me Too”: Exploring Accessibility Learning and Identity Formation in a Web Development Course

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Abstract: In this paper, we explore learners’ knowledge acquisition as it relates to accessibility-related identity formation. Utilizing Nasir’s work on learning, identity, and goals as our conceptual framework, we analyze students’ reflective responses to describe how learning about accessibility through implementation goals helps them foster identities as accessibility users, and how cultivating these identities helps further their understanding of web accessibility.

Introduction

Imagining themselves as the typical users of their sites, students center their own experience navigating a site and “if the design works for them, they conclude that it will work for everyone” (Rosmaita, 2006, p. 278). Thus, what happens when students are asked to implement accessibility that improve their own experience navigating the site?

Conceptual framework

Nasir (2002) explains how learning, identity, and goals are intertwined such that one creates the other and vice versa. She writes: “As members of communities of practice experience changing (more engaged) identities, they come to learn new skills and bodies of knowledge, facilitating new ways of participating, which in turn, helps to create new identities relative to their community” (p. 239). Through this relationship, while “new skills support the construction of [a] more engaged identity” (p. 240), a stronger identification encourages further learning by “prompting [community of] practice participants to seek out and gain the new skills they need to participate in their practice more effectively” (p. 240). Just as learning and identity help create each other, goals help create learning and identity, and vice versa (Nasir, 2002, p. 240).

Data and analytical approach

The responses for our content analysis were selected from a broader corpus (N=28) and are representative of students’ described experiences implementing and testing accessibility features for their website. Namely, students were asked to implement three main accessibility features or behaviours: 1) ensuring their site was navigable using a keyboard only, 2) ensuring toggling behavior was screen-reader friendly, and 3) ensuring their site properly implemented the change of focus required for a modal box. Students also had the option to implement an extra credit feature that allowed the ‘Escape’ key to trigger the closing of a modal while preserving the appropriate keyboard focus and were asked to state in their written responses if they had implemented the extra credit option. In addition, students wrote responses to the following prompts: “Reflect on the work that went into making your website accessible. Was it a lot of additional work? What was the most challenging part? Do you think that designing for accessibility also improves the usability of the site for all users? Why or why not?”

Accessibility learning and identity formation

As students learn about accessibility through related implementation goals, they are enabled to recognize how *they* are beneficiaries of accessibility. In recognizing themselves as users of accessibility, students are motivated to learn the skills necessary to achieve more advanced accessibility goals and thus benefit from accessibility even further. Using the term *accessibility user* to describe any user who uses accessibility features or otherwise benefits from web accessibility, we present the analysis of two student responses to describe how students develop and cultivate ‘accessibility user’ identities, and how that cultivation helps further their understanding of the topic. We chose the responses of these students because they incorporated examples from their personal experiences navigating their sites, while also providing the most in-depth responses to the reflection prompts.

Student A

As they work towards achieving the goal of implementing “press Enter to submit a post”, Student A learns that this common website behaviour they have come to *expect* is indeed an accessibility feature, and they recognize the importance of the assignment’s goal in their learning: “if not for the accessibility requirements I wouldn't have gone through the pain of implementing it.” In this process, the student begins to develop their own identity as an accessibility user noting “[i]t would be pretty annoying” to not be able to take advantage of the conveniences afforded by accessibility features. This identity formation helps them develop a deeper understanding of why accessibility matters: because it "improves the experience for users in general." With this understanding, the student is motivated to gain the skills necessary and "read *many* [emphasis in original] StackOverflow posts" to accomplish the accessibility goal of having a keyboard navigable site.

Student B

As Student B works toward the goal of testing their site's keyboard navigation, they recognize the convenience of being able to navigate a site using one's keyboard and *chose* to continue making use of the feature, thus cultivating their identity as an accessibility user: "in the end, I was using my keyboard to move around the page a lot anyway! The focus came in handy for me too." Their use of "anyway!" suggests that they felt the work put into the task paid off immediately and surprisingly, as they found their own navigation of the site to be improved with the accessibility feature. Like Student A, Student B's progress toward the implementation goal served as a motivator to further their learning about web accessibility as they "had a few strange bugs come up for a while" and had to work on debugging. They argue that despite their difficulty in resolving the bugs and the additional time spent doing so, the task itself was doable: "These definitely did take some additional thought and work to figure out, but overall, it absolutely was achievable, as demonstrated by my final product." By highlighting the evidence of their successful implementation, Student B demonstrates a sense of pride in their accomplishment.

Student C

Like Student B, Student C develops their identity as an accessibility user through the implementing and in particular, the testing, of their site since they *choose* to continue using keyboard navigation to "work with" their site because they found doing so "easier". Rather than be discouraged by the difficulty of implementing the task, Student C is optimistic about it becoming less difficult with more practice: "I'm sure if I developed that as a habit it'd be easier, but it did take some effort this time around." In fact, despite "quite a bit of additional work to get keyboard navigation to work properly," the student pursued a more advanced goal of implementing the extra credit feature, deepening their learning of accessibility. Furthermore, when they describe how another accessibility feature can benefit users in a non-disability related context: "I think all users can benefit from things like alt text (i.e., your browser might be slow one day and images don't load properly)", they plant the seed for deepening their own identity as an accessibility user the next time they find themselves relying on alt text due to something like a slow Internet connection.

Discussion

Finding ways to engage and deepen students' identity as users and beneficiaries of accessibility is crucial for helping students to sustain and improve their accessibility practices. In learning about web accessibility, students are enabled to foment their identities as users of accessibility, and as a result, are encouraged to continue their acquisition of knowledge and skills that will allow them to engage more deeply with this identity. As students acquire the skills necessary to pursue additional and more advanced accessibility goals, they deepen their learning and 'accessibility user' identities. While student identities as accessibility users are not a replacement for learning from and working with disabled users, our goal is to initiate a conversation on accessibility learning and identity formation. It is our hope that this early exploration motivates further work on these topics as a means of improving how accessibility is talked about, taught/learned, and implemented.

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Leveraging Intuitive Resources to Reason About the Coriolis Force

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Abstract: Traditional approaches to teaching the Coriolis force have been largely unsuccessful. Our team examined the intuitive knowledge students engaged when reasoning about the topic to design a purely conceptual intervention. In this paper, we discuss knowledge elements that are productive in the context of Coriolis phenomena.

Introduction

The Coriolis force is a challenge for physics instructors as traditional approaches involve demanding coordinate transformations with little conceptual explanation (Taylor, 2005). These instructional methods may be responsible for the numerous myths and misunderstandings that permeate the topic (Stommel & Moore, 1989). Our team set out to build a conceptual approach to the Coriolis force to address this deficiency. To this end, we investigated the intuitive knowledge used by physics students during discussions of the Coriolis force. Students have been engaging with natural phenomena for their entire lives. Through situated experiences, they develop a complex understanding of reality and its mechanisms long before they encounter their first physics class (McCloskey, 1983). We aim to describe how this intuitive knowledge could be leveraged during Coriolis force instruction.

Theoretical framework

The constructivist theory of Knowledge in Pieces (KiP) describes knowledge as a complex system composed of interconnected, discrete knowledge elements (diSessa, 1993). One type of knowledge element that is particularly relevant to physics education is the phenomenological primitive, or “p-prim.” P-prims are intuitive explanations of causal mechanisms and are developed by interacting with the physical world. They describe the causality of common events and young learners treat p-prims as “how the world works,” with no deeper explanation required. The p-prims which are activated (or not activated) will drastically influence the way naive learners perceive the causal mechanisms in unfamiliar circumstances. Through “cueing,” naive learners can be guided to activate productive p-prims. By identifying relevant p-prims which apply to a particular topic, instructors can adjust their lessons, activities, discussions, or experiments to intentionally direct students toward desirable p-prim activations.

Methodology

Our conceptual approach consists of a set of thought experiments that incrementally explain the origin of the Coriolis force for objects moving across the surface of the earth. Students first imagine a puck sliding across a frictionless, stationary, spherical earth to establish the shape of a straight line along the surface (called a “great circle”). Then, the students are challenged to transfer these conceptions to a rotating, spherical earth, followed by a rotating, oblate earth. In doing so, the students are guided to consider the connection between the earth’s rotation and its oblate shape, and subsequently how this mechanism deflects objects moving across the surface.

Eleven undergraduate physics students at a large university in the Intermountain West region of the US participated in 1-on-1 interviews. The researcher used a semi-structured think aloud protocol to introduce the thought experiments sequentially and ask the students to predict the motion of the puck in each circumstance. The interview transcripts were coded according to a knowledge analysis framework, which focuses on identifying the structure, origin, and development of knowledge (diSessa et al., 2015). The students’ responses were grouped by physics concept (such as “reference frames,” “friction,” “equilibrium,” and “gravity”) and reviewed to identify patterns within the students’ explanations, questions, difficulties, and predictions when engaging with each topic. The patterns were compared to lists of previously documented knowledge elements for identification.

Results

The p-prims which students use to understand balance and equilibrium have been well-studied and documented (diSessa, 1993). These p-prims are activated when students identify two agents attempting to achieve results which are mutually exclusive. These battles have two possible outcomes: the opposing agents will negate each other entirely, *cancelling out* any result (leading to a state of *dynamic balance*), or one agent will *overcome* the other (leading to *dynamic imbalance*). The conceptual approach offered several opportunities for the students to represent the phenomena as a pair of agents battling each other, thus activating this rich p-prim cluster. First, when switching from a stationary to a rotating earth, the students saw that the particles of the earth would have a desire to cross over the equator as they attempt to travel along their great circle. The symmetry of the particles across the equator helped the participants activate *cancelling* to predict that neither hemisphere would win out in the conflict. Upon arriving at this *dynamic balance*, all eleven students easily concluded that the opposing particles would pile up and create an equatorial bulge, which is consistent with the reasoning of physicists.

Next, the students were asked to consider a single particle on this rotating earth. Previously, the particle's motion had been driven by the inertial tendency to follow a great circle, resulting in an apparent slide toward the equator. However, as soon as the spherical earth was allowed to bulge outward at the equator, a new agent was introduced: the bulging equator would now act as an antagonist and push objects "downhill" toward the poles. The students displayed a strong intuition that one of these tendencies would *overcome* the other; several proposed a *dynamic imbalance* where the equatorial drift would continue if the effects of the bulge were minimal. Most students were able to foresee that this imbalance could not exist indefinitely: the students correctly associated the strength of the bulge's deflection with the size of the bulge and gathered that there must come a time when the bulge had grown enough to be on par with the equatorial drift. This is a timely activation of another p-prim called *Ohm's p-prim*, which describes how a greater action should achieve greater results. At that point, the students reactivated *dynamic balance* as the oblate shape of the earth *cancelled* the equatorial drift. This new equilibrium explained the causal mechanism behind the stability of the earth's oblate shape.

Finally, this equilibrium was perturbed when the students were asked to consider a puck moving east across the surface. As the bulge of the earth is fixed, its effect is constant. In contrast, the rotation rate of the puck was now faster than the earth beneath it. The students activated *Ohm's p-prim* again, this time connecting the strength of the equatorial drift to the rotational speed of the puck. This allowed them to infer that the equatorial drift of the east-moving puck would *overcome* the earth's oblate shape, deflecting the puck toward the equator. These intuitions were mirrored for a puck moving west across the surface (which would still be moving east, just slower than the ground beneath it). In this case, they reversed *Ohm's p-prim*, predicting that the puck's slower rotation speed would decrease the strength of the equatorial drift, allowing the bulge to *overcome* in this case.

Within these thought experiments, the students were asked to imagine a system that starts in imbalance, becomes balanced, and then is disturbed once again to arrive at a new, distinct imbalance. The students were remarkably adept at alternating between these complimentary p-prim clusters when prompted. This plasticity may have been enhanced by the relatively direct guidance of the semi-structured protocol. If so, it would support the predictions made by KiP researchers who emphasize the importance of cueing to reinforce helpful activations and the importance of contextual connections with prior knowledge (diSessa, 1993).

Discussion

The balance p-prim cluster forms a rich foundation for intermediate physics students to access when navigating the conceptual terrain of the Coriolis force. Though these resources may seem individually simplistic, their cooperation and synergy showcase the complexity and interconnectivity of intermediate learner's knowledge systems. As the students encountered unfamiliar, higher-order physics concepts, they activated these fundamental heuristics that have proven themselves through experience to reliably explain the natural world. This study highlights the potential of interventions which intentionally utilize students' intuitive knowledge. By cataloging knowledge activations, we confirm that intermediate physics students have the cognitive tools necessary to comprehend the Coriolis force on a fundamental level. As evidenced by the findings, guidance from instructors can significantly influence the manner in which students make use of their intuitive reasoning. Our hope is that these findings will inform instructional design for upper-division classroom curricula and enable physics educators to create Coriolis force interventions that will more effectively harness students' productive intuition.

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Centering Safety at Community Centers: Making Space for Youth Interest

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Abstract: Community centers hold powerful potential for interest development within marginalized youth. In order to effectively retain the presence and support the interests of such youth, fostering and maintaining a sense of safety is critical. In this work, we present preliminary findings from an activity system perspective (spanning rules, community, and division of roles) of analyzing a city-run community center. We use the Healing is Rhizomatic conceptual framework to develop an initial conceptualization of how different actors and behaviors support youth safety and interest, and the tensions that emerge in these processes.

Introduction

Woodland (2008) analyzed and envisions community centers as carrying potential to be the much needed reimagining of the traditional school day that enables rich interest development for minoritized youth, specifically Black boys. He highlights the need for a wide variety of factors including cultural relevance in programming and activities, and the need for safety. This is a particularly critical need in response to the constant and rising criminalization and victimization of Black and Brown youth (Parker, 2017).

In response to these concerns, we present pilot work at a community center run by a small midwestern city aimed at centering safety for youth from local low income non dominant communities. Specifically, we are interested in understanding the setup of the unstructured program as created and run by the YYA (Young and Young Adult) division of the city, the participation of the youth at the space, and how different interactions between youth and facilitators shape youth's sense of safety and interest.

Context & methods

In exploring youth safety here, we center the processes, tools, and relationships that offer a stable and contained space in which youth experience shifts with interpreting, feeling, and engaging with notions of vulnerability, awareness, and comfortability? We draw from Lopez's (2020) Rhizomatic framework for this investigation which describes felt sense, relationship, and place "nodes" ("anchors of being and experience"), and their relationship with experiences of "blockage" and "connection" as collectively forming a "bud". Lopez determines that focusing on the relations that form this "bud" is useful to "identify sites through which [youth] can access and channel healing".

Complementing this with Engeström's work on formative interventions (2011), we use activity theory to understand how different aspects of YYA enable (and also create tensions in) youth's experience of safety. We center youth as the Subject, and experience of safety and agency in this space as the Object of the activity system. The work is built on field notes collected over a period of 3 months by us (the primary author on this paper) who acted as a co-facilitator alongside prior YYA staff while collecting notes for potential design interventions to improve youth experiences. We start with presenting select vignettes from our notes that surfaces a mixture of tensions around safety and examine this vignette and other observations through activity theory's components: the broad themes of *Rules* practiced in the space; the varying ways that youth maintain their *Community*; and the *Division of Roles*, especially through lenses of social power that youth engagements.

Findings: Safety and interest

A particular youth who's cemented an interest in basketball enters the community center every day asking the same question, "the court's open today?" In one particular instance however, upon the youth's arrival, a YYA staff member attempted to engage him about his disruptive actions from an earlier event. Through the conversation, the youth kept evading answering any questions in the form of jokes and not responding to questions, to which the staff member firmly responded with "You can go downstairs until you're ready to have a conversation". Consequently, this decision made the youth upset as he spoke with another YYA staff member in a more intense manner. This staff member attempted to use a calmer tone with the youth to explain why the conversation was necessary. Eventually, the youth was allowed to rejoin the YYA space, but was told that the courts would not be open for him until later that evening.

The first staff member emphasized the adult vs. youth hierarchy (a *division of roles)* through his conversation style ending with the decision to initially exclude him from activities. It can also be used in tandem with Tools to describe the types of conversations both staff members had with youth. Not only do the staff members take on different roles in this conversation (stern vs empathetic, which we've observed are their respective roles in other conversations as well), they also had two different conversations, the first being punitive and the second being explanatory. This demonstrates the tension around youth safety through the reciprocity of safety for the community/activity system and safety for the individual.

Analyzing the "bud" that is nodes of felt sense, relationship, and place and their interaction with the blockage experience, it becomes clear that YYA centered safety in this interaction to make space for the youth's interest. Although the youth excitedly came in to play basketball, he was greeted with an unwanted conversation about his previous behavior. This initial felt sense (attacked, leading to humor as defense) paired with the emphasized adult-youth relationship he has with the first YYA staff member he spoke to, prompted a "blockage" to his initial interest, signaled by his tone after the first conversation ended. However, the second conversation was with a staff member he had a better relationship with, signaled by the conversational and explanatory tone. This allowed the youth to end the conversation feeling a sense of safety about being welcome in the space, dissolving the "blockage" and making a "connection" to access the place where he can explore his interests. The tool of conversation and relationships he had with the YYA staff members in the stable space of the Community Center allowed the youth to be able to experience shifts in his interpretation and engagement with feelings of awareness and comfortability regarding his previous behavior to feel safe pursuing his interest in staying in the YYA community and pursuing his interest in basketball.

Implications

We believe that this investigation offers a novel and deeper lens into different ways that safety for (minoritized) youth can be conceptualized and designed to support interest development. Our preliminary notes highlight: 1) the role of institutional *rules* and adult imposition in maintaining group safety – inviting us to explore what kinds of rules can enable such conversations and disciplinary actions to be productive while maintaining individual youth's senses of safety; and 2) the process of engaging in specific roles to affirm one's safety and comfort which might also limit the extent to which youth experiment their own potential interest in different activities – provoking us to recognize how to encourage youth to explore different activities and roles and challenge inequitable norms while staying as safe as they find comfortable (Lewis et al., 2018).

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The Utility of Alderfer’s ERG Theory of Motivation for Measuring Adult Learner Motivations in Informal Learning Environments

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Abstract: This study examines the utility of Alderfer’s Existence, Relatedness, and Growth (ERG) theory as a framework for understanding student motivations in informal learning environments. Data from 1038 students were evaluated to determine the ranking of motivations for studying Aikido; a Japanese martial art. Findings suggest that ERG theory is useful for the creation and interpretation of survey response data but requires additional methodological tools to assess the validity and reliability of its inferences.

Introduction

Alderfer (1972) found that Maslow’s hierarchy of needs (1943) (i.e., physiological, safety, belongingness, esteem, and self-actualization) can be best explained by three groupings: existence, relatedness, and growth (ERG). In ERG theory, the *existence* dimension is concerned with basic material existence requirements and is associated with Maslow’s psychological and safety needs. The *relatedness* dimension refers to social factors such as relationships with friends, family, and significant others and parallels Maslow’s belongingness needs and the extrinsic elements of the esteem category. The *growth* dimension is associated with one’s desire for personal development and is akin to the intrinsic components of Maslow’s esteem category as well as elements that reflect self-actualization. ERG theory also refines Maslow’s hierarchy by suggesting that the satisfaction of *relatedness* needs, or *growth* needs, are not always contingent on the satisfaction of *existence* needs. Whereas Maslow’s theory states basic needs must be satisfied before higher needs can be pursued, Alderfer’s ERG theory suggests needs can have different levels of priority for different individuals. The result of these revisions has allowed ERG theory to be applied to a wide range of studies on motivation, especially research traditionally outside the Learning Sciences.

Unfortunately, even if ERG theory could be useful for education research, it is susceptible to the criticisms associated with Maslow’s theory; that there are few empirically based findings to support its scientific use. Therefore, we argue that special attention must be placed on determining ERG theory’s methodological application and psychometric validity. To that goal, we conducted this study to determine if Alderfer’s ERG theory can be used as a psychometrically valid framework to guide the evaluation of motivations in informal learning environments. More specifically, we sought to determine if an instrument based on ERG theory could reveal different levels of priority of needs among learners. If so, this would both demonstrate how ERG theory can be validly applied to education research, and that criticism of the theory based on its association with Maslow’s hierarchy of needs should not preclude its use.

Methods

One of the researchers for this study is an instructor for the martial art of Aikido, giving us access to a national population of students. Since Aikido has over one million practitioners worldwide and is associated with many physiological and psychological benefits (Szabolcs, Köteles, & Szabo, 2017), we felt confident in hypothesizing that Aikido students could function as a sample population for a large group of learners motivated to pursue a goal. Therefore, by demonstrating how an instrument based on ERG theory can be applied to Aikido students, we can reasonably assume it is possible to do so for other student populations.

An item pool was generated by rewording a survey used by Ko, Kim, and Valacich (2010) to investigate motivations to study multiple martial arts. While Ko et al. (2010) also used ERG theory to guide the development of their instrument, they did not evaluate the validity of their findings. In total, our customized instrument operationalized 10 factors that were categorized and interpreted using the three dimensions of Alderfer’s ERG theory as follows: Our *existence* dimension included the factors of health, self-defense, mental wellbeing, skill mastery, and fun. Our *relatedness* dimension referred to the factors of social facilitation (i.e., comradery with fellow students), and affiliation (i.e., sense of belonging to a school or community). Our *growth* dimension was associated with the personal development factors of philosophy, value development, and cultural learning. To assess if the items in our pool were being operationalized in a way consistent with these dimensions, three teachers and three students were asked to categorize each question in our pool. Reaching full agreement, we arrived at a total of 30 items (3 items for each of the 10 motivational factors). We used a six-point Likert scale with one item from each motivational factor being negatively worded to solicit conscientious responses.

After the instrument was pilot tested, it was sent to subscribers of *Aikido Journal* – the leading Aikido publication in the United States. After which, the instrument was distributed to the popular Aikido Facebook group, that had over 30,000 members at the time of this study, and the Aikido subreddit, a discussion forum on the website Reddit, that had over 7,000 members at the time of the instrument's distribution. The instrument was also distributed by numerous teachers to their respective students. The breadth of which the instrument was distributed allowed us to minimize nonresponse bias and reach a diverse section of respondents not easily obtained in more controlled settings.

Data analysis and results

In total, data from 1038 students were included in this study. Two hundred and twenty-five respondents missed the presence of one or more of the reverse worded items, so we dropped these items from further analysis. Confirmatory factor analysis was then conducted on the remaining data using ERG theory as guidance. This resulted in the combination of the social facilitation and affiliation factors due to their conceptual similarity and because two affiliation items were removed due to low factor loadings. The resulting model had excellent fit (CFI = .994, SRMR = .038, RMSEA = .044) (Hu and Bentler, 1999). Multiple-group confirmatory factor analysis was also used to assess whether motivational differences between males and females were due to true differences or if they were artifacts related to differences in item interpretation. Using the configural, metric, scalar, and residual measurement invariance tests, we found our instrument was similarly interpreted by males and females.

Analysis of latent means revealed skill mastery was the main motivation for all students. When taking gender into consideration, there were some noticeable variations. For example, females appeared to be more motivated by *existence* related motivations (i.e., mental wellbeing, health) which are akin to Maslow's psychological and safety needs, whereas males were more motivated by *growth* related motivations (i.e., philosophy, value development). These findings do not necessarily contradict Maslow as his theory implies individuals address their physical and psychological safety needs before higher order needs are addressed. However, considering more than 80% of females in our study reported to have over three years of Aikido experience, Maslow's theory would also suggest that they would be less motivated by these lower order needs, which was not the case in our findings.

Discussion and implications

Although Alderfer's ERG theory is derived from Maslow's hierarchy of needs, this study serves as evidence that ERG theory has merit as a useful framework that can guide the operationalization and interpretation of motivations. The ease of which motivations can be mapped to, and interpreted by, the three dimensions of *existence*, *relatedness*, and *growth* suggests this theory is useful for research investigating the motivations to engage in learning environments. However, while we were able to successfully use Alderfer's ERG theory to account for and demonstrate the motivational variability between male and female students, additional methodological tools and assessments are needed to ascertain the true validity and reliability of the inferences the theory can generate. For example, a subsequent study should consider the use of path analysis to further evaluate the linkages between the dimensions of *existence*, *relatedness*, and *growth* or between the motivations themselves. Doing so may help uncover any casual relationships among the motivations and could help determine why students prioritize certain motivations over others.

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Exploring Changes Within a Cross-Context Community

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Abstract: Cross-context communities can benefit teachers by learning from different practices across schools, but such communities may be challenging to establish. This study examined how one cross-context mathematics teacher community consisting of elementary and secondary teachers evolved over two years. Preliminary findings suggested three changes in teacher interactions in the cross-context community: 1) with whom teachers interacted, 2) how they interacted with one another, and 3) what topics they discussed.

Introduction

Teacher communities provide opportunities for teachers to reflect on their practices, examine their strategies, and share experiences with their colleagues (Grossman et al., 2001). Within communities, teacher interactions help teachers learn how to interpret problems in practice and plan future teaching (Horn & Kane, 2015). Much of this research on teacher communities has been conducted within singular contexts (e.g., schools, grade levels, disciplines). However, schools often face challenges that are hard to address in one school alone (Stoll, 2009). Accordingly, educators have looked to expand teacher communities by connecting different contexts (Prenger et al., 2021), what we refer to as cross-context communities. *Cross-context communities* bring together members of different contexts, such as teachers from different levels, schools, or districts. These communities provide members with opportunities to share a broader range of experiences and perspectives (Stoll, 2009). Despite the benefits of cross-context communities, they can face barriers, such as a lack of interactions and shared goals (Prenger et al., 2021). It is less clear how interactions in cross-context communities evolve over time. Thus, this study examined changes in interactions over two years in one type of cross-context community: spanning elementary and secondary levels and connecting different schools. We asked: How did teachers' interactions change in a cross-context community?

Research design

We drew upon situated learning theory which emphasizes the impact of context on learning through members' social interactions within a community of practice (CoP) (Lave & Wenger, 1991). A CoP is a group of practitioners who have common interests and values in a specific domain (Lave & Wenger, 1991). They interact regularly to share information and learn from others' experiences to produce new knowledge (Lave & Wenger, 1991). A CoP includes three aspects: mutual engagement (collective activity), shared repertoire (shared tools, norms, and routines), and joint enterprise (shared goals). Bannister (2015) found that teachers developed a CoP through their shared repertoire (e.g., daily meetings), mutual engagement (e.g., curricular and pedagogical reforms), and joint enterprise (e.g., common goal to support all students). The community was beneficial when members had commonalities and interacted toward their goals. However, Grossman et al. (2001) found that teacher communities risk becoming pseudo-communities when members pretend to agree on values and lack authentic interactions. Thus, to benefit teachers' learning, it is important to understand how CoPs develop.

This study is part of a design-based research project (Bakker, 2018) aiming to support student transitions from elementary to secondary mathematics. The project involved a 3-year partnership with one school board in Canada, serving a large rural community. Elementary and secondary math teachers came together for regular meetings (5-6 meetings with 6-8 teachers per year). In this paper, we focus on the first two years to examine how the community developed. Our overarching goal was to support cross-context coherence in pedagogical practices. To do so, a central task of the community was to develop, implement, and refine versions of one instructional routine (a short lesson with a defined structure that can be adapted to different content and grade levels) (Lampert & Graziani, 2009). Meetings were led by a math coach, in three parts: a) check-in about implementing the routine, b) discussion of instructional strategies, and c) co-planning new routines.

For this paper, we drew upon videos of the check-in portions (occurring in 9 of the 11 meetings). Check-in allowed us to identify a) changes in interactions and b) whether meetings followed a consistent activity structure. First, we transcribed the check-ins to capture verbal and non-verbal discourse (e.g., gestures, gaze). Next, guided by our research question, we created initial themes to characterize interactions by answering analytic questions related to the components of CoPs (mutual engagement, shared repertoire, joint enterprise). We then looked across meetings within and across years to identify commonalities, exceptions, and changes in interaction patterns.

Preliminary findings and conclusions

Our preliminary findings revealed three changes specific to the cross-context aspects of the community. First, we observed changes in whom teachers interacted with. The interactions that happened during the first year were mostly between individual teachers and the math coach. For example, when a teacher shared her struggles in implementing the new routine in her classroom, the coach alone responded. The few interactions that did occur among teachers only occurred between those from the same school. Conversely, in year 2, we observed more teacher interactions across schools and grade levels. For example, when one elementary teacher shared student misconceptions, two secondary teachers respectively shared how they supported students in similar situations.

Second, as teachers developed a shared repertoire that spanned school contexts, their interactions shifted from passive participation to active exchanges of ideas. For example, in the first three meetings, they interacted by nodding, smiling, or saying “okay” or “absolutely.” In contrast, at a meeting in year 2, when one of the elementary teachers shared her teaching materials and student responses, a secondary teacher asked for more details about the materials. She then connected them to her classroom activities. Teachers from different contexts increasingly interacted when they found commonalities in learning activities across school levels over time.

Finally, interactions shifted in the focus of discussions: from discussing how to tackle challenges with students in their individual schools to developing joint enterprise across contexts. In year 1, teachers focused more on dealing with student struggles with new routines and lack of confidence rather than sharing common goals. They sought strategies to boost student confidence and support student struggles. However, in year 2, teachers started to connect their goals to instructional routines. For example, one elementary teacher told a secondary teacher, “Actually, next year, you will have some students who remember this routine because when I was with them, I did the same routine.” The secondary teacher responded, “Yes, it will be interesting.”

The preliminary findings of this study indicated three major changes in teacher interactions within the cross-context community. We interpret that these changes provide evidence of community development by establishing joint enterprise and shared repertoire through mutual engagement (Lave & Wenger, 1991). These findings contribute to expanding our understanding of cross-context community development by illustrating changes in interactions specific to cross-context communities. For example, like Bannister (2015), we found that teacher-to-teacher interactions were initially limited. However, our results also highlighted that *who* teachers interacted with changed and was related to context membership. Moreover, our findings are a first step towards the development of a framework characterizing cross-context community changes in interactions. Such a framework can be used by community facilitators to learn to anticipate possible changes in interactions and to plan structures to support similar community growth. Moving forward, we will further investigate how the design elements and other factors contributed to changes in teachers’ interactions.

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Ethical Complexity in Youth-Led Computer Science Curriculum Writing: Emergent Ethical Deliberation in Curricular Co-Design

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Abstract: Questions of ethics and politics are typically missing in computer science education (Vakil, 2018). Amid growing concerns about the intersections of ethics, race, and technology (Benjamin, 2019), youth voices are seldom centered. This study explores the emergent practices from youth who interrogated themes of ethics and technology in an OST community learning space as a part of our research practice partnership (RPP). We follow two vignettes where participants collective debates of morality; which we term ethical deliberations.

Research design, data collection, and methods

In our exploration we ask: (1) what pedagogical moves and framing did facilitators use to support sensemaking about ethics of tech and (2) what was the nature of student ethical thinking and discourse, and what shifts were observed over the course of the program? This program is centered around a design-based RPP project which focuses on the interests and perspectives of youth. Using a grounded theory (Corbin & Strauss, 1990) approach to identify trends in youths' negotiation of ethics and technology, a team of educators and researchers analyzed 10 hours of recordings and field notes to develop codes to identify patterns in participants' speech and interactions (Saldaña, 2015). We used a constant comparative method (Charmaz, 2014) involving iteratively working between codes and transcripts to identify the patterns and generated codes We describe as contributing to a collective deliberation of morality; which we term ethical deliberations (see Table 1 below).

Table 1
Counts of the codes for elements of ethical deliberation across vignettes

Code	Definition	Vignette 1 Counts	Vignette 2 Counts
Legitimacy	What is it?	17	6
Ownership	Who gets to?	0	2
Rules	How does it work?	1	0
Infraction	What was violated?	3	3
Consequence	What happened next?	0	3
Other		27	11
Total no. of turns		48	25

Findings: Elements of ethical deliberation

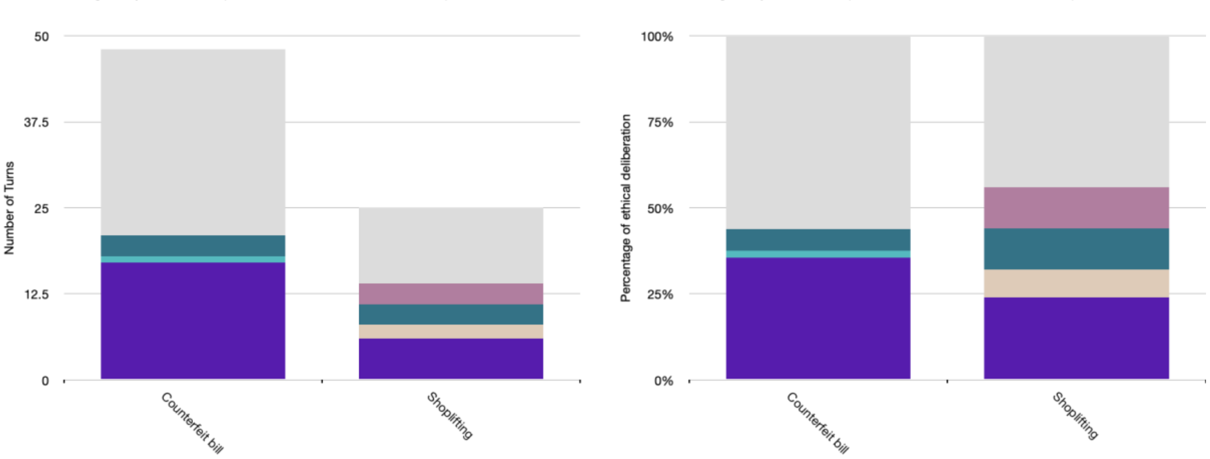
This poster presents data from two vignettes representing early shifts in ethical deliberations during our study. These conversations illustrate how participants took up a practice of using discussions as a way of interrogating and evaluating ethics both within and outside the realm of technology. In both cases, the data presented represents a zoomed in section to a larger conversation presented to participants as an ethical concept.

In the first vignette, we highlight a segment of a conversation that takes place on the first day of the program about the murder of George Floyd and the technologies present. Drawing on Winner's (1980) expansive framing of technology and ethics, Facilitator Moore presents the counterfeit bill as central technology to the case and prompts participants to consider how the clerk might have assessed the legitimacy of the bill; a determination that ultimately led to Floyd's death and the world-wide recognition in the weeks that followed. While racialized violence was quickly identified as a salient ethical issue by participants, there was little uptake on the role of technology or artifacts despite multiple attempts by facilitators. However, even in this introductory conversation, participants were able to use the discussion to interrogate how a counterfeit bill might differ from a federally minted bill (coded as rules) and how a counterfeit bill might be created (coded as infraction).

The second vignette highlights a discussion that takes place about halfway through the program on the ethics of shoplifting. We see collective and complex ethical sensemaking through participant-led cross talk through deliberating the ethics of shoplifting in a luxury retailer. In these quick turns, there is a judgment made of the luxury retailer by the collective that there are places where shoplifting might be considered appropriate due to need. In contrast with society's laws around shoplifting, this deliberation illustrates how participants were engaging in serious deliberation rooted in their lived experiences. Noticing the way participants responded to a luxury retailer, Facilitator Ian considered posing the same question based on human necessities and reframed his prompt to question how their stance may shift if someone was shoplifting food. We see an implicit uptake of justice and power in discourse by the participants that shows significant movement between the two vignettes.

Figure 1

Distribution of ethical deliberation across vignettes: total counts (a); proportion to the whole conversation (b)



(a) (b)

While the conversation in Vignette 1 was nearly twice as long as Vignette 2, there was significantly more concentrated ethical deliberation in the latter conversation. Additionally, participants have created a quasi "court" structure where they become the arbiters of what is deemed legal. In these vignettes, participants exhibited a practice of creating legal structures for societies. Critical race theorists have advocated for returning to the legal origins of modern policy (Ladson-Billings and Tate, 1995). We see this return as a natural way of engaging in ethical deliberation and a counter-narrative to normative ethics as they are defined in CS education.

Significance and implications

Our findings have implications for the design of computer science education that seek to center youth as equal partners in the complex work of ethical sense-making of emergent technologies. Deliberative discussions can serve as a powerful vehicle for rich engagement with the ethics in technology and should become a part of standard in computer science and technology education. While youth are ready to engage in deep, rich discussions, facilitators must create room for questioning and engage expansive views of tech ethics. We argue for standard practice in regular conversations in group discussion to increase complexity in ethical deliberations. Our future work will look at additional conversations to determine deeper relationality between the elements of ethical deliberations identified here.

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Uncovering Middle School CS Students' Understanding of Variables and Control Structures: A Cognitive Think-Aloud Approach

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Abstract: This poster presents findings on middle school students' understanding of core Computer Science (CS) concepts, such as variables and control structures, using cognitive think-aloud interviews with eight students. Each student worked on 16-22 formative assessment tasks designed to assess understanding on the 'Algorithms and Programming' middle school CS standards. Our study describes students' interpretations of the CS concepts and discusses potential factors influencing student interpretations. Significance and next steps are described.

Introduction and research questions

Education researchers and policy makers have emphasized introducing CS as early as possible to prepare K-12 students for future careers and life in a computationally intensive society. Many CS curricula, particularly for middle school levels, have been developed to help students understand key introductory CS concepts such as variables and control structures. These curricula predominantly employ a block-based programming representation which helps students learn core CS concepts without having to deal with complex syntax. However, some studies have explored and found that young students still encounter challenges in understanding the concepts of variables and control structures, even when using block-based code. For example, Mladenović and colleagues (2018) compared elementary students' misconceptions of loops in block-based and text-based programming languages and found that young students had misconceptions about simple and nested loops, even in block-based languages. Although some such studies have started to explore students' challenges with key CS concepts, there is still a need for research on middle school students' understanding of key CS concepts, such as variables and control structures, using a variety of programming representations, both block-based and text-based. Here, we report on a pilot study leveraging a cognitive think-aloud approach to uncover middle school students' challenges with the concepts of variables and control structures and identify the contributing factors. Our research questions are as follows: (1) What do middle school students' responses to various short assessment tasks reveal about their understanding of the concepts of variables and control structures?; and (2) What are the potential factors influencing middle school students' responses to CS assessment tasks?

Methods

Context

We employed an evidence-centered design approach (Mislevy & Riconscente, 2006) to design 75 formative assessment tasks aligned with fine-grained learning targets associated with middle school 'Algorithms and Programming' standards. Tasks used a JavaScript programming representation and a combination of block- and text-based formats for these tasks to align with the representation used in the CS Discoveries (CSD) curriculum that was familiar to all participating students (Basu et al., 2022). We present data collected from eight hour-long interviews with seven 8th-grade students and one 7th-grade student who worked on 16-22 tasks each. About half the students reported having taken CS courses in their previous grade levels. All students were instructed to independently think-aloud through each task during the one-hour interviews. All the interviews were audio recorded and transcribed.

Data analysis

Based on the cognitive interview recordings and notes, we developed a memo for each student by listing their final answers for each assessment task, how they described their problem-solving processes, challenges they faced, time taken to finish the task, and feedback on the tasks. The analytical approach comprised reviewing students' responses and their thinking processes and grouping their responses into five categories: 1) provided correct answers and correct reasoning; 2) provided correct answers but partially correct reasoning; 3) provided incorrect answers but a partially correct reasoning; 4) provided incorrect answers and inaccurate/irrelevant explanations; and 5) decided to skip due to lack of understanding of the task and/or the underlying concept.

Preliminary findings

Students' understanding of variables

Students demonstrated an understanding of how to *name variables* appropriately on half of the tasks (2 students each responded to 2 tasks on this aspect). There was only 1 task aligned with *variable initialization*, and the only student who responded to this task was able to provide the correct answer. In contrast, students struggled with *manipulating values of variables*, whether it be numeric variables, string variables, or variables representing compound datatypes such as lists. For instance, some students did not understand what a string variable is, so they had challenges parsing string variables. Some students did not understand when two numeric variables are linked by assignment such as "count = start + 1." Moreover, students struggled with using variables alongside loops and conditionals.

Students' understanding of control structures

Students answered most tasks on *nested loops* and *nested conditionals* partially or fully correctly (6 students each worked on 1-2 tasks on each of these two aspects). In comparison, students demonstrated difficulty understanding code that includes a compound conditional statement using Boolean operators as part of the condition. Students could neither accurately identify needed Boolean expressions for representing a condition nor predict the correct output of a program with a conditional including Boolean operators. For *repeated conditionals*, only 2 students worked on aligned tasks, and only one student answered correctly, albeit with partially correct reasoning. *Procedures inside control structures* was also difficult for students; 4 students each worked on an aligned task and only two students answered correctly with partially correct explanations.

Potential factors influencing students' reasoning

We found that some factors may influence students' reasoning, such as their prior programming experience and familiarity with JavaScript block-based and text-based representations. We noticed that most students reasoning process leveraged their prior programming experience. Students familiar with other block-based programming languages such as Scratch often tried to tie their reasoning back to that representation, even when not appropriate. Regarding code representations, we found that students generally preferred a visual block-based representation, especially some students who had never seen text-based code, even though the CSD curriculum programming environment allows them to toggle between block-based and text-based representations.

Discussion and future directions

This work is part of a pilot study for a larger project that aims to deepen middle school teachers' understanding of five Algorithms and Programming standards by implementing standard-aligned formative assessments. Our findings suggest that programming representation plays a significant role in formative assessment tasks and the types of student understanding and challenges that tasks can elicit. To forge deep conceptual learning, students should be exposed to different programming representations so that their learning is not limited to the affordances and constraints of one programming representation. Regarding the next steps, we are revising some of our formative assessment tasks to better capture student challenges and understanding of the underlying concepts.

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Social Context Challenges in Administering Authentic Assessments of Citizenship Competency

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Abstract: The authentic assessment framework from Gulikers et al. (2004), its research situated in an adult vocational nursing program, called for the use of an authentic social context. This dimension is not typically included in authentic assessment models that focus on K-12 education but is closely aligned with citizenship education. This poster identifies moments in earlier phases of a design-based research study when classroom social context complicated teacher assessment of student citizenship competency and proposes to study how to mitigate for it.

Introduction

Social contexts in classrooms can be quite different than the social contexts associated with real-world processes that teachers engage students with or simulate in citizenship education. In designing more authentic assessments of citizenship competencies that students may develop via engaging with complex problems with real-world value, the social context of the classroom may interfere with student abilities to fully demonstrate their competency. This poster aims to prompt conversations that will support the researcher in designing the third phase of a design-based research study that appears to have identified this concern in the first two stages of design.

Theoretical framework

Wiggins (1989) wrote of *authentic tests* that were contextualized, complex intellectual problems, representative to a discipline or profession. They required self-assessment, a public performance, and a multi-pronged view of student learning. Authentic assessments have realistic value of task and context (Herrington & Herrington, 1998), a fidelity of the task to real world conditions and a realistic social context (Gulikers et al., 2004) and are also authentic in value to students (Gulikers et al., 2008). Koh and Luke (2009) developed criteria for intellectual quality including knowledge manipulation, knowledge criticism and the value of using supportive task framing.

Purpose

The research proposed in this poster will be the third design phase in a design-based research (DBR) study. The purpose of Phase 1 was to collaborate with two Grades 6 and 7 teachers to design an authentic assessment of citizenship competencies that their students developed when participating in a real city planning public engagement process. Students generated individual ideas and were prompted to deliberate to prioritize which ideas would be submitted to the city process. The purpose of Phase 2 was to apply findings from Phase 1 in collaboration with a Grade 12 Political Studies teacher to design an authentic assessment of her students' competencies associated with deliberative dialogue, including prioritization, in rich simulations such as Model United Nations. The purpose of Phase 3 will be to collaborate with another teacher to design and administer an authentic assessment of deliberative dialogue requiring prioritization, but to focus design decisions and data collection on the influence of the social context of the classroom and how teachers can mitigate for it in designing and administering the assessment. I propose to write an exemplar of practice for teacher education as practical output.

Methods

The DBR process is structured on McKenney and Reeves (2018) model for educational design research, with practical and theoretical lines of inquiry, and an iterative process. Clinical partnerships were formed in each phase, with the researcher engaging in design with two Grades 6 and 7 teachers in Phase 1, and one Grade 12 teacher in Phase 2. Data collection involved design-process notes, annotated shared digital planning documents, observation notes, semi-structured interviews with teachers and student participants, and an examination of artifacts. Thematic analysis identified themes in what could be learned about the nature of citizenship competency and practical lessons for teachers in designing assessments of competency, resulting in the creation of exemplars of practice for each phase and a graphic organizer. I propose to use a similar methodology in Phase 3 but am seeking suggestions.

Selected findings phases 1 and 2

Phase 1

The Phase 1 findings that first raised questions about the impact of social context came from observing Grades 6 and 7 students deliberating in one of the classes. Their teacher had placed them into small groups based on the topic area of the individual ideas each student had generated for the city (e.g., transportation, recreation, and social planning), only pausing to separate two students with a history of conflict. Of five groups, two successfully navigated our deliberation process to determine which of their ideas to prioritize to develop further and submit to the city process. The teacher directly supported a third group, and I observed two groups, offering only a few nudges and reminders of the process described in scaffolding we provided. One group squabbled loudly and in good humour, teasing each other as they each wrote their own idea into a shared slide presentation, refusing to give priority to any of them. One student expressed his frustration to me as I passed, lamenting that his idea to fix a dangerous intersection should be more important than other transportation issues, but nobody was listening to him. The last group sat, in what two students later described as painful silence, before politely combining all their ideas into an unwieldy "dog park with food trucks and recycling centre" proposal. I did not collect any data to shed light on the transportation group's dynamic, but two student participants in the dog park group noted that they hardly knew each other and were used to working in friend groups, so were slow to start.

Initial analysis of student interviews, self-assessments, and observation notes in Phase 2 indicates that Grade 12 students may also have found deliberation to prioritize more difficult because of the social context of the classroom. Students engaged in five deliberations over five weeks, with regular formative feedback and self-assessment. In early deliberations, we noticed some students struggling to deliberate to prioritize when it involved eliminating other students' ideas or wishes. For example, when directed to generate just three priorities for their new mayor and council, half the groups submitted lists of ideas from all students in their group. In post-interviews, two students noted that deliberation seemed to get easier as everyone got to know each other better in the class.

Significance of study

When students in phases 1 and 2 were struggling to deliberate to prioritize, their teachers had to judge if this indicated less competency, lack of engagement, social pressures, or commitment to putting forth the best idea. Real socials contexts they emulated or simulated – strangers in a town hall meeting or world leaders negotiating at the United Nations – were not the only social contexts that appeared to be influencing students. That the social context in the classroom can initially impact competency to deliberate is aligned with work by Hauver et al. (2017), who interviewed Grade 4 students about how they navigated the social context when deliberating on an issue of authentic importance to them – how to spend playground equipment money at their school. The Hauver study did not include classroom assessment, but their interview process could offer guidance to Phase 3, in hopes that the next exemplar of practice generated from this study can offer some guidance in navigating simulated vs. classroom social contexts in designing and administering authentic assessments of citizenship competencies.

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Agile Design Research to Close Gaps: The Design of the Mentu Learning Platform

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Abstract: The Mentu Learning Platform is being designed to support high-quality learning in Latin America, focusing specifically on the needs of public schools that serve disadvantaged populations. With very promising results, we report on the design and implementation of the tool and highlight gaps from the actual product to the vision that is still under construction.

The Mentu learning platform

The percentage of students who are in learning poverty in Latin America is around 80%, an increase of 30% from pre-pandemic estimates (Saavedra et al., 2022). Mentu is a web-based tool that seeks to close educational gaps in Latin America, by offering high quality resources to both teachers and students, that are grounded in the Learning Sciences and in Learning Engineering (Goodell & Kolodner, 2023). We report on the design and results of a prototype of the platform used by over 4,000 students in 2022. Our vision is to expand the content to a full K-12 curriculum for Math and Language Arts.

Key elements of the design

The prototype was a replacement curricular unit on the topic of Fractions targeted to the 5th grade. The key elements are:

- **Gamification**: an animated narrative provides context and relevance for the learning activities; badges and points awarded for achieving learning objectives and desired behaviors (Kapp, 2012). *Vision: badges, medals, narrative and embedded games.*
- **Instructional sequence:** Grounded in the Teaching for Understanding model (Blythe, 1998; Wiske, 1999).
- **Pre and post tests:** standardized test administered using Concerto Platform (Oppl et al., 2017) at the start and end of the learning unit. *Vision: adaptive test that is used to personalize the upcoming content.*
- **Messing-about activities:** open and closed ended questions that introduce students to the topic, connect new ideas with what they already know and start engaging with the learning goals. *Vision: open-ended activities, digital and offline manipulatives, discussion, AI conversational agents, and student-directed planning of learning.*
- **Direct instruction and practice activities (*learning challenges*):**
- **Videos** 3-6 minutes of direct instruction. *Vision: interactive videos with embedded activities; on-demand video library.*
- **Infographics**: texts and images with explanations and multiple-choice questions. *Vision: embedded interactive manipulatives within the text; collaboration and discussion.*
- **Training**: closed-ended exercises ranging from operational fluency to word problems, with immediate feedback. *Vision: adaptive feedback and sequence of activities; collaborative activities.*
- **Reinforcement**: additional training and instruction for students who need it.
- **Formal Assessments**: series of word problems connected to the storyline. *Vision: adaptive test that gives access to badges for each standard.*
- **Synthesis activities:** seeks autonomous, self-directed application of learning in novel contexts. Synthesis activities use closed-ended and multiple-choice templates and thus share the challenges of assessing understanding with such questions (Wolf et al., 1991). *Vision: open-ended, hybrid, project-based activities that replace the current version of the synthesis.*
- **Social-emotional learning:** learning resources focused on learning how to learn, embedded throughout the learning journey on topics such as growth mindset, self-efficacy, note-taking and learning from videos.
- **Teacher dashboards:** Three types of dashboards were prototyped for teachers, providing both aggregate information at the class level and individual student data. *Vision: multiple dashboards and a range of available analytics coupled with interpretation support materials for both teachers and learners.*

Settings where implemented

3,500 students from 17 schools in Colombia in Fifth to Eighth grade, ages 10-16 for periods of 4-10 weeks. A survey was conducted before each implementation to understand users: used in computers and tablets; most schools have a computer lab –few use mobile devices; mobile devices are underused due to lack of wireless connectivity; devices shared by several classrooms; quality of connections and infrastructures vary greatly.

Description of each version

Version 1: 1,800 learners. Changes to the user interface, responding to feedback: interviews, focal groups, surveys and observation of user interaction recordings. Tweaks: added visual indicators of completed activities, added direct instruction on how to learn online, and improved data capture.

Version 2: 1,700 additional learners: standardized number of questions in the training exercises to 15; added support materials for those who did not demonstrate understanding; redesigned story and characters; implementation process in closer contact with schools and teachers, and an improved teacher training program.

Version 3: tested in 2023. New formats for instructional videos with improved motion graphics, and higher quality post-production; gamification: points for completion of activities and correction of responses.

Outcomes

In version 1, the standardized difference between post and pretest was 0.17, encouraging yet small. Additionally, students reported that they enjoyed using the platform (75%) and that they would like to use it every week (90%). For version 2, we found that the iterative improvements were fruitful: the standardized difference was 0.70. We are currently analyzing data to better understand the impact of each design change and continue improving.

Conclusions and next steps

Educational interventions that seek to improve the quality of learning tend to be complex and take very long times to design, implement, test and finally scale. Most never reach this last step. After decades of introducing computers in schools, technology in education has fallen short of its promise (Cuban, 2001; Reich, 2020). Yet, millions of children around the world are currently attending school and not learning. Agile software and business development methodologies, combined with Design Research focused on learning impacts, has the potential to create solutions where we have failed before.

Figure 1
Learning Journey

The learning journey includes animated storyline videos, instructional videos, infographics, practice exercises with feedback and assessments.

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Examining Active Learning Teacher Education Classroom Activities Using the ICAP Framework and Suggestions for Future Enhancements of ICAP

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Abstract: Active learning currently lacks a model to describe classroom activity design and sequencing. Chi et al. (2018) has offered the ICAP Framework to describe active learning. To test ICAP, we applied the framework to the observations of two teacher educators teaching. Analysis found that ICAP lacks descriptive capacity when different engagement levels occur simultaneously and that ICAP lacked prescriptive capacity to guide class sequencing.

Introduction

Provincial and state education systems have recently pivoted to 21 Century Competencies as important curricular outcomes. However, meeting these competencies while also meeting content-focused learning objectives is challenge for K-12 teachers who receive little guidance regarding how to integrate the 21 Century Competencies. Active learning may be a means to meet this challenge while also supporting pro-social components of schooling such as cultural responsiveness, inclusiveness, and social justice (Haak et al., 2011; Segarra et al., 2018). One possible site for integrating active learning into education is investigating how teacher educators (TEs) induct teacher candidates (TCs) into active learning under the assumption that this induction will encourage TC to use active learning in their careers.

Chi et al. (2018) has offered the ICAP Framework to define "active learning", which includes four levels of activity (interactive, constructive, active, and passive). *Passive* represents students listening without manipulating the information; *active* is where students work with information only using the information within the current lesson; *constructive* is where students are manipulating information and connecting that information to other knowledge outside the lesson; and *interactive* is where students are engaging in constructive thinking with others. Chi argues that these various levels can be assessed by observing student work and behaviors (e.g., worksheets, mind maps, debates, conversations, etc.) to determine if students are making interconnections between knowledge. In ICAP these interconnections are thought to avoid encapsulation of new knowledge. This allows the new knowledge to be applied more broadly and retrieved more easily.

This paper examines if ICAP's present form can serve as this set of guiding principles for active learning. Thus, we apply the ICAP Framework to two case studies of teacher education classrooms.

Methodology

The Teacher Educators (TEs) in this case study, Emma and Anna (pseudonyms), were selected because they described themselves as "active learning educators." Both were teaching discipline-specific educational praxis classes (Music and Science pedagogy, respectively) in a Central Canadian two-year masters-level teacher certification program. Their students were in their final year. We conducted three classroom observations totaling of 9 hours of observation per TE. This represented a quarter of the TEs' total class time for the semester. The observational data was analyzed according to the ICAP Framework.

Addressing difficulties in using ICAP to assess classroom behaviors

While the ICAP Framework appeared superficially clear, it became apparent in observations that it was common for multiple levels of ICAP behavior to exist simultaneously. For the purposes of reporting findings of class behaviors (next section) the highest behavior level seen was reported.

Findings

Case 1: Emma

Background: Emma was a teacher in grade 9-12 Music, Drama, and English for fourteen years, and a TE in music pedagogy for more than ten years. She is a tenured faculty member within her university department.

Observations: It was common for Emma to move across the ICAP Framework continuum and for her class to have many discussion-focused activities or individual-thinking activities. For example, one of the observed classes showed the instructional sequence of: 40 minutes in interactive level, 20 minutes in the constructive level, 10 minutes in the active level, 10 minutes in the constructive level, and finally 25 minutes in the active level. When the nine hours of observed class time were evaluated against the ICAP Framework, Emma spent: 24% of her classes in interactive; 27% in constructive; 46% in active; and 3% in passive.

Case 2: Anna

Background: Anna taught junior and intermediate English, Science, and Math for three years. As a TE she has been educating TCs for four years in Junior/Intermediate Science Pedagogy classes.

Observations: The classes observed for Anna were design-based learning focused. Anna also moved through various ICAP levels. For example, one of the observed classes showed the instructional sequence of: 40 minutes in the constructivist level, 5 minutes in the passive level, 35 minutes in the interactive level, 10 minutes in the active level, 10 minutes in the passive level, and 70 minutes in the interactive level. When the nine hours of observed class time were evaluated against the ICAP Framework, Anna spent: 46% of her class in interactive; 33% in constructive; 10% in active; and 11% in passive.

Discussion

Our observations support ICAP as a helpful, if incomplete, descriptive tool for determining if active learning is occurring. However, the ICAP Framework cannot account for variation of activity between students during some activities. For example, in situations where the TC students are engaged in different levels of activity at the same time, as with a TC student presenting to a class, the presenting student is operating at a different ICAP level than students who are listening. The same can be said for interactive-level (group) activities where TC students are engaging at different ICAP levels within the group. Less engaged students may be operating at an ICAP level of *active* while students who are more engaged may be operating at the *interactive* level. During group activities, this type of behavioral difference was observed within and across groups. In situations where different engagement levels are occurring simultaneously, it is unclear what the granularity of an ICAP-level rating should be (e.g., class level, activity level, student level, or highest level observed).

Another problem in ICAP is that there is no guidance regarding how much of each ICAP level is considered ideal. In Chi et al (2018), the authors clearly favor interactive- and constructive-level learning while being dismissive of the effectiveness of passive and active learning levels. This implies that ICAP sees little value in the passive and active levels of student activity. However, our TEs used activities that elicited all levels of student activity at various points of their teaching, and it is hard to imagine a class that entirely avoids any active- or passive-level instruction. Chi does argue that higher levels of ICAP subsume lower levels, however that is not what was observed within our study as the TEs had clear divisions between their instructional usage of each level. Thus, the question of what amount of each ICAP level is ideal is left open. Due to this, the prescriptive element of ICAP for class instructional design appears limited because the framework cannot provide an expression of what instruction *ought to be*, but rather can only provide an assessment framework for what the instruction *is*.

Conclusion and recommendations

While ICAP is a useful descriptive framework for determining the active learning behaviors elicited in a class, it cannot currently explain what ratio of the ICAP levels is ideal, or adequately express how to represent situations where multiple ICAP levels are occurring simultaneously. Further, our case studies show that exclusively operating at high levels of ICAP is not the behavior of our observed TEs, and it may not be achievable. Elaboration of these issues presents a rich target for the expansion of ICAP and could allow it to move from its present descriptive framework to a more useful prescriptive framework.

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Addressing Challenges in Creating a Community of Practice for Youth Advisors to Co-Design Health Research

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Abstract: Establishing domain, community and practice in a health-related community of practice consisting of youth advisors present challenges. Addressing challenges of involving young people in co-design makes it possible to combine online and in-person interactions to form a community of practice of knowledge-sharing benefiting both youth and researchers. A youth health community of practice facilitates connections and exemplifies an effective way of engaging youth as active partners and learners in the research and development process.

Background and aims

In global chronic disease discourse, most adolescents feel their voices are tokenistic (World Health Organization, 2017). Subsequently, health research has increasingly involved co-design including consumers throughout the research cycle (NHMRC, 2016). Youth must be 'engaged and empowered' to improve their health (UNICEF, 2020), doubling as a learning experience for them. However, establishing a youth health research community of practice poses challenges.

We led the Health Advisory Panel for Youth at the University of Sydney (HAPYUS) (Valanju et al., 2022). HAPYUS, consisting of sixteen youth advisors aged 13-18 years inclusive, was established in 2021 to advise research teams on adolescent chronic disease prevention. The first author was the first youth advisor in 2019-2020 and is now an undergraduate student and research assistant in the last author's research team. The last author is HAPYUS' assembler and leader. HAPYUS collaborated online through the application Slack during Australia's coronavirus lockdown, with online platforms being the most accessible interaction method for members living in regional areas. Nevertheless, youth advisors wished to interact in-person, which became possible with funding and a relaxation in coronavirus restrictions. In July 2022, we ran an in-person youth health research workshop for HAPYUS with Charles Perkins Centre. We aimed to co-design adolescent health projects, while introducing youth to research. Our research question was – how can we address challenges in coordinating the youth health research workshop within the community of practice framework? In this poster, we will diagrammatically answer this, featuring "a process of collective learning in a shared domain of human endeavor" (Wenger, 2009) with the community of practice framework's three elements - domain, community and practice.

Method - addressing challenges using the community of practice framework

1: The domain

The first element of a community of practice is having an identity defined by a shared domain of interest. While youth advisors were selected based upon their youth health interest, this does not in itself establish a community of practice. We addressed the challenge of establishing the requisite shared nature of the youth chronic disease prevention research domain through Slack. While online engagement is often seen as sub-par (Tice et al., 2021), it meant the shared domain of youth health issues was already established in a comfortable environment before the workshop - particularly helpful for youth who may lack the confidence to immediately engage face-to-face.

Figure 1

Diagram Representation of Youth Advisor Community of Practice Challenges and Solutions

2: The community

The second element of a community of practice involves shared interaction and learning together. HAPYUS had challenges in establishing community as youth advisors have inherent characteristics to consider – most are minors, geographically scattered due to the community's distributed nature, and have competing secondary school commitments. Additionally, building upon the domain established online to create a community is more effective in person, as learning community decreases online (Nubani & Lee, 2022). Since youth advisors were minors, they had to be financially supported by Charles Perkins Centre to potentially come with a parent/guardian, especially from regional areas. Moreover, the workshop was held in school holidays, away from standardized testing periods to avoid interfering with formal education. Furthermore, communities reproduce themselves with new members that subsequently become future community leaders (Barab & Duffy, 2000). We are evaluating how to sustain this community, with youth moving onto employment or further study. However, given that the first author was a youth advisor before HAPYUS and subsequently co-ran the workshop, community reproduction has potential.

3: The practice

The third element of a community of practice is shared practice and resources, requiring sustained interaction and time (Wenger, 2009). In the workshop, youth advisors co-created a community-based text message intervention for improving adolescent physical and mental health – 'HEALTH4ME'. Youth advisors created a message bank in groups based upon priority areas and determined the intervention's scheduling. Establishing shared practice and resources with young people can be challenging. Youth have unique insight into their own lived experience but are not research experts. Furthermore, engagement is required for sustained interaction - difficult in a day-long workshop. Hence, youth advisors were accompanied by two external researchers per group who did not participate in co-design but guided them, providing research expertise necessary in practice for youth to learn and contribute. For motivation, we conducted a scavenger hunt led by the first author around the university campus of the workshop with prizes as a break, and a networking lunch to meet researchers in a casual format - much more effectively conducted in-person than online. Youth advisors were thus motivated and guided in practice.

Conclusion and future directions

After the workshop, HAPYUS created a private Slack channel by themselves without researchers, but included the first author who was only a year older than some of the youth advisors. This suggests there may be value bridging the gap with young people as researchers in an intermediary role alongside established academics. This facilitates knowledge-sharing more effectively than if the student and teacher of research were strictly separated.

HAPYUS was a pilot study. We received a Medical Research Future Fund Consumer-led grant to recruit many more adolescents for future iterations – researchers in partnership with youth will continue to shape this community of practice. We welcome insights into how we can improve this community of practice through a poster link for anonymous feedback or contact details for asynchronous communication.

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Characterizing Problem Solving Discourse During Middle School Students Rubik's Cube Play

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Abstract: This study characterizes problem-solving discourse of middle school students as they worked collaboratively to solve the Rubik's Cube. In our analysis, we developed 12 categories to characterize students' problem-solving discourse. Results indicate the dyads approached the problem-solving task very differently, a reflection of the problem task's complexity and the diversity of students' organic approaches to collaboration and discourse.

Introduction

Next Generation Science Standards (2013) emphasize the importance of training scientific problem solvers and providing a curriculum that teaches science and engineering problem solving practices. Effective science and engineering education practices are those that provide foundational theoretical knowledge while providing opportunity for utilization of skills to develop authentic learning practices (Wang et al., 2013). Overall, this combination leads to a more meaningful learning experience. Over the years, learning through problem solving has become a widely used pedagogical approach to help students extend their knowledge and understanding by providing them with the opportunity to apply it in a real-world context (Wang et al., 2013). However, experience and knowledge alone are not sufficient in creating expertise. A study on expertise development suggests that one would need to be able to contextualize and create the mental processes involved in the actual problem-solving practice to develop expertise (Ericsson, 2008). Our study would like to give an opportunity to students to be critical and creative problem solvers. We are doing so by allowing students to choose their own partner (working in a dyad) to try and solve the Rubik's Cube without any guidance. Our study focuses on examining students' problem-solving discourse as they are engaged in the Rubik's Cube play.

Theoretical background

In problem solving literature, a problem is defined as a goal-oriented task where multi-step action is needed to reach a desired goal (Duncker, 1945; Newell & Simon, 1972). These multi-step actions are elaborated more by Goel and Pirolli's (1992) framework by describing that problem solving activity involves four different sub-steps. These steps are as follows: first, problem exploration and decompositions, second, identification and interconnections among the components, third, finding a solution to the sub-problem, and fourth, synthesizing the partial solution into the problem solution. We chose this definition because the problem space of a Rubik's Cube is complex. It encompasses various parts of the cube and requires multiple steps of sub-goal completion. While the goal of the Rubik's Cube solved pattern is having each of the sides being a single color, the solution is not immediately apparent. There are many configurations that can be utilized in solving a Rubik's Cube (Korf, 1997). Due to the problem-solving complexity that is embedded within the cube, we thought Rubik's Cube would be the right platform to explore middle school students' problem-solving discourse. Hence, this study is interested in investigating and characterizing the types of problem-solving discourse that middle school students engage in as they are solving a complex puzzle such as the Rubik's Cube. In this study, students work collaboratively in dyads on solving the Rubik's Cube without any guidance from the classroom teacher and/or the researchers.

Methods

We recruited 40 middle school students from a diverse, urban middle school in the United States. Students picked their own partner where they sat side by side. Each of the tables in the classroom was equipped with two action cameras where students were video-taped and audio-recorded. Each of the students were then given a Rubik's Cube that had been scrambled in the same exact configuration. The study was conducted in 45 minutes (one class period) during the students' science class. The set-up of the cameras, picking a partner, and distribution of the Rubik's Cube took about 20 minutes. The students were then given a total of 25 minutes to think-out-loud and work collaboratively with their partner to solve the Rubik's Cube. The audio data was transcribed verbatim. The video data is analyzed to examine the students' gestures and the manipulation of the Rubik's Cube. For this paper, we selected three illustrative cases of dyads chosen based on the amount of productivity, task related discourse, and conversational turn taking. Through an emergent coding process and iterative cycles of reliability check-ins, we created a coding scheme and developed 12 categories that characterize students' problem-solving discourse during the Rubik's Cube activity.

Results

Our research question is: What types of problem-solving discourse do students engage in as they solve a complex puzzle such as the Rubik's Cube? To address this question, we developed 12 categories and calculated the percentages of each of the dyad's discourse (see Table 1). Table 1 shows the three dyads engaged in goal setting/planning roughly the same amount. However, there is a difference in students' reflection. We found dyad 1 utilized the most spatial language to describe the orientation of their Rubik's Cubes' pieces and colors. However, dyad 1 has the lowest percentage of observation (status update), meaning they did not inform one another regarding their individual progress as often as others. Dyad 2 had the lowest rate of observation (spatial consideration), but the highest in observation (status update). This means they did not utilize spatial language to describe their observations but were the most engaged in informing one another regarding their progress. While all dyads were engaged in strategy sharing conversation, dyad 3 spent more of their time engaged in this category. Dyad 3 decided to turn their cubes in the same way, ensuring both cubes were always kept in the same configuration, thus resulting in more strategy sharing. All dyads discussed the difficulties and complexities of solving the Rubik's Cube. However dyad 2 exhibited the highest percentage of engagement in the categories of intentional teaching and requests for assistance compared to others. This is because one of the students in dyad 2 solved one side of the cube within the first three minutes of being handed the cube while their partner struggled. Hence, the struggling partner requested assistance many times resulting in higher engagement in these categories.

Table 1
Percentages of each category of discourse from three dyads

	Code title	Dyad 1	Dyad 2	Dyad 3
1	Goal setting/planning	10.07%	7.32%	9.55%
2	Reflection (prior knowledge)	13.18%	0%	0%
3	Reflection (prior strategies)	2.33%	1.22%	3.37%
4	Observation (spatial consideration)	17.83%	2.44%	12.34%
5	Observation (status update)	3.88%	17.07%	15.17%
6	Strategy sharing conversation	13.18%	9.76%	19.10%
7	Intentional teaching	5.43%	9.76%	1.12%
8	Request for assistance	0%	10.98%	1.69%
9	Articulation of challenges	13.95%	8.54%	10.67%
10	Behavior/discourse clarification	8.53%	12.20%	8.43%
11	General conversation	5.43%	12.20%	15.73%
12	Conversation with researchers	6.20%	8.54%	2.81%

Discussion

Our study found the three dyads in our study took a very different approach to solve the complex problem. Dyad 1 used a lot of their prior experience and knowledge. One of the partners in dyad 2 relied heavily on their partner for help. Dyad 3 decided to execute every move in exactly the same way. These three different approaches provide unique insight into understanding how students engage in a complex problem-solving process. While our students showed that they took on the problem-solving steps described by Goel and Pirolli (1992), this study allowed for the examination of these processes at a more micro level. We were able to witness the goal setting process take place, including how often students modified their goals throughout the task based on their observations of the cube. Students articulated challenges, discussed, and developed new strategies to solve the cube, as they were moving through the different stages of problem-solving discourse. These findings provide insight to the importance of student discourse and collaboration when presented with a complex problem-solving task.

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The Presence of African Voices in Building and Sustaining the Learning Sciences Knowledge Community

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Abstract: This paper critically examines the building of knowledge and sustaining of community in the learning science. We explore the presence of Afrikan voices in the Learning Science and question whether the ISLS community is engaged in epistemological violence. Our findings indicate that the Afrikan voice is present in the ISLS community but there are imbalances in terms of which journal these voices are heard.

Introduction

The world is diverse, composed of different life forms – of which humans are one. As human beings, we can have different epistemologies, axiologies, and ontological perspectives. Does our ISLS community reflect this richness of diversity? This question can be asked, especially regarding the ISLS conference. The theme for the 2023 year's annual meeting, "Building knowledge and sustaining our community," demands the ISLS community to engage in "strengthening the theoretical basis for social and computer-mediated practices for teaching and learning,", especially in light of "growing opportunities for digital and social media for knowledge building among teachers, researchers, and learners."

Our paper focuses on the building and sustaining, which anchors the call. We aim to critically explore the 'who' in building knowledge and the "what" in sustaining the community. This critical examination is essential because it calls for the community to reflect on the richness of our world. Moreover, it is through such examinations that we can answer the concerns about whether our work "could be labeled epistemological racism" (Scheurich & Young, 1997, p.4) or reflect what Spivak (2015) termed epistemological violence whereby some exist only in shadows unable to speak.

One of the spaces in which the building and sustaining of community occur is in our journals. At the 2016 ICLS Conference, Ludvigsen et al. (2016) argued that the vision for the future of the field must include ensuring that "the journal receives a high number of research papers that can challenge the frontiers within the field of … the learning sciences" (p.17). We argue that although the high number is great, the diversity of voices is equally important. Although the learning sciences is a global community, there are regions in the world, such as the Afrikan continent, that are still not well represented. Therefore, long-term efforts should include promoting the field and creating targets for the near future (Ludvigsen et al., 2016) to increase contributions and advance the field.

In the six years since Ludvigsen et al.'s observation, we have noticed increased work related to social justice and representation. Many members of the community build on the rich traditions of equity-oriented scholarship across many disciplines to explore how social stratifications, racial and cultural backgrounds infiltrate classrooms; hinder learning, and recreate inequities (Uttamchandani, 2018); thus, expanding the learning sciences community.

Building on this move toward equity and on the desire to expand and strengthen the presence of other regions in the learning sciences community, we examined in this paper the presence of Afrikan voices in the field. We used the term Afrikan voices to refer to research conducted in any Afrikan country and published in any of the major journals in the field. This review, therefore, explores the question of Afrikan presence in the learning science scholarship by examining the number of research conducted in Afrika that make it to the learning sciences journals.

Methods

Drawing on Ludvigsen et al. (2016) argument about the need to increase the number of research papers, we contend that publications in some of the prominent journals in the field are a good measure of Afrikan presence in the field. For this reason, we focused on four journals: Information and Learning Sciences, Journal of the Learning Sciences; Instructional Science; and International Journal of Computer-Supported Collaborative Learning. These journals were selected because they either have Learning Sciences in the title or were endorsed by the learning sciences international society on their website.

To address our main research question, we performed a literature search in the four journals using terms such as Africa, and/or African. Articles published between 2016 and 2022 were searched. This period was selected because it corresponds to Ludvigsen et al. 's (2016) call for a greater presence of other regions worldwide.

Inclusion and exclusion criteria

Articles were included if a) the study was conducted on the African continent; and b) the publication year fell between 2016 and 2022. Papers were excluded if the research was conducted outside of the African continent and did not fall within the timeframe selected in this paper. The search yielded 39 articles, and our findings are discussed below.

Findings

Our results show that 39 papers were published in the four journals included in our review. The details are presented in table 1 below.

Table 1
LS articles focusing on Afrika

Journals	Number of Articles
Information and Learning Sciences 1	37
Journal of the Learning Sciences	1
Instructional Science	1
International Journal of Computer-Supported Collaborative Learning	0

The findings convey that African voices are present in the learning sciences but are not evenly distributed across the different journals. Based on our research, the Information and Learning Sciences journal has published the highest number of articles, accounting for 95% of the articles we reviewed.

Conclusion and future research

Returning to our earlier premise, the conference theme provides us with an opportunity to ask what knowledge is being built and what community is being maintained in the learning sciences community. In this paper, we focused on the Afrikan region and explored if the voices of Afrikan scholars, which we refer to as the Afrikan voice, is present. We conclude that Afrikan voices are present in the learning science, but there is a heavy tilt on where these can be heard.

Our aim in this paper was not to compare the quality of the journals in which Afrikan-related articles are published. However, it is worth stating that the two journals most promoted by the ISLS community have the least publication from or about the continent. Building on Spivak (2015), though we do not have enough data to present causation, we argue that the data reveal a form of epistemological violence whereby the "subaltern" although "can speak and know their conditions," (p. 78) have voices in one journal and appear ominously mute in others.

In this submission, we present a brief accounting of the Afrikan voice in the learning sciences while at the same time contributing to the call for a more diverse building of knowledge that we can then sustain. This building and maintaining, if it is to be equitable, must include a critical examination of why some are in the shadow and the margins. While the paper focuses on Afrika, we are aware that this is not the only voice in the shadow. Hence our future research will expand this research to see which voices are dominant in the learning sciences and which voices are silent. We also intend to examine the articles we found focusing on Afrika to discern the methodological and theoretical stances informing the research.

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Deadline Extensions as Public Pedagogy: Envisioning the Ethics of Care in Academic Conferences

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Abstract: Research into the role care plays within processes of learning has largely overlooked the pedagogical implications of this work within academic conferences. In response, we present emerging findings from a duoethnographic study of our responses to the final deadline extension to this conference. Our findings indicate that extending the deadline of conference proposals represents a compassionate public pedagogy, albeit one with contested ends.

Introduction

Care refers to and defines the behaviors and relationships between individuals in learning contexts (and otherwise) that emerge from a concern for the feelings and needs of others (Noddings, 2012). Within extant literature into the work of academic researchers, scholars largely position care as either a research framework to work towards (Shefer, 2020; Vasudevan et al., 2022) or a tool that defines the socioemotional aspects of professional development (Bozalek & Winberg, 2018). Building on this foundation, we turn towards the public pedagogies of academic conferences as another space to explore the education praxes of an ethics of care. Here we draw on Giroux's (2004) definition of public pedagogy, or the process of informal and incidental learning that potentially presents a subversive response to dominant narratives perpetuated within public media. The circulation of public messaging by academic conferences, for instance, potentially represents a form of public pedagogy because of its ability to undermine the overwhelming narrative of academia being a cutthroat institution where intellectual laborers need to constantly produce new knowledge, allowing conference attendees to develop a new understanding of academic identity through this incidental process.

Drawing on these complementary bodies of literature, we respond to the following research question: how do conferences deadline extensions contribute to the ethics of care within public pedagogy? And what learning opportunities emerge in response? To address this question, we conducted a duoethnography in response to the final deadline extension for this conference by exploring our own reaction to the announcement. Our findings reveal that the announcement acted as a means to extend an ethics of care, one that embodied a public pedagogy through the production of spaces for further knowledge construction and identity development.

Methods

For this study, we rely on a duoethnographic research design (Norris & Sawyer, 2012). Duoethnography positions researchers themselves as the research site through autobiographical writing and other forms of self-reflective data collection but expand the scope of research beyond an individual experience through a comparison across researchers (Rose & Montakantiwong, 2018). Drawing on an embedded challenge to post-positivistic framings of qualitative research (e.g. limiting researcher bias, establishing validity), this study "portray[s] knowledge in transition" (Norris & Sawyer, 2012) related to our shifting understanding of the pedagogical possibilities of deadline extensions that emerged through analysis. The two researchers (Peter J. Woods and Colin Hennessy Elliott, both early career scholars who have attended the conference 3 and 4 times respectively) created personal narratives in response to the final extension announcement that shifted the deadline by 24 hours. We then shared these narratives, asking questions and challenging perceptions of each other, before drawing out three themes (relational core, pedagogical space, and disciplinary identity development, with each described in detail in the findings and discussion section) from moments of overlap and juxtaposition via an open and emic approach. Again drawing on duoethnography, we center on the depth of understanding that emerges through a critical and thorough exploration of these two rich narratives rather than searching for validity through a broad data set (Norris & Sawyer, 2012). We therefore provide insight into an emergent framing of the role of care within the public pedagogies of academic conferences and their organizational praxes.

Narratives

In response to the extension announcement, we produced the following narratives. They are presented here with minimal editing due to limits on the length of submission.

Narrative from Woods

The extension came as a huge relief. I caught it after working on a symposium that was being a giant pain. Having the extra space to work was great, and not just from a logistics perspective but from an intellectual perspective as well. The extra time, on a certain level, feels like an invitation to dig deeper into ideas, to create new pathways to explore, and develop new ways of engaging with what has already been engaged. In this sense, it also feels like an invitation to identify the work I want to do with the field I am slowly engraining myself in and speaks to the ethics of the organization. The fact that it was framed as a response to the hardship of completing things on time speaks to the commitments of the organization, one that goes against the hyperproduction inherent to modern academia and makes me appreciate/identify with the organization even more.

Narrative from Hennessy Elliott

I first heard about the extension of the deadline from a message from a collaborator. I was not able to spend the amount of time working on our paper that I had wanted the past weekend. I felt relief with the realization that I could spend the next morning making changes and spending time with our argument. The extension meant I could sleep on it, instead of working through the later evening and early morning up to the deadline. Getting to sleep after getting my children to sleep was a gift that this extension gave me. The gesture of the extension felt like an invitation to spend a little bit more time on our submission to make it even better. As others may pose, that little bit of extra time could have been spent if planned for differently. Yet, this extension and previous extensions offer a view of deadline flexibility which opens more intellectual space to consider our relationship with the society and the conference itself.

Findings and discussion

Through our emergent analysis, we produced three themes related to an ethics of care within public pedagogy. First, the narratives position the extension within the *relational core* of an ethics of care (Noddings, 2012). While Woods names this explicitly, stating that the extension "speaks to the ethics of the organization," Hennessy Elliott embeds this notion when he states, "getting to… wake up the next morning to do the final edits was a gift that this extension personally gave me," highlighting the relational nature of this decision. Second, this ethics of care created *pedagogical space* to construct new knowledge. As Woods says, the extension allowed them to "create new pathways to explore and develop new ways of engaging with what has already been engaged." Hennessy Elliott related this theme to an ethics of care when he claims that "finding this out meant I could sleep on it, instead of working through the later evening," aligning the pedagogical nature of this work with public pedagogy's inherent challenge to the domineering nature of institutions (Giroux, 2004). Third, the narratives align with Shefer (2020) by framing the ethical and pedagogical impetus of the extension with *disciplinary identity development*: Woods claims that "it also feels like an invitation to identify the work I want to do with the field" while Hennessy Elliot states the extension provided "more intellectual space to consider our relationship with the society and the conference." In turn, the conference extension, a choice positioned within an ethics of care, produced a pedagogical space intertwined with these ethics. These emergent findings therefore illuminate the public pedagogies of academic conferences, revealing how messaging and organizational choices contribute to the ongoing learning processes of academic communities.

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Disinformation as an Emergent Phenomenon: An Agent-Based Modeling Curriculum to Address Fake News

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Abstract: To help youth develop the ability to identify disinformation and impede its spread, we constructed a curriculum unit composed of Agent-Based models that simulate the spread of disinformation in both in-person and online environments. Preliminary evidence shows that learners reflect on cognitive biases upon guided interactions with the models, and that participants seemed to connect the skills addressed in the models to real-life situations.

Introduction and theoretical background

We developed an agent-based computational modeling (ABM) unit to support learners in reflecting on the cognitive processes and systemic phenomena associated with disinformation. The spread of disinformation is well-suited for ABM: it is challenging to conduct experiments in the real world, some of its effects are non-linear, and it involves several actors and relationships (Starbird et al., 2019). Russo and Blikstein (in press) describe the models and their design specifications. Our tool leverages the affordances of ABM and visualization to examine the effect of cognitive biases, social connections, and fact-checking behaviors on disinformation spread. Those factors have been associated with media literacy, and research has recommended their development as part of the efforts to confront digital extremism (Rea, 2022). This poster is part of a larger research project (Russo, Blikstein & Penalva, 2021; Russo & Blikstein, 2022) that aims to investigate causes and approaches to deal with the impacts of disinformation fueled by contemporary media practices. In this poster, we focus on ways in which the models promote reflection about (1) cognitive biases at play when we consume media and (2) phenomena experienced by participants in real life.

Methods

We extend Rand and Wilensky's (2008) computational models to reproduce the spread of disinformation. We designed and tested a sequence of 4 new NetLogo models that allow for exploration of causes and implications of disinformation spread. In this poster, we focus on cognitive biases, fact-checking behavior, information channel, and average number of connections within the population. We interviewed 4 US undergraduate and graduate students (22 to 24 years of age). One-hour Zoom interviews began with general questions regarding participants' media consumption habits, their understanding of disinformation, and their understanding of bias in information spread. Participants then opened and explored the models in sequence. The interviews were audio- and video-recorded. Researchers took notes during the interviews and while rewatching the recordings, and defined emerging themes (Charmaz, 2006). Those notes were then analyzed for interaction with the NetLogo models and potential learning outcomes.

Preliminary findings

Intuitive conclusion as part of an insightful discussion

Among the models' features, cognitive biases were the most frequently discussed by participants. Remarkably, before interacting with the models, only one participant (Xue, pseudonym) stated that bias assessment was one of the standards that she uses to detect "fake news." All 4 participants manipulated the "bias" slider to verify its effects on the model's behavior. One participant (Yeong, pseudonym) concluded that, predictably, when bias goes down, the spread of disinformation is "much, much lower." That conclusion, albeit intuitive, was embedded in a broader discussion about the nature and implications of biases, which highlights the essence of instruction supported by agent-based modeling: the interaction enriched a conversation that potentially led to the type of insight that the models aim to instill in the learners. This is illustrated by the following dialogue:

> **Researcher:** Do you want to adjust the level of biases to check your idea [about biases]?
> **Yeong:** I can test the bias first. So now that the bias is lower. [...] the information is not spreading as fast [...] I'm thinking about the reason. Is it because people have already set their way of thinking? Wait, they're not that set in the way of thinking as there is less bias. So they're more able to analyze the situation in a more logical manner, and not just believe, like, information that they think is likely to be correct.

As we see, upon the researcher's cue, Yeong starts to experiment with the bias control and notices how it changes the model behavior. While he observes the model, he starts to draw conclusions about biases and their effects on people's disposition toward new information. Here, the model does not explicitly tell what biases are. Instead, it provided a visualization of the phenomenon and generated reflection by the learner.

Association between interacting with models and understanding real-life phenomena

Some participants engaged with the potential of the models to explain lived experiences. Upon interaction with the models, Eliot asked for further explanation about cognitive bias in news reporting. During that part of the dialogue with the researcher, he connected the model's results with prior real-life experience, namely linking bias with his grandmother's understanding of COVID-19-related news. In his concluding reflection, Eliot expressed increased awareness about how powerful biases can be and how some media outlets might exploit them. He provided an example of connecting with his family members through social media and instant messaging platforms, and the need to verify the news they read on those channels. He said: "It makes me feel how differently I would feel if I couldn't directly talk to my family or my family [couldn't] directly communicate with me to see what's *actually* going on." This tendency demonstrates the potential of the models as learning tools, and a similar tendency has been found in other testing situations. For example, another participant reflected that she didn't expect that "things would spread so much faster in social media and instant messaging than in in-person communication." A third participant was surprised by the effectiveness of fact-checking in controlling the spread of disinformation. Although those conclusions do not represent the *only* possible scenario – which was emphasized by the researcher – they reinforce the well-documented ability of agent-based modeling to instill reflection about phenomena in a way that would be less likely to happen otherwise (Tseng & Son, 2020).

Discussion and future directions for research

In this project, we employ ABM to develop a learning experience about disinformation. We explore the affordances of ABM to simulate scenarios containing networked communication and emergent phenomena. Interaction with the models potentially affords the emergence of understanding that can be much harder to achieve using direct instruction. By testing the unit, we gained insight into its potential: we verified that the models facilitated discussion and reflection on cognitive biases and their implications in real life. Learners also reflected on the effects of fact-checking. In advancing this research project, we understand that improvement is needed on the demographics of the sample so that it reflects audiences beyond post-secondary students in the US. We also plan to refine the design of the models in a way that emphasizes non-linear effects associated with different factors and develop a research design that allows learners to conduct more sophisticated experiments with the models.

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Understanding the Influence of Stereotypical Perceptions of Scientists on Middle School Students' Science Achievement

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Abstract: Stereotypical perceptions of scientists are often thought as important influences on learners' future pursuit of science careers, but less research has focused on more proximal learning outcomes, such as middle school science achievement. In this study, we used the Draw-A-Scientist Test to identify commonly held stereotypes among middle school students about scientists. We then examine the potential relationships between these stereotypes and student performance in their science class.

Background

Research in the learning sciences aims to understand how attitudes, beliefs, and stereotypes about scientists and science impact learners, particularly in STEM fields (Potvin & Hasni, 2014; Osborne et al., 2003). Stereotypical imagery of scientists and scientific knowledge generation, internalized by learners, may explain why American universities struggle to retain STEM students, especially those from underrepresented minority groups (Whalen, 2016). The Draw-A-Scientist Test (DAST), a visual data tool, is used to elicit learners' beliefs about science (Chambers, 1983). The DAST checklist, comprising 16 indicators, is used to analyze student drawings of scientists (Finson et al., 1995). Despite numerous studies showing persistent stereotypes of scientists as men in lab coats working in laboratories (Ates et al., 2021; Ferguson & Lezotte, 2020; Meyer et al., 2019; Thomson et al., 2019; Miller et al., 2018), less attention has been given to the role of these perceptions in learning outcomes, such as academic achievement in science class. Researchers in this study sought to address how stereotypical representations of scientists held by science learners influence their academic achievement in middle school science classes.

Method

Study context

This study is part of a larger research project funded by the National Science Foundation, which aims to expand the understanding of culturally responsive teaching and technology integration on middle school students' engagement, attitudes, and achievement in science. The project included multiple schools in the Midwest, but this study focuses on data collected from students at one urban middle school in the region.

Participants

Participants in this study consisted of 42 students taught by two middle school science teachers. Of the 37 participants for whom demographic data was available, about a third (29.7%, n = 11) identified as male and two-thirds (64.9%, n = 24) as female, with two students (5.7%) responding with "Prefer not to say". In terms of race/ethnicity, about half of these individuals self-described themselves as White (56.9%, n = 21), with the remaining participants (43.2%, n = 16) describing themselves as another race/ethnicity (e.g. Asian, Black/African American, etc.).

Data sources

We used the DAST-C checklist, adapted from Finson et al. (1995), to measure middle school participants' stereotypical perceptions of scientists. The checklist includes indicators such as lab coats, eyeglasses, and symbols of research. Coders evaluate students' drawings by indicating whether each indicator is present or absent. The DAST-C typically calculates scores based on the quantity of indicators present, but we grouped the 16 indicators into three categories: *Scientist Appearance*, *Scientific Context*, and the *Nature of Science*, based on thematic similarities.

We collected gradebook data for student participants of this study with assistance from our middle school science teacher collaborators. Students at this school were graded quarterly based on the percentage of total points earned on assignments, quizzes, etc. Seeking to generalize our measure of academic achievement across the entire academic year, we calculated the average value of students' percent grade between the four grading periods. These values were used in the linear regression analysis described in the following sections.

Results and discussion

Following these descriptive analyses, we then fitted a linear regression model to predict students' yearly grade based on their scores on the three primary categories of DAST indicators (i.e., *Scientist Appearance*, *Scientific Context*, *Nature of Science* scores). The model was fit using Ordinary Least Squares estimation methods. Although we did observe a few potential outliers, there was little substantive reason to remove these 4 observations from our data, and the assumptions of OLS regression appeared to be reasonably met regardless. Thus, the model was fitted using all 42 responses. See Table 4 for coefficient- and model-level summaries.

Table 4
Coefficient Estimates and 95% Confidence Intervals for a Model Predicting Middle School Students' Cumulative Science Grade by Categories of Indicators Contained in the Draw-A-Scientist Test Checklist

Predictors	*Estimates*	*CI*
(Intercept)	81.97***	70.08 – 93.87
Scientist Appearance	-7.05*	-14.02 – -0.07
Scientific Context	7.02*	1.19 – 12.84
Nature of Science	-19.39**	-32.73 – -6.05
Observations	42	
R^2 / R^2 adjusted	0.387 / 0.339	

* $p < .05$; ** $p < .01$; *** $p < .001$.

Previous DAST research primarily focuses on students' desire to pursue science careers and neglects how stereotypes may influence learning outcomes (Meyer et al., 2019; Cundiff et al., 2013; Mason et al., 1991; Finson et al., 2002). This study addresses this gap by examining how conventional representations of scientists relate to middle schoolers' science grades. Findings indicate that stereotypical appearances of scientists and danger-related indicators are associated with lower science grades, while knowledge-related symbols are associated with higher grades. However, the sample size is limited, and future research should consider using multiple DAST measures for students. Overall, this study provides context into middle school students' perceptions of science and extends the DAST research by categorizing indicators into thematic structures, revealing distinct relationships between stereotypes and science learning outcomes. In future work, we hope to both utilize larger sample sizes and examine how these stereotypical perceptions might change over time.

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Creating an Assessment for Research Collaborations

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Abstract: Achieving transdisciplinary knowledge integration can be challenging. It calls for crossing both disciplines and practices to build new knowledge. By assessing collaborations, we could provide feedback to help guide the process of integrating knowledge. The development of such a tool begins with understanding what aspects of collaborations are important for successful knowledge integration. This poster presents examples from four interviews to make recommendations for adaptation of research frameworks towards assessment.

Introduction

Common complex challenges in Education, like literacy or systemic inequality, call for the ongoing research efforts across disciplines (Rittel & Webber, 1973). Collaborative, cross-disciplinary approaches inherent to the Learning Sciences are vital to making an impact. But, while collaboration across disciplines can be effective for innovating, the form collaborations take changes the expected output of a research project. Additionally, difficulties fully integrating knowledge across groups (e.g., research practice partnerships or participatory design studies) can hinder the level of innovation and inclusivity these approaches can offer. Thus, tools designed to measure these impacts are critical for helping us to better understand and improve the collaborations within the Learning Sciences.

Assessing collaborations in the learning sciences

To design an effective tool for examining and guiding the collaboration process within Learning Sciences research, we explored existing frameworks and research on multiple disciplinary collaboration, focusing on those that distinguished between different levels of knowledge integration. These were few, and none provided a framework for assessing Learning Sciences collaborations. We focused on the MIT-D framework, which proposed a comprehensive general framework for studying elements of multi-, inter-, and transdisciplinary collaborations on research projects in any field (De Oliveira et al., 2019). Although often referred to generally as “interdisciplinarity” in the Learning Sciences (Sawyer, 2005), Choi and Pak (2006) identified different forms of knowledge integration occurring in collaborations across domains, each of which are used in Learning Sciences research. Multidisciplinarity, interdisciplinarity, and transdisciplinarity denote different levels of collaboration, with ease of collaboration decreasing as potential for innovation increases (see Figure 1, below). Transdisciplinarity builds on individual (multidisciplinary) and researcher-only (interdisciplinary) collaborations to holistically incorporate the scientific abilities of researchers with stakeholders’ inherent expertise (Bernstein, 2015), but is the most difficult to implement effectively. Students, teachers, and other stakeholders typically do not share the same type of education or training as researchers, which can complicate knowledge integration and create power imbalances in collaborations (e.g., Maynard et al., 2020). Using the MIT-D framework, researchers could study units (e.g., scientists or research projects) on a combination of four dimensions (Individual Abilities, Content, Collaboration, Outputs and Outcomes). We used this framework instead as the starting point for an inquiry into the relevant categories of assessment in Learning Sciences collaborations. However, this framework presents two significant limitations to its use as the foundation of a collaboration assessment in the Learning Sciences. First, as the Learning Sciences often targets complex educational problems situated within multiple levels of social context (Nathan & Wagner, 2010), an effective framework should include variables at multiple scale levels, as well as considering inputs and outputs impacting the same research project. Second, the framework is too general to be used directly as an assessment instrument, instead intended as a foundation for additional inquiry. In this case, we sought to tailor examples and framework attributes to examining problems within education research (e.g., “facilities and equipment’s suitability to research” suggests physical sciences). “Access to data” might be a more relevant component of successful education research collaborations. Bearing these limitations in mind, we sought to identify the core aspects of Learning Sciences collaborations that should be assessed to support innovative research outcomes.

Methods

We conducted semi-structured interviews with four Learning Scientists in the United States. Our interview protocol was based on the MIT-D Framework and additional collaboration and Learning Sciences literature (e.g., Alvargonzález, 2011; Choi & Pak, 2006; Pea & Linn, 2020; Peffer & Renken, 2016). Interviews were 30 minutes long, conducted via Zoom, and transcribed for analysis. We used provisional coding, an exploratory method that uses a "'start list' set of codes prior to fieldwork" (Miles & Huberman, 1994, p. 58) and evolves as researchers analyze the data, based on our literature review. We discussed the coding scheme and applied it independently to interviews in multiple passes to achieve agreement about the final, two-level coding scheme (Saldaña, 2015). This poster presents the final coding scheme displayed in a matrix, with first level codes presented as nested within second level codes.

Preliminary findings

Themes explored in this analysis revealed opportunities for utilizing and adapting the MIT-D Framework for the creation of a knowledge integration assessment tool (see Table 2, below). Themes are discussed fully in this poster. Within each category of input (research team or organization), the four themes on the left speak to significant considerations that impact both ability to collaborate and integrate knowledge within transdisciplinary research teams. Outputs resulting from these factors include both scientific production as an endpoint (e.g., the publication of research findings) and input for future collaborations (e.g., building networks for future research or the individual skill and expertise development of researchers).

Table 2

Proposed foundations of collaborative, integrative transdisciplinary research.

	INPUT TYPE		**OUTPUT**
	Research Teams	**Organizations**	**Impacts**
Problem Space	*Research Problems*	*Priorities*	*Production*
Relationships	*Cooperating*	*Collaborative Culture*	*Networks*
Knowledge	*Representing*	*Scientific Production Resources*	*Growth*
Research Activities	*Conducting*	*Integrative Resources*	*Domain Integration*

Conclusion

This revised framework could form the foundation for future Learning Sciences collaboration tools or assessments. Research teams would benefit from ways to gauge their level of knowledge integration and build intentionality into collaborative practices. Notably, not all variables in a project are within collaborators' control, but nevertheless suggest consequences for the effectiveness of collaborations. Next steps for this research include the incorporation of interview data on non-scientist Learning Sciences research collaborators to further align the framework and design assessments to support collaboration.

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Navigating Tensions: Dominant Traditions and Culturally Sustaining Practices in Music Learning

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Abstract: Culturally sustaining pedagogies offer a complex way of thinking about arts learning. In this single case study, I analyzed an interview with a young musician, exploring his experiences with both dominant and culturally sustaining learning. I found that teachers create culturally sustaining environments and ensembles, and young artists can cross boundaries to author their own culturally sustaining learning practices. Implications for supporting young artists to articulate, navigate, and confront their own cultural and scholarly influences.

Introduction

As young artists engage in learning and making music, they experience tensions in the ways arts practices are prioritized or marginalized in across learning settings. Culturally sustaining pedagogies (CSP), (Paris & Alim, 2014), offer a complex way of thinking about arts learning (Dahn et al., 2022). This asset framework helps us understand current conflicts and tensions in academic contexts, and encourages centering nondominant perspectives in teaching artistic theories, artistry, and histories (Peppler et al., 2022). One way adolescent artists learn is through engagement in identity processes (Halverson & Sheridan, 2022), seeing aspects of their cultural identities respected and reflected in their academic arts classes is legitimizing. Culturally sustaining arts practices can be particularly meaningful for those from non-dominant backgrounds who may not feel represented in mainstream academic settings (Pepper et al., 2022), however arts curriculum in academic contexts and cultural institutions is largely rooted in patriarchal, Eurocentric traditions (e.g., Charland, 2010).

The theoretical foundation driving my inquiry for this poster is CSP, specifically through connected arts learning (Peppler et al., 2022). Connected arts learning offers “a framework for how to support learner-centered and equity-oriented creative educational experiences” (Peppler et al., 2022, p. 265), positioning interests, relationships, and opportunities as key to culturally sustained learning. By better understanding how artists learn across contexts, learning scientists and educators might better design and evaluate programs and spaces toward inclusive, CSP. I consider how artists engage in music learning by asking the following questions: *How do young artists experience both dominant arts practices and culturally sustaining arts practices in academic settings? How do they create opportunities for self-driven culturally sustaining arts learning, making, and performing?*

Methods

This poster is based on a pilot study conducted in preparation for my dissertation in which I interviewed five young adults. Four had just graduated from college and one was in his final year; all were either music or theatre majors. For this single case study (Cresswell & Poth, 2018), I focus on one representative case, Miles, a 22 year old Black, male, saxophonist who grew up in a middle class Black neighborhood in greater Los Angeles and attended college in Orange County, California. The interview questions were based on culturally sustaining frameworks (Paris & Alim, 2014) and connected arts learning (Peppler et al., 2022). I analyzed the interview by creating an event history timeline with specific quotations to support each connected arts learning experience. I then interpreted the timeline, looking for learning experiences where Miles identified either culturally sustaining or dominant arts practices, then memoed to interpret each moment (Cresswell & Poth, 2018).

Findings: In school, out of school, and authoring CSP

Miles described a range of experiences across in-school and out of school contexts. Similar to prior research (e.g., Charland, 2010), Miles characterizes foundational courses and ensemble experiences in music, in both high school and college, as rooted in western practice. These in-school courses are considered the fundamentals and core to continuing an academic music pathway. In his high school music theory courses, they learned what he calls, “the ‘rules’ or the music theory associated with classical European music, in the common practice era, which is basically about 1600-1900.” This continued into college where he learned musicianship, theory, and history from “almost strictly classical, European” perspectives. When Miles reflected on his academic foundations, he emphasized that he did enjoy learning and playing classical music even though he only engaged with it when at school. He explained that, “as far as seeing myself with the music or relating to the context in which the music was made, I wasn't really aware of that stuff until late high school.” In his earlier learning experiences he was just happy to learn and play. It wasn’t until around his junior year that he began to question the disconnect between cultural music (heritage/ethnic, pop/youth) and classical music that followed the “rules.”

Not everything happening at school was rooted in western tradition. Miles did encounter learning that came from a culturally sustaining place. The first example of CSP that Miles shares, came from an engaged teacher who moved beyond the traditional curriculum to make learning meaningful for his students. Miles describes an encouraging learning environment, “giving all the props to my band director, because he wasn't a jazz major. He's a classical oboe player who just busted his butt to be able to give us the resources to be able to learn for ourselves.” This teacher moved beyond his own experience to make sure his students had access to music and genres to which they could connect. This was meaningful for Miles, and he identified the extra work it took, “to this day I’m baffled about how he did [it].” Additionally, Miles explained that while most ensembles, band and orchestra, at schools play traditional western repertoire, in jazz band, “I was able to play other music because jazz [band] just ends up being ‘not classical.’ They end up playing a lot of pop tunes, funk tunes, basically it just becomes an outlet.” The jazz band became a special context for CSP in school, allowing students to explore a range of repertoire and perform music that they were excited about and related to.

Through his school years, Miles emphasized the ways he and his peers created self-driven opportunities for CSP through organizing their own band, practicing and performing music of their own choice, from jazz to rock and roll. “A couple of cats and I made a band, and that was our vehicle for playing for those three years. We had people in different grades in the band; played in those festivals in different places, driving to Venice and playing at different restaurants and things of that sort.” This band became a space to bring individuals’ culture and pop-culture into one context, where students were self organized and created music together.

When Miles reached college and took his foundational courses, he started to question what he saw as missing cultural contexts. Though a few professors were thinking about CSP, like one who taught a course on only female composers, most were still deeply entrenched in western musical traditions. Miles realized he could make choices about the musicology and history that he learned, that he could value diverse cultural perspectives in his academics. He took an independent study where “The purpose was our curriculum, as is taught in the states, for music. Through that process I read papers and became really really aware of how bound these things are. Then I started noticing how it affects students in the way that they think.” Here Miles made a change from being a consumer of his academic learning, to becoming an author, or what he calls being a “proactive learner.” As an author, he made an intentional effort to decenter dominant, Eurocentric practices, incorporating critical readings and diverse culturally connected perspectives.

In the past, Miles had taken his cultural interests to out of school contexts, like performing with his band. Now, Miles realized that he could compose music, from within his own program, and present it legitimately within the academy. “It was an intermediate composition class where we worked with dancers, and the theme was climate change. So basically, I made a piece that depicted humanity losing their battle to climate change.” Here Miles described how he was able to incorporate an aspect of his generational and political culture into the music that he composed in class, for other students.

Conclusion

This case highlights the ways dominant practices are taught as foundational to learning music theory, history, and through repertoire. While Eurocentric perspectives still dictate the “rules” of music, CSP occupies a special place in schools, especially in high school contexts before students have interrogated their prior learning. As young artists enter adulthood, they are able to reflect on how their learning affected their artistic, academic, and professional choices. Applying culturally sustaining frameworks will help us understand the ways social and scholarly knowledge constructs affect artistic thinking and arts making, so young artists better understand how to articulate, navigate, and confront their own cultural and scholarly influences.

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“Sparking” Math Talk in a Fraction Ball Classroom Lesson

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Abstract: The Fraction Ball has demonstrated positive impacts on rational number learning. fractions and decimals through basketball. We explored activity features that sparked math talk discussions. We found that 6th graders engaged in minimal math discussions that were mostly preceded by teacher prompting. Future designs might leverage student prior knowledge by incorporating increasingly difficult questions to support peer-led discussions.

Introduction and background

The current study explores how a game-based math lesson supports math talk in a 6th grade math classroom. Fraction Ball is a basketball game where arcs and colors are added to the design of the court to support fraction and decimal learning. Fractions are a notoriously difficult content area (Braithewaite & Siegler, 2018), Fraction Ball is a way for students to stay engaged with difficult content through play-based interactions. Previous research on Fraction Ball has shown significant improvements on rational number reasoning (Bustamante et al., 2022) and the math language environment (Alvarez-Vargas et al., under review). This study investigates how the activities support student math dialogue.

Fraction Ball classroom lessons were guided by the learning science principles that students learn best when they are engaged in meaningful, socially interactive, iterative, and playful activities (Hirsh-Pasek, et al., 2015). We contribute to research on developing active learning opportunities enriched by conversation as dialogue math vocabulary connects students' understanding of abstract concepts to improve understanding (Purpura et al., 2019). Though, Fraction Ball helps students learn abstract rational number concepts and groups’ gameplay increases the rational number language (Alvarez-Vargas et al., under review), open questions remain regarding the extent of the math talk episodes between students and what activity routines spark dialogue. We identify what preceded the students’ math talk to form design conjectures that elicit mathematical classroom discussions. We engaged in participatory design to understand Fraction Ball activity design influences math discussions in a 6th grade classroom, and ask (1) *How do groups engage in math discussions during the classroom activity?* and (2) *What events precede and encourage group math discussion?*

Figure 1
Right: A group engaged in the Fraction Ball Sparks Activity. Right: The students worksheet sample.

Methods

As part of a larger design-based research project focused on Fraction Ball, we collected video data during a 16-minute lesson involving students watching a WNBA game and hypothesizing the shot locations (Figure 1). We analyzed video and audio data, transcribing interactions of two student groups who provided consent. We utilized a validated coding scheme (Alvarez-Vargas et al., under review) to quantify math talk occurrences and their sequence within each group. Additionally, we identified the events preceding math discussions using the Levels of Math Talk Community Framework (Hufferd-Ackles, Fuson, & Sherin, 2004).

Findings

Table 1 presents the total math talk utterances and what precedes them by group. In group one, four students engaged in 19 math talk episodes, which included an average of 4 math talk utterances per student. Of the 16 talk episodes, 12 were preceded by the teachers' active classroom facilitation including asking questions, directing group discussions, probing for student thinking, and clarifying student's explanations. In group two, the four students engaged in 14 math talk episodes, which included an average of 5 per student. Of the 14 talk episodes, 11 were preceded by the teachers' active classroom facilitation including asking questions, directing group discussions, probing for student thinking, and clarifying students' explanations.

Table 1
Events that preceded math talk episodes by group.

Preceded math talk?	**Definition**	**Example**	**Group 1**	**Group 2**
Teacher prompts	Teacher prompts tasks or asks group targeted questions.	Teacher: "Talk to your group and get your final score."	12	11
Sparks video	Actions in video elicit student explanation or questioning.	Student: "That's two whole points right there."	4	0
Student directed questions	Students ask questions to clarify features of the activity. [not explicitly encouraged by activity]	Student: "Oh this [court section]. Which one are we talking about?"	1	2
Worksheet	Worksheet task elicits student explanation or questioning.	Student: "Wait, how did you get this?" Gesturing toward worksheet	1	0
Student Prior Knowledge	Students reference experiences relevant to court or math not explicitly taught in this class session.	Open discussion among students about what the basketball court looks like	1	1
		Total Math Talk Utterances	19	14

Discussion

Our study reveals that teacher prompting primarily instigated student discussions, with secondary contributions from worksheet comparisons and student-directed questions when calculating different total scores. This preliminary analysis paves the way for further exploration of math talk across all Fraction Ball lessons, potentially informing future designs to encourage peer-led discussions.

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Exploring Teacher Beliefs Around Critical Action Curriculum: Outcomes From a Learning Exchange

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Abstract: This paper reports on a co-located critical action curriculum design workshop held in India, as part of a two-year learning exchange with teachers. The workshop drew on prior work with teachers on local issues. The research found that teachers believed the local context was important to critical action curriculum design, and that such curricula could motivate students with low interest. The paper contributes to understanding teachers' self-efficacy in designing critical action curricula.

Introduction

The CALE (Critical Action Learning Exchange) professional learning community supports teachers in developing culturally responsive and empowering pedagogies for K-12 pupils confronted with economic, health, and sociopolitical challenges (Carvalho et al., 2021). This paper examines the lesson plans and attitudes toward critical action curricula from a two-day workshop conducted on September 2022 for secondary school teachers in Bengaluru, India. Teachers created lesson plans addressing socio-environmental issues affecting their students during the workshop, which included a session on TinkerCAD and Scratch. The study addresses the need for culturally responsive pedagogies that encourage students' local purpose in authentic cultural contexts and belief systems. The following research questions guided our work: *(a) What are some attributes that teachers perceive as central to an effective critical action curriculum? (b) How did such curriculum co-design influence teachers' perceived instructional self-efficacy?* Critical pedagogy is the guiding framework for the CALE curriculum, which empowers students to contribute to the resolution of critical issues and overcome their sense of powerlessness (Freire, 1970). Through critical consciousness, students challenge oppressive structures and ask questions while teachers guide them with necessary resources and support. Teachers' attitudes and beliefs are crucial in integrating critical action into the curriculum, and understanding their self-efficacy beliefs can contribute to the success of innovative projects like CALE. Self-efficacy refers to belief in one's capability to organize and execute courses of action (Bandura, 1997). Critical action integration is a new concept for Indian teachers hence teachers' self-efficacy can help us understand their instructional goals and aspirations toward critical action in the classroom.

Method

In partnership with a teacher-leader from a secondary school in Bengaluru, India, a workshop was conducted to help teachers design lesson plans. The workshop was designed based on the school's priorities and utilized the six components of the CALE framework to develop open-ended prompts. Fourteen female teachers with varying levels of teaching experience participated in the two-day workshop, which was led by two researchers for 2.5 hours per day. Six science teachers attended on the first day, and seven mathematics teachers attended on the second day. The workshop included icebreaker activities, critical making and critical action discussions, and hands-on activities using TinkerCAD and Scratch. Additionally, a storytelling approach was used for critical action. After the workshop, teachers discussed socio-environmental and economic issues with their students and submitted lesson plans based on common themes. Five teams (2 per team) submitted their lesson plans, which served as primary data sources for the study. The teachers' self-efficacy, beliefs, and attitudes were assessed using a survey questionnaire adapted from Bandura's teachers' self-efficacy scale (Bandura, 2006). Participants were asked to indicate their agreement on 11 items (e.g., critical action can enhance students' motivation to learn) on a five-point Likert scale ranging from strongly disagree to strongly agree.

Analysis & findings

The five lesson plans submitted by teachers were analyzed using content analysis (Mayring, 2015). Individual researchers analyzed the lesson plans and came up with codes that were grouped into broad categories after conflicts were resolved. Thematic analysis was conducted, and themes emerged, including context-specific problem identification, curriculum integration, criticality & action orientation, suitability of activities, and inclusion of 21st-century competencies (Clarke et al., 2015). The results of the teacher attitude and belief survey questionnaire were compared with the lesson designs to gain more insight into the teachers' views on critical action. Our analysis focused on answering the first research question, exploring themes that arose in relation to effective CALE curriculum design. The theme of 'context-specific problem identification' emphasized the importance of selecting a problem statement specific to the local context. For instance, teams 1 and 2 focused on wastewater management through critical making and rainwater harvesting; teams 3 and 4 addressed economic disparity; and team 5 tackled global warming. This theme is particularly important for Bengaluru, a city recently affected by floods and characterized by financial inequality. 'Curriculum integration' emerged as an essential theme, emphasizing the integration of school subjects and critical action. Three teams explicitly connected curricular concepts. The theme of 'criticality and action orientation' emphasized an actionable plan by teachers to encourage students to take a critical perspective on the issue. For instance, an excerpt from team 1:

> *"Students should visit and collect information from the people who are affected. Conduct water quality tests. Develop and test a model for an innovative and efficient water filtration system and recover resources."* - Team 1

The above quote reflects teachers' understanding of critical action and their belief in enacting it with an actionable plan. However, in one of the cases (team 5), their approach was generic and the lesson plan was devoid of actionable items related to the curriculum.

> *"Projects that reduce the global temperature. Avoid products with a lot of packaging. Drive less, recycle more, plant a tree, etc. Make your voice heard by those in power, respect & protect green spaces, cut consumption & waste, and reduce your energy use."* - Team 5

For Research Question Two, we used both quantitative and qualitative analyses to examine participants' attitudes and beliefs toward CALE. Survey responses and lesson plan designs were used for this purpose. Our findings showed that participants had a strong interest in CALE approaches (M= 4.0, SD = 0.0), and felt more confident using them in the classroom (M= 4.14, SD= 0.37), indicating a level of self-efficacy in critical action. However, despite this positive perception, participants reported feeling uncomfortable using CALE approaches in the classroom (M= 3.71, SD = 0.75), which was further confirmed through qualitative data. 80% of participants reported a 'fear of change' or 'lack of time' as reasons for this discomfort. Nevertheless, participants believed that a CALE-based curriculum would help in motivating students (M= 4.57, SD= 0.78) and promoting collaboration (M= 4.57, SD= 0.53) between students. They also felt that CALE approaches would instill 21st-century competencies in children (M= 4.14, SD= 0.37). Our analysis also revealed that team 1 had a better understanding of critical action, while team 4 was less flexible in integrating it into the curriculum. The suitability of activities also differed among teams based on their chosen problem statement.

Conclusion

The study aimed to prepare Indian high school teachers to integrate critical action in classroom teaching. Results showed teachers were interested in integrating it, believed it could develop students' skills, and were confident in implementation, but not comfortable due to a lack of time and fear of change. Acknowledging fear of change is a positive step. Understanding teachers' views is important as they are forerunners of the CALE community. The study helps understand the relationship between teachers' self-efficacy and critical action understanding. The limited participants and contextual nature of the study must be considered. The longitudinal study is part of a larger project involving science and math teachers in southern India, with plans to expand globally. The teachers' lesson plans being implemented soon.

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Understanding Higher Education Teachers' Re-design process and Design Principles: Two Cases from Mainland China

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Abstract: Enhancing teachers' learning design capacity is increasingly recognized as important in helping teachers create effective learning environments and experiences. However, there is limited understanding of university teachers' existing design practices and motivations for course improvement. This study examines the course re-design process of two teachers at a Mainland Chinese university. The findings reveal different design processes, driving motivations, and challenges encountered, and the need for a common language to communicate LD concepts and pedagogical decisions.

Introduction

The increasing emphasis on technology-enhanced learning and student-centered approaches in higher education necessitates significant changes in teachers' practices, skills, and beliefs (Goodyear, 2015). Learning Design (LD) aims to involve teachers, learning sciences researchers, and instructional designers in creating pedagogically aligned learning environments and learning experiences (Mor, Craft & Maina, 2015). Despite efforts to develop frameworks and tools to enhance teachers' LD capacity and competence (Laurillard et al., 2013), there is a paucity of research on how teachers go about the design process in their everyday professional practice (Bennett, Agostinho & Lockyer, 2017). Understanding these processes is crucial for effective intervention programs supporting professional learning and technology-enhanced pedagogical innovations (TEPIs). This study investigates higher education teachers' design decisions when revising previously taught courses, differentiating between novice teachers adapting existing designs and experienced teachers revising their own courses. It addresses the following research questions: 1. What guiding principles do teachers use when redesigning a course for the first time, and how do they go about the redesign process? 2. What motivates teachers to redesign their courses, and what approaches do they take in the redesign process? 3. What challenges emerge during the redesign process, and what support do teachers need?

As the design process is multi-layered and complex, decisions must be made at various levels, from course level to individual learning tasks (Law et al., 2017). Teachers play a crucial role in transforming pedagogical innovations into practice, with the success of curriculum innovations largely dependent on their understanding and engagement. By examining teachers' design processes and decisions in authentic design practices, this study aims to inform the development of effective support programs for successful TEPIs.

Methodology

This study is part of a larger design-based project that aims to understand authentic design practices of higher education (HE) teachers. Insights from the study will inform professional learning programs and the design of LD supporting tools to enhance teachers' LD practices and capacities. Conducted at a Science and Technology university in Mainland China, the study purposively recruited in-service teachers with experience in course redesign. Consent was obtained from the 16 teachers who participated in the study. Face-to-face interviews were used as the main data collection method, content analysis was employed for data analysis. This paper discusses and compares two of the teachers' course redesign process. Teacher A, a less experienced teacher, took over the first-time teaching of a major elective course for Biology undergraduate/master students with existing course materials. Teacher B is an experienced teacher with overseas teaching experiences before joining this university several years prior to the study.

Results

This study explored how teachers redesigned their courses and what motivated them to make subsequent revisions. Results of the analysis for Teachers A and B are summarized below.

Teacher A's first round of redesign was guided by three principles: integrating theory with practice, linking research and industrial applications to teaching, and using authentic contexts and materials. Guided by these design principles, his first round of redesign followed a top-down, broad to specific process, and mainly focused on preparing PowerPoint slides, planning for how to conduct the lectures and lab sessions. Changes in the second round were mostly to the course structure and learning activities, including new content, re-sequencing topics, and integrating ICT tools. Challenges emerged in designing effective learning tasks and applying educational theory to practice. Teacher A expressed a need for effective design templates of successful practices and a tool to facilitate the representation of the learning activities and support design process.

Teacher B had taught the course he redesigned three times before, adhering to two principles: situating students' learning in a social context and engaging them in authentic disciplinary practice. Based on these design principles, the course was divided into blocks, each with a sequence of learning activities (lectures to illuminate theory, lab work, and group projects), and underpinned by the same pedagogical strategy. The group projects require students to engage in disciplinary practices such as problem formulation /problem solving and play an important role in helping students to achieve the targeted learning objectives. Teachers B's three cycles of redesign were driven by various factors such as observed/reported difficulties experienced by students and increases in student numbers. The first redesign involved splitting the class into two groups and adding a discussion component to address students' difficulties in conducting labs and projects. In the second redesign, co-teaching, cross-course collaboration as well as university-enterprise collaboration were introduced. The third addressed students' difficulties by providing supplementary instruction in Chinese (English was the official medium of instruction for the course) and simplifying group projects.

Discussion

This paper presents two cases of course redesign with notable differences. Teacher A's redesign was more content-focused, loosely guided by some pedagogical design principles, which is similar to previous reported studies (Stark 2000; Bennett et al., 2017). Teacher B's cycles of iterative redesign were underpinned by the same set of consistent design principles, demonstrating clear design granularities, and providing clear rationale that drove the redesign decisions. Teacher B's redesign practices were systematic operationalizations that paid attention to the coherence and alignment of the underpinning pedagogical design principles, which is rare in literature reporting on authentic teacher practices.

These findings suggest that pedagogical considerations and design decisions are interconnected. A focus on coherence and aligned pedagogical considerations at different design granularities may promote constructive alignment in learning design (Nguyen & Bower, 2018). This paper also contributes to the literature on why and how university teachers redesign a course. There are a variety of reasons that drive the redesign of a course, including students' feedback and their diverse learning needs, contextual factors such as the learning spaces and human resources, and faculty teaching and learning policies etc. The study also identifies challenges and similarities in teachers' needs, highlighting the importance of a common language for effective design articulation, communication, adoption, and reuse. This supports the call for a unified way of documenting and describing teaching practice, guiding teachers to better communicate design ideas for professional learning. This will in turn serve as a stimulus to improve teaching and learning quality (Law et al., 2017; Law & Liang, 2020) and foster professional learning communities around learning design across institutions and disciplines.

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A Dystopian Game for Change: Building Asynchronous Learning Network Through Co-Design Partnerships Across Disciplines

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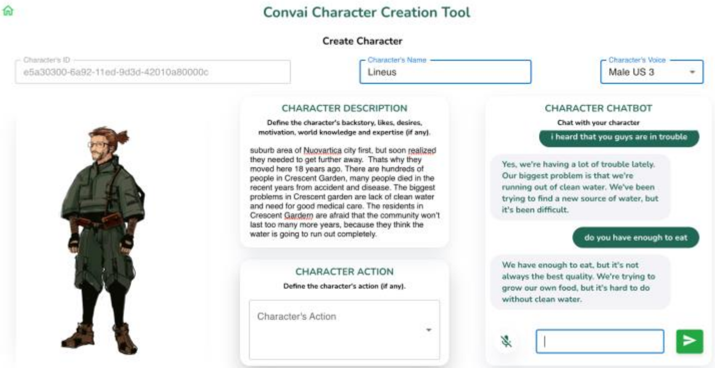
Abstract: This paper is a design-based study of a collective inquiry-based game set in a dystopian world that engages high school students to reflect critically and build media literacy within various disciplinary contexts. We report on the preliminary design activities for an educational game undertaken closely with technology consultants and three high school teachers (Arts, English, and STEM). This paper reports on our first phase of design-based research (Brown, 1992), in which we work closely with teachers, game design experts, and technology consultants to develop an understanding of learning goals, gameplay dynamics, and learning environments (Gee,2005; Squire, 2006; Djaouti,2011), that would be suitable for students to collaboratively building an embodied game-based learning experiences.

Theoretical perspective

How can we help students thrive in a world of disinformation, convoluted and messy social dynamics, and the fluid identities that characterize their lives and flavor their learning? 21st-century education must provide future citizens with learning that empowers them against an uncertain or inequitable future (Freire, 2020). Student resilience to fear and anxiety must grow organically through self-direction, self-organization, and self-regulation (Garrison, 1998; Hayes, 2006; Peters & Slotta, 2010; Papacharissi, 2011). Our work is guided by the notions of critical pedagogy (Freire, 2020; Giroux, 2020), learning communities (Brown & Campione,1996), and collective inquiry (Peters & Slotta, 2010). Our approach is to develop an asynchronous learning network for collective inquiry in hybrid high school classrooms in a dystopian universe. *The Fall of Artica: A Way Back Home (FoA)* aims to facilitate students' critical thinking and collaboration with various contexts, engaging critical actions in embodied synchronous and asynchronous game-based learning environments. The dystopian settings can support meaningful narratives and interaction modes, enabling community building through collaboration, communication, design, and critical making (Carvalho et al., 2022). FoA aims to connect students' identities with critical conversations around dystopian literature, empowering them with meaning and purpose for the different subjects they learn. This poster presents our progress in developing the FoA game concept, including theoretical perspectives, game elements, and a co-design method for developing gameplay.

Figure 1
Convai Chracter Creation Tool: Lineus



Character's ID: e5a30300-6a92-11ed-9d3d-42010a80000c
Character's Name: Lineus
Character's Voice: Male US 3

suburb area of Nuovartica city first, but soon realized they needed to get further away. Thats why they moved here 18 years ago. There are hundreds of people in Crescent Garden, many people died in the recent years from accident and disease. The biggest problems in Crescent garden are lack of clean water and need for good medical care. The residents in Crescent Gardem are afraid that the community won't last too many more years, because they think the water is going to run out completely.

i heard that you guys are in trouble

Yes, we're having a lot of trouble lately. Our biggest problem is that we're running out of clean water. We've been trying to find a new source of water, but it's been difficult.

do you have enough to eat

We have enough to eat, but it's not always the best quality. We're trying to grow our own food, but it's hard to do without clean water.

Research questions

(1) How do game elements vary with curricular context? (i.e., English, Arts, and Science?) (2) How can technology support the face-to-face collective inquiry-based gameplays in critical pedagogy and disciplinary learning afforded by the narrative, conceptual, physical, and interactive game elements?

Methods and data collection

We adopted a five-stage co-design method to create the first playable prototype: Understanding design goals by meeting with three teachers (Arts, English, and STEM) to understand their learning goals and required resources. Through three co-design meetings with each teacher, develop shared understandings with teachers about G4C, critical pedagogy, and learning communities; understand teachers' courses and curriculum; develop broad ideas about what *FoA* could look like. This study collects and analyzes different forms of data: (1) Interview video and audio recordings, transcripts with three teachers, and a new media expert. (2) create material: backstories, transcript of the chat between students and an A.I. empowered learning assistant (3) collect student feedback and artifacts (game concept art such as characters, environment, and props) throughout the gameplay (4) share student artifacts online to students outside of visual art class (5) narratives and quests that create by other classes or from another school.

Findings and discussions

Co-designing with three teachers, we articulated the learning goals, curricular elements (quests, cards, characters, etc.), and gameplay experience that addresses their course requirements. One art teacher anticipated that students would be excited about designing quests and creating game assets for fellows. The gameplay is a generative model in which students engage with the existing plotlines and interact with characters to develop game elements based on their own or collective understanding of the plotlines. Students choose quests from the character that match their personal or collective interests. They allocate, combine, and create game elements and level up their skills in designing and creating. Progress within the game is measured by their level of engagement and the connection they create between the game elements and the wider community. Gameplay is concerned with supporting the collective inquiry of students, collecting game assets guided by the plotline. Students take on "quests" and resolve challenges or solve mysteries within a community of peers by interacting with objects, characters, and other game artifacts. This way, they collectively uncover hidden plotlines and critically evaluate their co-constructed dystopian fiction (e.g., identifying misconceptions or contradictions). Engagement in a game narrative creates the need to find information, allocate resources, collaborate with others, practice communication skills, cross-compare evidence, make critical decisions, think systematically, etc. Although the project is in its early stage, it has opened many conversations about designing learning experiences in specific contexts. This work moves us toward an accessible and inclusive game-based learning environment, which may open further research opportunities relating to learner engagements, tangible and embodied interactions, blended learning, empathy, social justice, cultural inclusiveness, critical making, and more.

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Supporting Focus on the Process of Learning, Rather Than the Product, in a STEAM Activity

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Abstract: This study explores how the design and facilitation of a STEAM activity during a professional development workshop supports a focus on learning through the process. How the activity was introduced and the whole group reflections – both mid-activity and at the conclusion of the activity - supported participants in making observations and focusing on the process, rather than the end product.

Introduction

Learners are often focused on the outcome or product of an activity, rather than the process of learning. The end goal is to get a correct answer or result on a lab or exam or to replicate an example artifact. A focus on the product or outcome is reinforced when learning is assessed through final answers and products. Focusing solely on products has been found to stifle learning, as it does not value learning that occurs during the process of working through an activity (LeJevic, 2013; Perignat & Katz-Buonincontro, 2019). However, many recognize that value should be placed on learning that occurs during the process of completing an activity, experiment, or project. For example, the *Next Generation Science Standards*, a set of standards used by many states in the United States, emphasize the development of science and engineering practices as an important aspect of learning science and engineering (National Research Council, 2013) and the *National Core Arts Standards* include a focus on creating art through processes such as conceptualizing, developing, and refining (National Core Arts Standards State Education Agency Directors of Arts Education, 2014). In this study, we begin to explore: How can the design and facilitation of an activity provide opportunities for learners to focus on the process, rather than the product?

Framework and methods

To address this question, we draw on the Tinkering Design Principles framework developed by Petrick et al. (2013), which positions tinkering and making as forms of legitimate peripheral participation in STEM and STEAM communities of practice. This framework emphasizes, among other aspects, facilitation through modeling STEAM practices, inviting learners to participate via multiple pathways, and prioritizing reflection. The present study uses this framework as a basis to investigate the ways in which such facilitation can support a focus on process, rather than product.

The context for this study is a two day, in-person STEAM (Science, Technology, Engineering, Art, Mathematics) professional development workshop. This study focuses on one of the activities that emphasizes science and art called Suminagashi, a process of paper marbling developed in Japan. Suminagashi inks are dropped into a bin of water, where they float, spread, or sink depending on the density of the ink, the application technique, and the surface tension of the water. The participants use the ink bottles, brushes of various sizes, and other objects to apply and manipulate the ink and create designs (Figure 1) which are then transferred from the surface of the water to various types of paper.

The data for this study consisted of video recordings of the Suminagashi activity from five different in-person workshop groups that were held in geographic locations across the United States. The participants included educators from a variety of institutions, including public library systems, science centers, art museums, and K-12 schools. We focused analysis of the data on the whole group reflection discussions of the activity. A facilitator introduced the activity by demonstrating the process of Suminagashi and then the participants had time to create Suminagashi prints. The facilitator led two whole group discussions – one in the middle of the activity and one at the end. The participants were paused during the middle of the activity to look at each others' prints, ask questions about techniques, discoveries, and choices, and encouraged to think about what they had tried out and observed while creating their prints. A similar discussion was held at the end of the activity to reflect on their learning during the activity. We transcribed the video and analyzed the transcripts using emergent coding (Strauss & Corbin, 1998), looking specifically at how participants talked about how the facilitation and design helped them focus on the process of doing the activity.

Findings and discussion

Overall, many participants noted the ways that both the design and the facilitation of the activity opened up opportunities to focus on the process. Specifically, participants noticed that activity was designed to focus on open-ended exploration, with the facilitator emphasizing that there was “no right way” to approach the activity and using language to position the activity as an “investigation” that relied on observation and other science and art practices. For example, one participant said, “I like that it started out more open ended though, just exploring, because it made me more, feel more free to just dive in” and another added that it “took the pressure off.” One interpretation of these comments is that learners sometimes feel pressure to produce a particular kind of product, and the actions of the facilitator in removing the pressure off of focusing on a final product allowed participants to focus on exploring the process of Suminagashi. Another participant provided more detail about how the facilitation allowed her to focus on the process, saying:

> I think how she [facilitator] started with close observation. And giving us an opportunity to observe and ask questions. Which when we came to our tables, we continued to act in that way. Where if she’d set it up and said, okay, this is what Suminagashi is, you put some drops, and then you put your paper in and it makes a design. We would have come back and just done that. We wouldn’t have come back and like, what’s happening?

Here, the participants discuss the importance of how the activity was introduced and how they were encouraged to make observations and explore using different materials, rather than being told a specific way to do the activity. This encouraged them to try different approaches, make observations, and try again. How the activity was structured and facilitated supported participants’ explorations in an open-ended way, rather than focusing on a specific end product.

This study reiterates the importance of the ways in which STEAM activities are facilitated. Calls for participating in authentically integrated STEAM involve drawing on a number of overlapping art and STEM practices. As legitimate peripheral participants, apprentices in STEAM learn the ways of being in practice through facilitator modeling, invitation, and guided reflection. Our study illustrates the importance of these facilitation strategies in opening up ways to focus on making and tinkering processes rather than products. Our results imply that facilitators should explicitly state norms, especially when they may be different than the norms of many learning spaces, and reinforce these norms throughout the activity. Group reflections, where participants have opportunities to observe and discuss what others have done, and then continue their own inquiry with broader insight from the group, are also useful for putting focus on the process, rather than the product.

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Modernizing the ADDIE Instructional Design Framework for 21st-Century Instructional Designers

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Abstract: This conceptual paper examines three main characteristics that support adult learning in workplace training: autonomy, motivation, and meaningfulness. To better support adult learners within workplace training, this paper proposes The Extended ADDIE model by modernizing arguably the most popular workplace training framework, ADDIE, through an intentional and explicit design process. The Extended ADDIE Model is a collaborative, engaging, and inclusive instructional design framework incorporating adult learning theory, collaborative learning theory, and inclusive learning environments.

"Until recently, there has been relatively little thinking, investigating, and writing about adult learning. This is a curious fact considering that the education of adults has been a concern of the human race for such a long time. Yet for many years, the adult learner was indeed a neglected species" (Knowles et al., 2020, p. 18).

Introduction

"It is, first and foremost, a matter of viewing learning from the perspective of the learner, because adults are not very inclined to learn something of which they cannot see the point on the basis of their own life situation." (Illeris, 2003, p. 1) Workplace training and instructional design are part of an increasingly popular industry that focuses on a group of learners that has not been researched as effectively as K-12 learning or higher education. The ADDIE model is the foundational instructional design model that is arguably still the most popular instructional design tool today. ADDIE is an acronym for Analyze, Design, Develop, Implement, and Evaluate, a highly conceptual and generalized concept that is foundational in its approach. Branch (2014) describes the ADDIE model as one of the most effective design tools, as it's a guiding framework that is active, multifunctional, situated, and inspirational. Although this model is a good basis for training, it is missing the important factors that draw connections from the content to the learner. When workplace training is designed like this, there is less emphasis on the learner's needs which risks decreasing engagement and being less effective.

Modernizing ADDIE

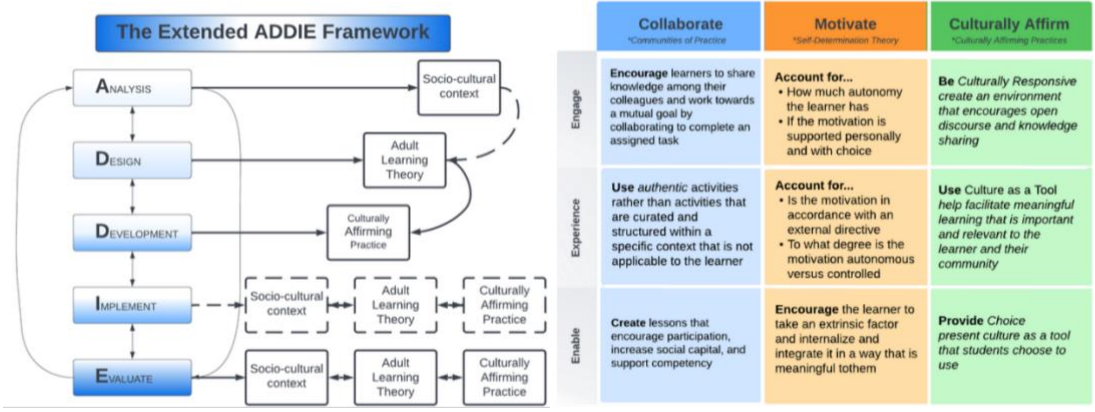
The Extended ADDIE framework seeks to address the learner's needs by recognizing the individualistic and cognitive process of learning and connecting it to the collaborative and social nature of knowledge building. To ensure that the learner is interested, motivated, and engaged, the designer must understand how adult learners learn and how to support their learning best. The instructional designer should intentionally design a learning environment that is cognizant of the varying needs of diverse learners. To support adult learning is to support learner autonomy, motivation, and meaningfulness. In an effort to foster independence and motivation, the designer should provide scaffolds that support the learners' autonomy through extrinsic motivations using the self-determination theory. The designer facilitates meaningfulness by first incorporating communities of practice by situating the learner in an authentic context and, secondly, by being inclusive of culturally affirming practice that affirms and creates a sense of belonging for the learners. Situating these theories into practice is further developed below, explicating the interconnectedness of these concepts within the framework.

Andragogy affirms that learners have the capacity to be self-regulated and intrinsically motivated, but to what extent? To address this, I look at the self-determination theory introduced by Ryan and Deci. Ryan and Deci confirm that while humans have naturally intrinsic motivational tendencies, it is equally as important to cultivate and support these tendencies – for it is easily disrupted by conditions that are unsupportive (Ryan & Deci, 1985). Therefore, it is not important to find how to instill intrinsic motivation; instead, it is to encourage it. It is important to lead the learner towards self-regulation through internalization and integration – which are processes that have the learner absorb a value or regulation, *internalize*, and acknowledge the regulation as their own and incorporate it as a sense of self, *integration* (Ryan & Deci, 1985). Beyond one's personal stake in professional development, a learner is situated within a socio-cultural context that the learner interacts with daily. Lave and Wenger challenge the notions of traditional learning with the concept of communities of practice. They argue that learning is not only individualistic but a social process that is historically and culturally situated. They further explain that working groups are continuously working towards a joint goal that is mutually beneficial and social by nature. Wenger writes, "Communities of practice differ from other kinds of groups found in organizations in the way they define their enterprise, exist over time, and set their boundaries" (Wenger 1998, p. 4), on top of the autonomy given to the participants as they develop their identities within the group over time. Designing the educational environment around a "community" encourages interaction between individual participants as well as interactions within an authentic context. Learners will be able to use prior knowledge to make connections to the current content; they are able to situate themselves within the greater community and the job; and, lastly, build social capital. These factors are important for the learner to fill the psychological need for competence, autonomy, and relatedness, which increases learner motivation, interest, and engagement for more efficacious workplace training.

The Extended ADDIE model

I examine and propose a modernized approach to workplace training that bridges the gap between corporate efficiency and meeting learners' needs. To do this, The Extended ADDIE Framework (Figure 1) and corresponding guidelines (Table 1) integrates adult learning theory, collaborative learning, inclusion, and intrinsic motivation into the individual and interdependent components of the ADDIE model (Analyze, Design, Develop, Implement, and Evaluate).

Figure 1
(a) The Extended ADDIE Framework (left) and (b) Guideline for the extended ADDIE Framework



	Collaborate *Communities of Practice	Motivate *Self-Determination Theory	Culturally Affirm *Culturally Affirming Practices
Engage	**Encourage** learners to share knowledge among their colleagues and work towards a mutual goal by collaborating to complete an assigned task	**Account for...** • How much autonomy the learner has • If the motivation is supported personally and with choice	**Be** *Culturally Responsive create an environment that encourages open discourse and knowledge sharing*
Experience	**Use** *authentic* activities rather than activities that are curated and structured within a specific context that is not applicable to the learner	**Account for...** • Is the motivation in accordance with an external directive • To what degree is the motivation autonomous versus controlled	**Use** Culture as a Tool *help facilitate meaningful learning that is important and relevant to the learner and their community*
Enable	**Create** lessons that encourage participation, increase social capital, and support competency	**Encourage** the learner to take an extrinsic factor and internalize and integrate it in a way that is meaningful tothem	**Provide** *Choice present culture as a tool that students choose to use*

Conclusion

The proposed extended framework addresses the learner's needs by recognizing the individualistic and cognitive learning process and connecting it to the collaborative and social nature of knowledge building. To ensure that the learner is interested, motivated, and engaged, the designer must understand how adult learners learn and how to support their learning best. The Extended ADDIE framework's guidelines delineate the learner's needs and give explicit direction on engaging the learner, enhancing the learner's experience, and enabling the learner to connect to the content. This improves the efficacy of workplace training by facilitating competency, agency, and relatability through the intentional use of andragogical principles, communities of practice, and culturally relevant pedagogy. Modernizing this framework provides the opportunity to research and enhance adult learning theory and engage a once-neglected population.

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Supporting Collaborative Learning and Development of Students' Science Identities in a Biology Classroom

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Abstract: An important part of our study conducted in a Grade 11 Biology classroom was supporting students' development of science identities. This study included 55 students who participated as a learning community, co-constructing a collective knowledge base, supported by technology environments. Through the Career Exploration activity, students learned about their peers' interests and became more knowledgeable about various careers; through their subsequent discussions, students were motivated to further explore their science identities.

Objectives

A learning community approach, such as developing and advancing a shared collective knowledge base (Bereiter & Scardamalia, 2014) and supporting inquiry-oriented discourse (Fong & Slotta, 2018; Slotta & Najafi, 2013) was applied and described in this paper. In a science classroom, students are engaged with their peers in a model of a scientific community (Bielaczyc & Collins, 1999). This study examines the context of a scientific classroom learning community, and how students' interactions with peers, materials and activities can foster the development of career identity. Our research question: "How does learning in a collaborative environment supported by the KCI Model and technology contributes to the development of students' career identities?"

Theoretical foundation

Identity can be regulated by culture and context (Leary & Tangney, 2012). It has also been shown that social context can improve an individual's motivation -- by providing support and by contributing to an individual's interests (Thoman et al., 2007). Besides, if a student feels that other classmates are interested in a science subject, they may also express a higher interest (Nazari et al., 2017). The role of conversations has also been studied as a means of gaining value about topics, where students can socially verify and build their perception of an activity as interesting and valued (Nolen, 2001). In collaborative activities, students develop their understanding of the topic and achieve shared representations of it (Clark, 1996). Talking with others about one's educational interests and receiving social recognition during these conversations have been shown to increase interest in science careers (Jackson et al., 2018), where interest is a primary driver of science identity (Maltese & Tai, 2010).

Method

For the development of this year-long curriculum, design-based research methodology was applied and guided by a theoretical model of Knowledge Community and Inquiry (KCI). The curriculum was co-designed with a teacher of a Grade 11 Biology class consisting of three cohorts, totaling 55 students. Throughout the semester, students in all cohorts contributed their ideas to the emergent collective knowledge base and built on their previous ideas. A series of inquiry activities was designed, using a variety of technology environments and materials to support students' collaborative work, along with a Career Exploration activity where students collectively built knowledge about and connections amongst a wide range of science-related professions. Exploration of science careers was a focus of at least one lesson in each unit, in which students contributed to the community Career Folder (on Google Drive), collaboratively editing Google Docs and adding details to the careers posted by other students. Up to six students from three cohorts could contribute to each career page. Students researched and added to the career description, made connections to other professions, explored university/college programs that would support the career, researched the level of demand for each career and the starting salary, and added interesting videos and articles. They also discussed how various careers related to each curricular unit. This growing collective knowledge base served as a platform for further discussions and exploration of potential science careers.

Data sources

Data included tables, documents and personal journals created by students individually, in groups and as a class. Co-constructed tables and documents to which students contributed their responses represent a collective knowledge base built during the school year. Students' answers to science identity questionnaires were collected and coded. Three central questions were asked: 1. What are some interesting career directions that were connected to this course, which you may not have considered before? 2.What is your current thinking about a career? Was it influenced by anything you encountered in this course, and if so, how? 3. Should teachers make a stronger emphasis on career connections within their courses? How can we help students keep thinking about their career?

Findings

Through exploring different careers and contributing to the class Career Knowledge Base, students built their understandings of various careers in science and of their own science identities. In their Career Pages (23 documents created), students identified connections to almost 100 different professions. The top three careers of interest were Neurologist (7 students contributed), Oral Surgeon (6 students), and Forensic Scientist and DNA Analyst/ Pharmaceutical Chemist (5 students per each). The maximum number of words describing a career in a collaboratively created document was 1432 (the career of Neurologist). Students connected their careers of interest to many other careers (e.g., the career of Epidemiologist was connected to 19 other careers). Also, 60 links to various resources related to future careers were added by students. The Career Exploration activity helped students gain insights into specific career interests or discover careers of which they had not been previously aware. They also became informed about qualifications required to pursue certain careers. The Career Exploration activity, including collective knowledge work and discussions about careers, was emphasized by students as helping them see connections between different science fields, industry and other fields, such as business or law, and become interested in exploring various careers. Students indicated in their questionnaires that the exploration of the college and university pathways of each science career was valuable. Collaborating with each other as a classroom learning community, through the exploration and recognition of their peers' interests, social verification and building their perception of the activity as valued allowed students to develop their interest in the topics.

Scientific and scholarly significance

This study demonstrates the potential of a learning community approach achieved through a collaborative student work by progressively adding to and making use of a collective knowledge base, through discussions in groups and as a class, in helping students to start developing interest to and knowledge of many science careers, and contributing to the formation of their science identities. This study contributes to the literature on the factors influencing the development of science identities and will be of interest to a broader educational community.

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Peer Relationships in Hybrid Learning During COVID-19: Inferences From One Online Class

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Abstract: The COVID-19 pandemic popularized remote interactions in higher education, necessitating examination of their effectiveness in supporting peer relationships. Our qualitative study of one online class in a hybrid graduate program found varying levels of meaningful peer connections, with students relying significantly more on teachers to create interaction opportunities. Group work, course content, and pedagogical approaches emerged as crucial factors in fostering connections, while asynchrony due to lack of collocation and technology failures posed barriers.

Introduction

Higher education institutions have increasingly adopted online classes and programs over recent years. Even for in-person programs, experience with the technology during the COVID-19 pandemic promoted higher adoption of remote interactions like Zoom team meetings and office hours. As such, it is crucial to examine how interpersonal connections in education have been affected by these remote learning setups and whether students can form meaningful relationships. Through semi-structured interviews, the current study investigates peer relationships in a graduate-level online class offered during Fall 2021, when COVID restrictions had largely loosened. As an online class in a mostly in-person program, the class provides a unique window into a potential future where in-person instruction is supplemented by increased online interactions.

Peer relationships in education have been described using various terms. To simplify the concept for participants, we use a basic, all-encompassing definition: relationships among student peers. We rely on two primary theoretical frameworks to situate our study. The Community of Inquiry framework posits that social presence as mediated through teaching presence facilitates the main goal of cognitive presence (Garrison et al., 2000). Considering the class's extensive use of group work and Slack, we also examine virtual group dynamics (McKenna & Green, 2002). Some of its features, including a lack of physicality and the translation of virtual identities into real identities, can well be translated into online learning communities.

Considering the literature review and the course nature, we form the following research questions:

1. How are peer relationships formed in an online class compared to a traditional in-person class?
2. What factors promote or limit peer relationships in an online class?

Methodology

The studied course was a graduate-level Master of Education program at a Northeastern U.S. graduate school. Although the program was mostly in-person, this specific class remained online due to COVID's lingering impact, with course content delivered through Zoom and Canvas. The class focused on teaching novice students to use specialized software to collect and analyze learning data. A previous iteration of the class had been studied to examine how students consume asynchronous video lectures (Schneider et al., 2022).

Out of the 30 students in the class, 12 students (7 female, 11 Asian, 11 local) participated in the semi-structured interviews. We did not collect information on the participants' prior acquaintance before the class, but it is reasonable to assume that students might be acquainted without deep connections since the class occurred during the program's first semester. The interview protocol covered three main topics: past experience; experience in the class; ideas for an ideal tool to build community in the class. Using ATLAS.ti, the authors adopted a flexible, thematic coding procedure to code the interviews (Deterding & Waters, 2021). Given the small size of the data, both coders coded all transcripts and discussed discrepancies to reach consensus on the codes. Inter-coder reliability was not calculated.

Results

RQ1: Different levels of peer relationships can be meaningful to different students.

Even though all the students were in the same class, they reported a wide range of peer relationships that they considered meaningful, from friendships to collaborators in group assignment and to mere conversation partners. Interestingly, some self-reported meaningful connections were not necessarily reciprocal. The reasons for these differences are hard to pinpoint, but students' varying expectations and circumstances, such as family commitments or time constraints, may contribute. However, it is crucial to note that all these students mentioned a general lack of connection in the class. Feelings of loneliness and missed potential career opportunities were among the issues they faced due to insufficient peer connections.

RQ1: Students relied on pedagogical practices to make personal connections.

When asked how they initially connected with peers they eventually formed relationships with, half of the students mentioned connecting through group projects, either during weekly pair/group assignments or the final project. A few students also reported initial connections through conversations in Zoom breakout rooms. All of these bonding opportunities were created intentionally by the teaching team to encourage collaboration among the students. Four out of the remaining six students formed bonds through a social media messaging service that members of a specific shared demographic already used. All four students expressed that they found a sense of connection through the class. Beyond this group, only one student initiated spontaneous communication with peers in addition to the existing pedagogical structure. This contrasts with peer connections formed in in-person settings, where students described naturally forming connections through affinity groups related to hobbies and identities, sometimes outside the classroom.

RQ2: Failure to connect was mostly attributed to the online format itself.

When asked about factors negatively impacting peer relationships in the class, students initially struggled to find an answer. When asked about *other* classes in the program that helped students feel a strong connection with their peers, students frequently cited classes that dealt with subject matters conducive to more personal topics. Students also mentioned that given the technical nature of the class in question, the difficulty of the course could induce stress for the students. When pressed, a few students attributed the problems of the class merely to the fact that it was offered online. In fact, all five students who expressed frustration of lacking connection in the class attributed the failure to the online format in some way. Notably, the only student who was not located locally expressed frustration that they missed out on all opportunities to connect because they could not be on campus. However, a review of the remaining interviews showed that only a small number of students made efforts to meet in person despite being collocated. Finally, technical challenges, like network issues, also created barriers to connect.

Discussion

The current study's findings align with the CoI framework and empirical research (e.g., Kaufmann & Vallade, 2020), emphasizing pedagogical design's role in forming peer relationships in online higher education. However, since our study focused on an online class within a hybrid program with many local students, we have additional insights. First, despite numerous opportunities, students had minimal in-person interactions and relied on teachers to establish communication. Second, even within a small class, students had varying levels of meaningful peer connections, potentially influenced by their enrollment expectations. Lastly, students emphasized the importance of course content in forming peer connections alongside pedagogy.

Our findings prompt further research into the reasons for students' lack of initiative in forming relationships in such scenarios. Additionally, our findings imply that incorporating course concepts tied to personal experiences in online classes with impersonal subject matters may encourage peer connections. The study's main limitation is the self-selection bias of interviewees, who generally attributed the class's problems to the online setting. Future work should connect these qualitative findings with quantitative and qualitative data from the class to better understand peer relationships in online higher education.

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Technology Innovation Papers

PhoneIoT for Teaching 'Internet of Things': Smartphones to Promote Accessible, Engaging, and Authentic Experiences

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Abstract: We rely on a vast network of devices that communicate autonomously to provide many of the services we use every day. However, the enabling technologies behind the Internet of Things (IoT) are often not taught in K-12 classrooms, in part due to the need for hardware. But most teens in the United States have smartphones. Thus, we introduce *PhoneIoT*, a mobile app that allows students to access their smartphones programmatically over the Internet. *PhoneIoT* supports access to live sensor data from the device and controlling a customizable display on the phone's screen. *PhoneIoT* allows students to learn the fundamental concepts of distributed computing and networked sensing using NetsBlox, a simple but powerful extension of the Snap*!* block-based programming environment. Because both *PhoneIoT* and NetsBlox are free and open-source, instructors are able to teach these advanced computer science topics even remotely without extra hardware.

Introduction

More and more, the programs and tools we use every day rely heavily on Internet connectivity to provide complex services. For example, Google Maps uses the location of connected smartphones (even if the app is not open) to approximate traffic statistics by keeping track of the number of phones in a given area. This is an example of distributed sensor networks, which are becoming increasingly important in our daily lives. Such sensor networks are the *Internet of Things (IoT)*, an umbrella term to describe a network of internet-connected sensors and devices that can be used to gather data or perform actions remotely, and potentially on a large scale. Despite being such a ubiquitous reality in modern computing, there are few opportunities for K-12 students to have hands-on experience with these topics. There are existing curricular activities as well as out-of-school clubs and makerspaces that engage students with tangible computing technologies like Raspberry Pi and Micro:bit, which can both act as or interface with simple sensors and actuators over USB or Bluetooth. However, they rely on local connectivity and are disconnected from the ubiquitous internet and IoT. Lastly, due to the cost of hardware and the logistics of keeping track of it, as well as a lack of teachers familiar with these technologies, few schools offer IoT experiences in schools.

A concurrent reality is that close to 90% of teenagers in the US already own a personal smartphone, and this number is only expected to grow (Sandler, 2022). Mobile devices such as these come with a wide variety of sensors including an accelerometer, gyroscope, microphone, camera, and GPS location service. Additionally, they are fully Internet-capable out of the box, allowing external software to easily communicate with them. Because of this, smartphones present a cost-effective opportunity for introducing students to distributed computing ideas such as the Internet of Things by using their own devices. By using everyday devices instead of relying on expensive or specialized hardware, students are able to engineer and examine the world around them through more practical, authentic, and engaging hands-on projects.

In this paper, we describe *PhoneIoT*, our free smartphone technology innovation and associated curricular activities for high school computer science (CS) students, designed to allow students to connect to and interact with their smartphone over the internet. *PhoneIoT* leverages NetsBlox, an extension of the block-based programming environment Snap*!* (Harvey et al, 2013) that makes networked communication and web data easily accessible (Broll et al., 2017).

Design principles & related work

***Easy entry point to hitherto-inaccessible, advanced networking ideas*:** The list of existing tools which allow students to create their own standalone mobile apps from a block-based programming environment is small but growing. This includes programming tools such as Thunkable (Siegle, 2020), App Inventor (Wolber, Abelson, & Spertus, 2011), and Pocket Code (Wolfgang, 2014). Some of these tools (Thunkable, for instance) are similar to *PhoneIoT* in that they provide access to some Internet-based resources (similar to NetsBlox services) and live sensor data from the phone. However, these are all strictly app development tools supporting projects local to the device, unlike *PhoneIoT* which exposes the device to the internet for students to manipulate in a distributed environment, thus making distributed computing and networked sensing accessible to students. For instance, with *PhoneIoT*, students could easily create a single server-like project that runs in the browser and connects to several phones to implement a distributed chat app. This feature is significant, given recent findings of a meta-analysis of (only 12 existing) K-12 IoT curricula, which concluded that K-12 physical computing/IoT experiences are restricted to the IoT ‘sensor layer’ and few-to-none expose students to the crucial underlying ‘networking layer’ due to its complexity and lack of tools (Abichandani et al., 2022).

Accessible & engaging experiences: *PhoneIoT* is designed to be quick to set up and simple to use. “Low floor, high ceiling” has been a crucial guiding principle for the creation of novice programming environments for K-12 learners dating back to Papert's (1980) work on children and LOGO. A low floor entry point is suitable for all students and a high ceiling supports the curiosity of all learners. Block-based programming in general, and in particular, Snap! (a Scratch derivative), have been designed for providing gentle introductory programming experiences to K-12 learners, and have especially benefited minoritized students and those with less preparatory privilege and prior programming knowledge (Goldenberg et al., 2018; Weintrop et al., 2019). Even students who have never used NetsBlox before can learn the basics and build their first distributed app in one class period.

Interactive & Customizable**:** Unlike other tools like Sensor Fusion and Cumulocity (Hendeby et al., 2017; Srirama et al., 2017) which allow for reading sensor values remotely in real time but restrict users to only using the device as a sensor hub, *PhoneIoT* promotes interactivity through a customizable phone display which affords engagement in event-based graphical inputs and remote controllers (see below). Additionally, tools such as Cumulocity are complex and expensive due to running in fee-based, specialized cloud environments.

Promoting creativity, authentic engagement**:** Since the phone is a personal, easily accessible device, *PhoneIoT* provides excellent opportunities for developing projects that promote creative, authentic engagement. For example, the phone’s dedicated step counter sensor opens up a world of possibilities for ‘quantified self’ data science activities that promote personally and culturally relevant projects and artifacts (Lee et al., 2021).

Broadening participation through physical computing and interdisciplinary connections**:** Recent research highlights several benefits associated with physical computing, including increased motivation for students (especially from diverse backgrounds) because working with sensors is tangible and affords interdisciplinary projects (Sentence & Childs, 2020). We ensure broad accessibility through making the *PhoneIoT* app freely available on both Android and iOS, and designed to cover as many phone models and versions as possible.

Protecting Student Privacy**:** To address justifiable student privacy concerns related to providing convenient access to sensors, such as the camera, microphone, and location, *PhoneIoT* proactively (a) prohibits any network communication when the screen is turned off or the app is put into the background, (b) limits the functionality of some sensors, such as the microphone so that *PhoneIoT* cannot be used for eavesdropping (c) prevents direct access to the camera; users must explicitly click an image display (with appropriate optional settings) to take an image from the camera and store it in the display after confirmation, and (d) password-protects each request to the device and passwords automatically expire after 24 hours.

PhoneIoT design: NetsBlox, access to sensor data, & custom interactivity

NetsBlox enables two key features: 1) accessing web-based services, which reach out into the Internet to effect changes or collect and return information, and 2) message passing, which allows two NetsBlox projects running anywhere on the internet to communicate and exchange data. Using these simple networking primitives, students can design powerful applications such as a live weather map or chat server, or remotely control virtual or physical robots (Brady et al., 2022). *PhoneIoT* taps into these existing concepts to provide two core features to students’ projects: 1) the ability to access live sensor data from the device, and (2) the ability to configure and control an interactive custom display on the phone. When the app is opened, simply pressing the “Connect” button connects the device to the NetsBlox server. Also shown on the screen are the device ID and password, which are needed for a user’s NetsBlox project to connect to the device through the server (Figure 1a).

Students can access **sensor data** from *PhoneIoT* in one of two ways. The first (somewhat simpler to introduce to students), is by sending an explicit request to the device through the *PhoneIoT* service in NetsBlox. For example, Figure 1b shows how this can be used to instantly tell the current device location. Explicit requests are convenient if sensor values are only occasionally needed: for instance, when the project is first started. However, it is often the case in practice, both in the classroom and in industry, that live sensor values are needed continuously; *PhoneIoT*’s second sensor access mode does exactly this. The *listenToSensors* function in the *PhoneIoT* service can be provided a list of sensor and update period pairs; it then requests the mobile device to send a message to the student’s NetsBlox project with the specified sensor data every time the update period elapses. Figure 2 shows how to request and receive location updates every two seconds. Note that this *streaming* technique has the added benefit of automatically breaking the values up into separate variables like “latitude” and "longitude" rather than receiving a list as in Figure 1b. With these two simple techniques, students can immediately begin accessing all of *PhoneIoT*'s supported sensors including the accelerometer, location sensor, and microphone, the magnetic field sensor, gyroscope, orientation sensor, or step counter, in their programs.

The second main feature of *PhoneIoT* is the **custom interactive display**. This lets students display information from NetsBlox graphically on the phone screen with labels, text fields, image displays, etc., as well as receive information from the user such as button presses, text entry, and joystick manipulation. The *PhoneIoT* block provides *addButton*, *addImageDisplay*, and *addJoystick*—functions that add a widget/element to the screen. These all typically take as input the location and the size of the new widget as well as an optional input which is a list of other values to set; these can control the orientation, font size, text color, background color, and other properties of the widget. Figure 3 shows an example of two widget-adding functions and the resulting phone screen; the image display has been filled with an image taken by the user's camera.

Importantly, one of the optional settings for a widget is an "event" (message type) to send to the student's project whenever the user interacts with the widget, such as pushing a button, moving a joystick, altering the textbox text, or updating the image. This allows instructors to cover important CS topics such as graphical interface design and event-based programming. This feature allows students to implement custom remote controllers for their NetsBlox projects. The example in Figure 3 is all the code needed to send images and text from a student's phone and display them on the NetsBlox stage running in the browser.

Figure 1

(a) Code required to initially connect to a PhoneIoT device ("device" variable holds the device ID) (Left) and (b) Example request for current device location in terms of latitude and longitude (result is displayed) (Right)

```
call PhoneIoT / setCredentials device 25e627fb
```

```
call PhoneIoT / getLocation device
```

Figure 2

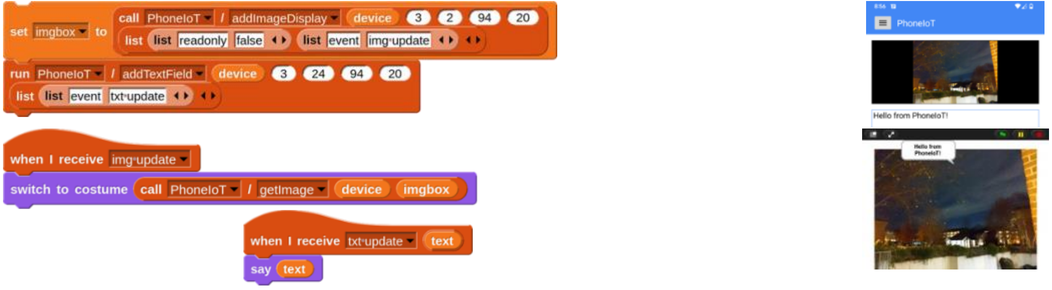
Requesting and receiving location updates every two seconds (2000ms)

```
call PhoneIoT / listenToSensors device list list location 2000
```

```
when I receive location latitude longitude
say join latitude   longitude
```

Figure 3

Example code to make NetsBlox sprites display camera images and say messages from the phone. The top-right image is the phone screen (cropped); the bottom right is the running NetsBlox project.



```
set imgbox to call PhoneIoT / addImageDisplay device 3 2 94 20
    list list readonly false   list event img·update
run PhoneIoT / addTextField device 3 24 94 20
    list list event txt·update

when I receive img·update
switch to costume call PhoneIoT / getImage device imgbox

when I receive txt·update text
say text
```

Preliminary evidence from pilot summer camp

Summer camp description:

PhoneIoT was used in a recent online summer camp to introduce students to distributed computing (DC) and IoT. After a brief introduction to NetsBlox and its DC features through a Weather app and MovieDB app, our project-based, hands-on curriculum advanced to multiple interesting *IoT* applications first involving robots, and then *PhoneIoT* apps such as: (1) streaming and plotting 3-axis acceleration data in real time; this project concept was eventually expanded from gathering raw data into a more engaging app where students recreated the classic labyrinth game with a twist: they could tilt their phone to control the ball on the NetsBlox stage; (2) creating graphical controls such as virtual buttons and touchpads, some of which were later used to implement remote controllers for games such as pong. All projects were done as iterative exercises: the instructors showed the *PhoneIoT* or NetsBlox feature and then students had to complete partially complete code. The capstone project was to turn their phone into a remote controller to command virtual robots (which had been previously introduced in the camp's robotics component) with custom controller layouts and behaviors. Students were free to use any

PhoneIoT features, resulting in creative original projects such as slider-based throttles for each wheel, single joystick-based steering/driving, and button-based controls for discrete commands (e.g., "turn left 10 degrees"). As the final challenge, students used their custom controllers to compete and drive their robot around an obstacle course in as short a time as possible. All students completed all tasks.

Feedback and results:

Nine students of color participated in the pilot camp (6 male, 3 female; 6 Asian, 2 Black, 1 Hispanic) from 9, 10, and 11th grades. Student engagement in the camp was very high. In the post-survey, students ranked rank the 2 distributed computing, 3 robot navigation, and 2 *PhoneIoT* projects from 1 (highest) to 7 (lowest). The *PhoneIoT* projects ranked the highest with average score of 2.2 for the tilting game and 3.2 for the remote controller app. There were significant average pre-to-post gains registered on 4-point likert scale survey questions on confidence, ability, and interest in CS. On the question on knowledge of how to build IoT applications, there was a significant gain on the mean score: 1.4 (pre) to 2.9 (post). Open-ended responses on students' camp experience suggests that their perceptions of computer science became more positive and the camp expanded their understanding of this vast and growing discipline. Sample responses were: a) "*Before, I did not have a lot of experience in "Internet of Things," but this camp provided an excellent introduction. It allowed me to understand how hardware (robots, phones, sensors, etc.) interact with code. Overall, it gave me a good understanding of the field and allowed me to think about it as a potential career option*." b*) I learned a lot about how hardware interacts with the software we make over the course of this camp*." c) "*Programming in general is very broad and we can expand it to many things in computer science.*" d) *I saw ways we use coding in real life, before I thought they couldn't go beyond a computer screen."* These positive findings from our pilot are encouraging and validate our approach and the design principles behind the *PhoneIoT* innovation to make the growing Internet of Things topic accessible and engaging to K-12 students. Our ongoing work involves expanding *PhoneIoT* activities to include more personal apps such as mapping one's walking or running route and overlaying points of cultural and community interest.

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Optimizing Assessment of Knowledge Transfer Through Computational Thinking: An L&D Project

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Abstract: This technological innovation is an outcome based on a call for action to develop a more holistic understanding of computational thinking during problem-solving. Given that the potential to facilitate the transfer of computational thinking skills to more complex and novel problems is critical in higher education, the goal of this innovation was to design an assessment that captures the latter. Through a design-based process with computer science students as co-inquirers, an existing transfer tool was optimized by combining formative-iterative and data-mining assessments at various difficulty levels. Potential outcomes of the design process are discussed considering future educational interventions with computational thinking.

Inspiration for the innovation

This learning and development (L&D) project is based on a need for a combined assessment to unblur *computational thinking (CT)* in educational research. Fostering CT to optimize learning is imperative to solve problems, critically analyze information, communicate, and think creatively and to succeed in an ever-changing digitally powered workforce. For example, we know that students with pedagogical experiences in programming or robotics and personal experiences such as solving puzzles and playing board or card games have mobilized their CT skills in various contexts. Consequently, determining a combined form of assessment that would contribute to a more holistic and complete understanding of CT would seem necessary, especially when assessing its potential to facilitate the transfer of CT skills to more complex and novel problems.

According to Wing (2006), CT implies the ability to engage in five *cognitive processes* to solve problems efficiently and creatively. These include: (1) Taking a large and complex problem, and breaking it down into smaller, more manageable problems or steps, (2) Looking for patterns among the problems, (3) Removing unnecessary detail from the problem, (4) Formatting a general solution, and (5) Coming up with new insights based on the solutions to the problem. Over the last decade, several forms of *assessment* tools have been developed and deployed with varying degrees of adequacy to measure three CT dimensions stated by Brennan and Resnick's (2012) framework: "computational concepts" (e.g., sequences, conditionals, operators); "computational practices" (experimenting and iterating, testing and debugging, abstracting); and "computational perspectives" (expressing, connecting, and questioning). This leads to the affirmation of the need for complementary and unbiased CT assessment tools in educational interventions (Grover, 2015; Román-Gonzáles et al., 2019). It also raises the need to properly combine and provide a more balanced and comprehensive "systems of assessments" at different phases of CT educational interventions and evaluations.

Goal for the technological innovation

A scoping review of CT assessment tools (Cutumisu et al., 2019) revealed that out of 39 studies, $n = 9$ combined multiple measures, such as programming artifacts, surveys, and tangible tasks, to assess different facets of CT (Grover et al. 2015). Moreover, Román-González et al. (2019) provided insights into how to combine assessment tools for a comprehensive evaluation of CT interventions in educational settings and classified them according to their evaluative approach: diagnostic tools (e.g., the Computational Thinking Test by Román-González (2015)), summative tools (e.g., Meerbaum-Salant et al. (2013) in the Scratch context), formative-iterative tools (e.g., Dr. Scratch from Moreno-León et al. (2015)), data-mining tools (e.g., Grover et al. (2017) from the Blockly environment), transfer tools (e.g., Bebras Tasks measuring CT skills' transfer to real-life problems by Dagiene & Futschek (2008)), perceptions-attitudes scales (e.g., Computational Thinking Scales by Korkmaz et al. (2017)), and vocabulary assessment (e.g., verbal expressions of CT language by Grover (2011)). Whereas the diagnostic and summative tools are beneficial to collect quantitative data during pre-post evaluations, they are based on student responses to predefined CT items and provide snapshot images of computational concepts (Brennan & Resnick, 2012), without considering computational practices and perspectives. On the other hand, skills transfer tools provide more authentic assessments that are contextualized in "real-life" problems and assess the extent to which students transfer their CT skills onto different kinds of problems, contexts, and situations; these tools are ideal for educational interventions. Finally, the formative–iterative and the data-mining tools are mainly used during the learning process, in specific programming environments. Data generated from the latter tools are more aligned with learning analytics and thus informative of students' cognitive processes, and, especially useful at analyzing the source code of the programming projects and recording the learner activity in real-time.

From a pedagogical point of view, the potential use of multiple assessments raises concerns regarding the adequacy of capturing CT dimensions at different moments (i.e., before, along, and after) of an educational CT intervention (see example with educational robotics from Chichekian et al. (2022) & Chichekian et al. (under review)). Given that longitudinal research designs that examine CT learning paths are valuable in educational intervention studies that extend beyond the end of the intervention, formative–iterative, data-mining, and skill transfer tools should be included. Additionally, it was pointed out that although different types of CT assessment tools have been developed for grade levels ranging from kindergarten to university students, most of them (84.6%) applied to K-12 settings (Yadav et al., 2016). This is consistent with the growing emphasis on CT curricula for primary to high school students. Considering the most common research designs in educational settings, assessments for different CT dimensions, and the range of the student population age, the goal of the current technological innovation was to *optimize* an existing transfer tool that focused on the learning process during a "real-life" problem-solving task by (1) integrating formative-iterative and data-mining assessments and (2) developing incrementally challenging versions of the tool (i.e., easy, medium, difficult).

Design principles

In the first phase of the design process, a literature review was conducted regarding the relationship between CT and knowledge transfer in higher education. This was accomplished by a summer (2021) intern who had applied to a project we had submitted through MITACS Globalink research. The latter provides funds to undergraduate students all over the world who have applied and been selected through a competitive process to work with a professor on a research project for 8-12 weeks during a summer semester. First, a list of tools measuring the application of CT was extracted from the readings that resulted from the literature review search. Second, the type of tool was defined (e.g., survey, multiple choice, problem-solving task, logic game). Third, because CT concepts have been a popular target for research and curricula development, generalized computer science principles, such as algorithmic thinking, abstraction, and problem decomposition were used as categories to classify the problem-solving tasks found in each tool. A second rater (a computer science instructor) validated 25% of the categorization and a 90% agreement was reached (the remaining was resolved through discussion until full consensus). Fourth, a difficulty level (easy, medium, difficult) was assigned for each task based on the time it took to solve the problem and the length of the word problem. Fifth, the 135 problem-solving tasks that were extracted from all the tools were randomly selected and distributed equally to 9 evaluators (university professors, graduate students, and industry partners) to receive feedback on (1) the agreement of the categorization, as well as a suggestion of another category in case of disagreement and (2) suggestions on how to increase the level of difficulty for each problem.

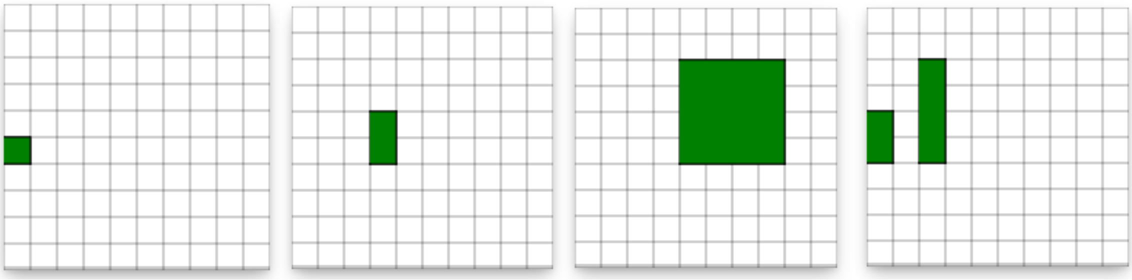
In the second phase of the design process, a 12-week internship was organized the following summer (2022), but this time with three first-year students (2M, 1F) in a computer science technology program and with the collaboration of a computer science instructor. The overall purpose of the internship was to provide novice students in a career-oriented program an opportunity to learn how to design an interactive web version from a pen-and-paper version of a task and implement it into a web component. This implied understanding complex structures and technical details regarding problem-solving and programming logic skills. During the internship, students worked online through a shared collaborative platform. Funding for the internship was provided by Social Sciences and Humanities Research Council of Canada. Before the internship, the computer science instructor and the researcher met to select a handful of problem-solving tasks out of the 135 that were identified in phase 1. The selection criteria were based on the task's potential to be modified and become more interactive, as well as the possibility to be rewritten in different versions based on a difficulty level. Given that the goal of the current technological innovation was to optimize an existing tool by combining formative-iterative and data-mining assessments in a context where a potential transfer of CT skills would be possible, we opted to limit our selection of problem-solving tasks to the Bebras tasks (https://www.bebras.org/). These tasks consisted of a set of activities requiring the students to transfer and project their CT skills to solve "real-life" problems. As such, the Bebras Tasks were classified as a CT skill transfer assessment tool and because they did not require any prior knowledge of any software or hardware, they could be administered to individuals without any prior programming experience. These tasks also easily catered to the implementation of learning analytics. For example, programming for click counts from the beginning to the end of task completion was embedded as a form of data-mining assessment and a playground was added before the actual problem-solving task as a form of formative-iterative assessment. Automated feedback was also incorporated into the actual task completion by providing students with two occasions to solve a problem wherein an animation of their wrong solution would be available for viewing before a second attempt.

At first, the students worked in a team on one problem-solving task that they collectively opted for and wrote a program collaboratively. Next, they each selected three different problem-solving tasks to work on and continued autonomously but with weekly meetings with the computer science instructor to share their progress and receive feedback. Once an initial version of the prototype comprising 10 problem-solving tasks was ready, a brainstorming session took place with the three students, the instructor, and the researcher to propose ideas on how to add incremental complexity in each task based on the suggestions provided regarding the difficulty levels in Phase 1 and revisit the wording, formatting, and visual representation of each task while considering principles of EDI. A first pilot was then tested with close friends and colleagues to ask for feedback and refine the prototype. Feedback questions focused on the user experience, namely ease of understanding regarding the description and goal of the task, text and response field formatting, and picture quality. Suggestions on how to improve user experience were also part of the feedback that was sought. The latter resulted in (1) modifying task descriptions to clarify the expected outcome and the role of the playground, (2) revisiting the levels of difficulty for each task, and (3) refining the visual representation (i.e., colors and sizes of images). In the next phases, a pilot is anticipated to be launched with a larger population from an online crowdsourcing platform to validate the tasks with other forms of combined assessment (e.g., surveys on CT skills), and in Winter 2023 testing the tasks with a sample of elementary preservice teachers in math education classes. See Figure 1 for an example of the task Plant Life (an interactive version will be available during the presentation).

> The Beaver loves flowers and has invented a simple programming language for visual design based on the idea of plant life. Each plant starts with a square called “a”. A visual object can perform three operations: Grow(), Split(), Die(). The following program (not shown here) explains these operations. Once you have understood how the plant functions, try to replicate the plant represented next to the list by placing in order the correct sequence of commands.

Figure 1

Plant Life Starting Position for All Levels (a), Easy (b), Medium (c), and Hard (d) Difficulty Levels



(a) (b) (c) (d)

Potential outcomes of the design process

Providing evidence of how CT is generalizable and how it can transfer to different and novel problems (Barr & Stephenson, 2011) can shed light on the underlying factors that contribute to the development of competence in CT. On an *educational level*, CT is a good predictor of academic performance (Haddad & Kalaani, 2015), suggesting that it could be used as an early intervention indicator to increase students’ retention and progression in all disciplines. It can also inform the design of learning experiences that calls upon knowledge transfer in novel situations and that embeds incremental levels of complexity regarding the application of CT in a problem-solving process. Further efforts could also focus on exploring the validity or the pedagogical usefulness of the current tool during educational interventions. Ultimately, interactive tools that provide insights about learning analytics can be assessed alongside cognitive ability tests not only to create appropriate CT interventions to improve students’ CT skills and attitudes, but also potentially contribute to other testing services such as PISA or admission tests.

Similar to co-op opportunities that combine academics with practical paid work experience for undergraduate and graduate students, paid internships for novice college students at the beginning of career-oriented or technical programs proved to be beneficial to initiate collaborative work among peers and with experts from the field. Encouraging student interactions (amongst each other and with the technology being developed) in the design process of technological innovation is optimal for positive learning experiences, especially in the early years of a career program to maintain a certain level of motivation and engagement. While the involvement of students during the design of this technological innovation focused more on the development of skills and knowledge for college and career readiness, the need to integrate more recent framings such as situated CT (identity, participation, creative expression) and critical CT (political and ethical impacts of computing, justice) (Kafai et al., 2019) are warranted for the advancement of a pedagogical perspective in line with learning theories.

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Using a Visual-Based Coding Platform to Assess Computational Thinking Skills in Introductory Physics

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Abstract: Developing assessment tools for computational thinking (CT) in STEM education is a precursor for science teachers to effectively integrate intervention strategies for CT practices. One problem to assessing CT skills is students' varying familiarity with different programming languages and platforms. A text-neutral, open-source platform called iFlow, is capable of addressing this issue. Specifically, this innovative technology has been adopted to elicit underrepresented undergraduate students' debugging skills. We present how the visual-based coding platform can be applied to bypass programming language bias in assessing CT. In this preliminary study, we discuss design principles of a visual-based platform to effectively assess debugging practices – identification, isolation, and iteration – with the use of iFlow assignments. Our findings suggest how the ability of iFlow to test parts of a program independently, dataflow connectivity, and equity in removing biases from students' various backgrounds are advantageous over text-based platforms.

Introduction

In STEM education, computational thinking (CT) has become a critical component in preparing students for the technical workforce (NSF, 2020). Practitioners are, however, facing problems integrating and assessing CT in the STEM curriculum (Wang et al., 2021). CT presents an additional stumbling block for underrepresented groups in building the pipeline for computational-related careers (Thomas et al., 2018). Our central proposed intervention strategy is for students to create computational solutions to science problems without, at first, requiring them to master intimidating syntax and semantics. This can be accomplished with the aid of a visual-based programming tool, so that we can make students' computational thinking visible while they are shaping it (Ainsworth et al., 2011). We collaborated with the developers of one such tool, called iFlow, where we can create a beta version suitable for our needs. The goal is to design assessment tools for evaluating the effectiveness of visual-based programming in facilitating students' CT skills. We report on one of the assignment questions for eliciting CT skills of debugging, which students self-identified as a barrier in our preliminary study (Hylton et al., 2021).

Innovative visual-based programming platform – iFlow

Visual-based programming was implemented by the application of iFlow. Inspired by the Unified Modeling Language and dataflow programming paradigm, this constructionist environment (Papert, 1991), named iFlow, models a program as an executable directed graph depicting the structure of a computational solution and the interactions among its constituents. The results emerge as data flow through these interconnected elements (see Figure 1 as an example). While there exist successful dataflow programming products such as Grasshopper, LabVIEW, and Simulink, most of them are tailor-made for specific applications that may not be appropriate for introductory courses. For example, Grasshopper only works within the Rhinoceros 3D computer-aided design software, LabVIEW is mostly used in data acquisition and instrument control, and Simulink focuses on modeling multi-domain dynamic systems. By comparison, iFlow is a general-purpose, Web-based, and integrated computational environment designed for students to solve common problems encountered in the science curriculum, with an objective to meet diverse educational needs of students with various backgrounds and interests in science. To clarify, although it bears some resemblance to system dynamics software such as Stella and Vensim, iFlow is not a system dynamics modeler. In iFlow, the representational blocks are directly manipulable (e.g., pulling a slider changes the variable it represents). Their changes can be immediately transmitted across the connector networks, updating the linked nodes on their way and making the entire diagram interactive

iFlow debugging assignment

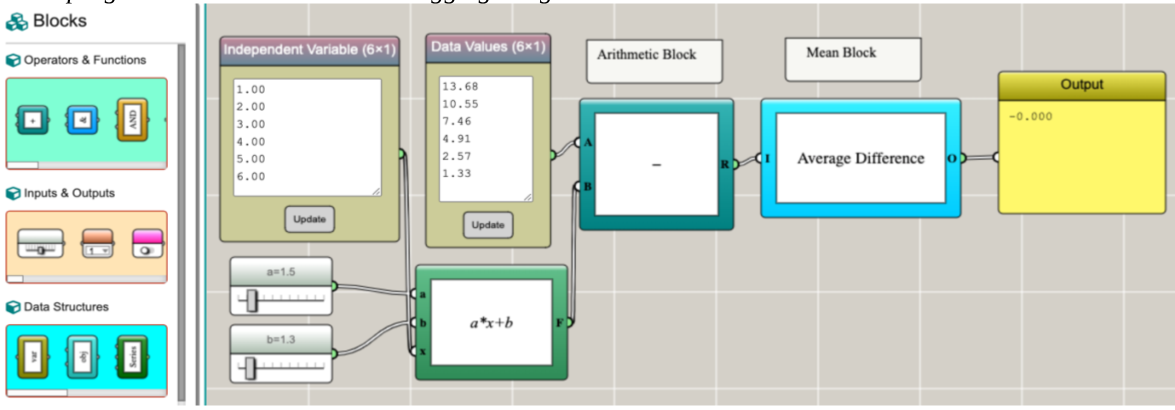
We describe an assignment intended to elicit and assess users' debugging skills. The assignment prompt is:

> Your lab partner devised a method to test whether the function shown in the *Multivariate Function block* (the green block in Figure 1) is a good fit to the data. S/he decided to subtract the data values from the function values (using an *Arithmetic block* [see Figure 1]) to see how

close they are as a test of goodness of fit. S/he also decided to average the difference of each data point (using the *Mean block*), and since the average is 0 as shown in the *Output block*, s/he decided that the fit is very good. Your job is to decide whether you agree or disagree with your lab partner's work, and if you disagree to improve on the work.

The assignment in Figure 1 illustrates some of the blocks where we can store arrays, define functions, assign variables, do arithmetic computations and statistics, and display outputs. The assignment program was constructed by dragging appropriate blocks from the left "Blocks" palette to the working canvas. The function of each block was described to the student via a manual and training exercise. The blocks are connected via the nodes on the left and/or right sides of the blocks, which represent the input(s) to and output(s) from the blocks. Each block has properties that are listed in table form (by right clicking on the block) that can control each block. The assignment was given to 13 STEM majors in an Introductory Physics lab. A post-activity survey was implemented to collect students' reflection and feedback.

Figure 1
iFlow program associated with the debugging assignment



Independent Variable (6×1):
1.00
2.00
3.00
4.00
5.00
6.00

Data Values (6×1):
13.68
10.55
7.46
4.91
2.57
1.33

a=1.5

b=1.3

Output: -0.000

We hypothesize that this visual-based programming can enhance students' cognitive processing of data flow, which would lead to a stronger performance in more traditional computing tools, such as text-based Python and visual-based LabView. This question can be used to assess debugging skills, because it purposefully introduces an error in testing the goodness of fit, which is an essential part of common data analysis in introductory physics courses. The error introduced is averaging the deviations to gauge goodness of fit. This will not work since some deviations are positive and some are negative. Students with more advanced debugging skills should be able to graph the data and fit function with iFlow (see Figure 2) to realize that the fit is not good.

Assessing cognitive processes of debugging in iFlow

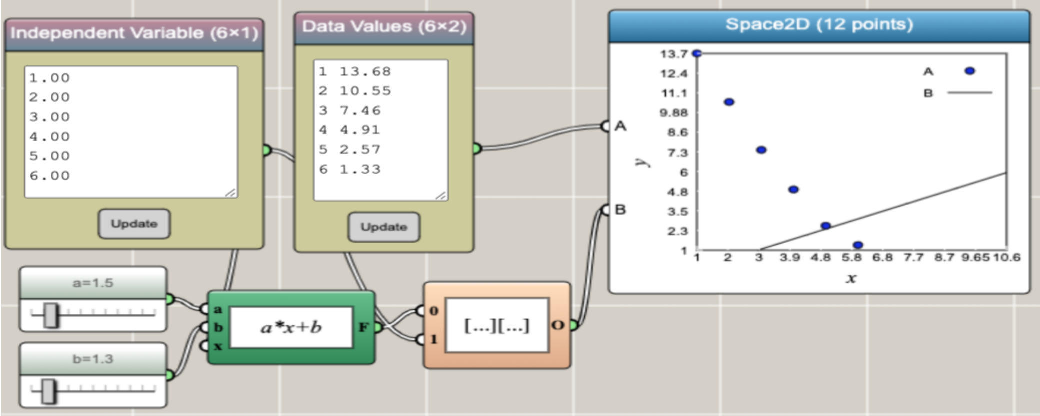
iFlow program makes the assessment of debugging practices easier, because it could not only help assess the processes involved in fixing errors, but also resurface the cognitive processes of completely understanding the errors. Such affordance could mitigate the problem, where errors are often fixed without systematically investigating them, and thus, learners are prone to repeat the errors (Li et al., 2019).

We classify the debugging practices dealing with errors into three cognitive processes—identification, isolation, and iteration – adapted from the work of Weintrop and his colleagues (2016). *Identification* focuses on how one makes sense of the solution, *isolation* focuses on one's systematic investigation of the issue, and *iteration* focuses on how one reproduces and fixes the error. To illustrate each cognitive process, we prompted the students with the following questions as a protocol in eliciting thought processes: 1) *Do you AGREE with the given solution? 2) If Yes, explain your reasoning in the space below. 3) If No, you should improve on your solution. 4) Record ALL the things you did to justify your decision and to improve the solution. These things should include anything you did to acquire information needed to understand ALL the issues you identified. For example, if you tried to understand the properties of a block outside of the computational problem, then it should be included in the list of things done.*

For numbers 1-3, we expect students to spot some issues in the solution shown in Figure 1. For example, the deviation (computed by the arithmetic block) can average to 0 as shown in the output block, but with further investigation, a graph generated by an exemplar student (see the Space2D block in Figure 2) reveal that the solution proposed in Figure 1 is inadequate. For number 4, students are prompted to list their actions, so that we can evaluate whether they engaged in the investigative processes. For instance, students should research the error enough to eliminate the canceling of the deviations by comparing the data values (shown as the blue points in Figure 2) to the line fitted to the data (shown as B in the legend of Space2D block in Figure 2). Another issue is the type of function, and students should realize by the practices involved in *isolation* and *iteration* that the linear function is not the best solution.

Figure 2

Sample systematic investigation of an exemplar student on the computational errors in goodness of fit.



```
1.00
2.00
3.00
4.00
5.00
6.00
```

```
1 13.68
2 10.55
3 7.46
4 4.91
5 2.57
6 1.33
```

Design principles of iFlow in assessing debugging

Assessing cognitive processes of debugging can be done in common text-based programming, but visual-based programming has some advantages over text-based programming (Navarro-prieto & Cañas, 2001; Saito et al., 2017; Weintrop & Wilensky, 2017) and assessment. First, iFlow helps its users to investigate blocks independent of the rest of the program, which usually cannot be readily done in text-based programming (e.g., usually, one has to disable the rest of the program in order to check one part). For assessment purposes, iFlow makes it easier for students to isolate and trace back the steps without breaking the entirety of the programming solution (e.g., Figure 2). For researchers, iFlow is advantageous over text-based programming, because we can evaluate what the tendencies of users are when they engage in debugging, such as: 1) identifying an issue based on the visual computational solution, 2) deciding which part of the visual-based computational solution is a reasonable cause of the error, and 3) systematically studying how the cause of error. Therefore, iFlow better helps the practitioners and researchers evaluate investigative processes pertaining to how students isolate errors and fix them.

Second, we believe that iFlow encourages debugging because it visually shows connectivity and relationship among different components on the same page. The hierarchical linearity or non-connectivity involved in the text-based programming usually overwhelms novice students, preventing them from even attempting to identify the issue (Mosemann & Wiedenbeck, 2001), which deters any assessment endeavor. In visual-based programming, students can trace the source of error and test various ideas in a more systematic manner. Correspondingly, the inputs of text-based codes could be assigned hundreds of lines back in the program before being called into computing. Such a gap and lack of connectivity may demotivate students in science classes to engage in the practices of debugging. As a result, iFlow is more suitable than text-based platforms in assessing debugging, since the interface is more welcoming for users to engage in debugging practices.

Third, all of the students can be provided with an equal background in iFlow, which may not be possible if the same platform, such as Python or Excel, is used in the science courses for assessment purposes as well as coursework. The coursework platform for assessment may impose bias since students would have varying backgrounds and familiarity. For instance, we may not be able to assess the cognitive processes in *isolation* correctly if some of the students already know how to deal with the purposeful errors. These students can bypass some of the debugging sub-practices, which makes their prior knowledge interfere with the assessment. Thus, the validity of the assessment is jeopardized.

Discussions and implications

In this technology innovation paper, we only presented the application of iFlow to the assessment of debugging skills. Based on students' positive feedback, such as "*The biggest thing is that iFlow is the most straightforward [compared with Python]. If there's anything that you're not understanding, you are able to just see it.*" we conclude that visual-based programming would be efficient in assessing debugging skills, such as the ability to see the various connections shown on iFlow interface. A few of the advantages are: ability to test parts of a program independently, dataflow connectivity, and equity in removing biases from underrepresented students' various backgrounds. Visual-based programming, such as iFlow (Hylton et al., 2021), is an innovative technology to teach computational thinking in STEM courses. It is a powerful platform not only for students to be able to solve computational problems in science, but also for researchers to assess pupils' learning in various aspects.

The assignment developed for assessing debugging skills can be applied to both text-based and visual-based programming. In our future studies, we plan on building debugging skills of students in STEM courses by an appropriate intervention whose effectiveness can be assessed and refined using appropriate debugging rubrics.

Nevertheless, with the promising affordance in assessing CT in STEM education, there are some limitations to this innovative technology. For instance, iFlow requires more development, as is planned, so it is more responsive to the various needs and provides a smoother interface, such as comparing similar computational solutions side by side without the need to open multiple cloud files. In addition, because the interface is different from conventional text-based programming, it requires constant customization of different manuals and user training materials that are tailored for instructional use.

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Designing a Student Progress Panel for Formative Practice: A Learning Engineering Process

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VitalSource

Abstract: Providing students with research-based learning tools is a necessary part of developing learning environments, and additionally, the design of those learning features is critical for their success. It is well established that doing practice questions while reading is better for learning—yet how how students monitor and navigate to this formative practice in the learning platform can impact the success of this study tool. In this paper, we address the learning science and design considerations of a student-facing progress panel using the learning engineering process model as the development framework. Student data and survey feedback is interpreted from the first class of university students to complete the formative practice using the progress panel in the textbook e-reader platform. Directions for future iterative improvements and research are also discussed.

Introduction

The shift to digital textbooks provided an opportunity to transform passive texts into interactive, learn-by-doing resources. Formative practice is well known to be beneficial for students, but the research on the learning science principle, the doer effect, established that doing formative practice while reading was not only effective for learning, but causal (Koedinger et al., 2016; Van Campenhout et al., 2023). To bring this active learning approach to more students, artificial intelligence was used to generate formative practice for thousands of digital textbooks to provide students with a free learn-by-doing study tool. Yet the existence of the practice questions themselves was not sufficient to fully support students. Students needed a way to monitor their progress and navigate to the questions. In this paper, we discuss the design process of a student-facing data dashboard and the first data and feedback gathered from students using it in a Public Relations course at a major public university.

The learning engineering process (LEP) model (Kessler et al., 2022) is used as a framework to describe the design process, the first implementation of this student progress panel in natural learning contexts, and the initial data collected that will inform future iterations. While learning engineering as a practice applies engineering design methods with human-centered design and data-driven decision making to support learners (Goodell et al., 2022), the LEP is a model that provides structure for solving educational challenges (Kessler et al., 2022). This design example serves as a case study for applying learning engineering for student-centered design and development at large. The LEP is grounded in context: who are the learners, who is on the team, and what is the central challenge? The central challenge for this project was to design a data dashboard that would provide students with basic information about the practice available and completed while also providing navigation functionality. This feature needed to be a seamless component of the e-reader and accessed by all learners in all learning contexts in any textbook for which the questions were available. A team of learning scientists, designers, engineers, and product managers worked together to create the final solution presented here.

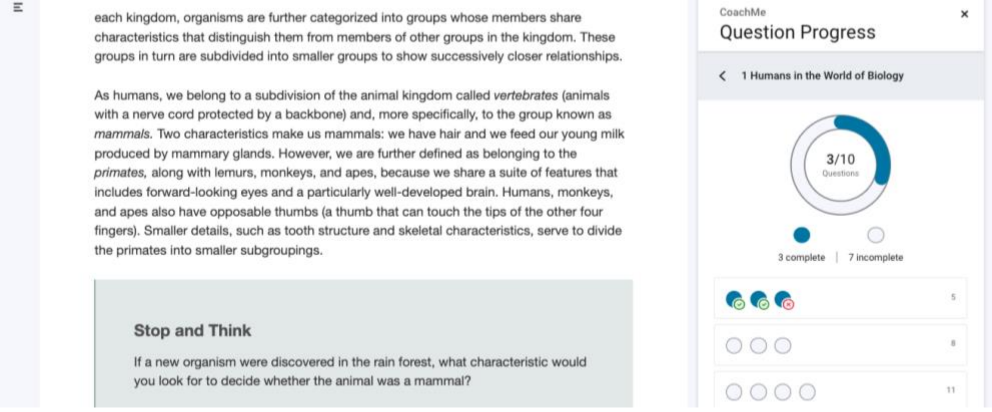
Design

The LEP creation phase includes design, development, instrumentation, and implementation planning (Kessler et al., 2022)—all of which was necessary to create the progress panel, and each step was occurring concurrently. Instrumentation (the data gathering) would be done through both platform clickstream data as well as student surveys, all of which would occur during the research project. Additionally, the design stage itself went through iterations until the final design was completed. Three primary objectives guided the design of the progress panel: ease of navigation between progress and questions, user recognition of question progress and completion status, organization of question progress to increase motivation. Within each design iteration, we considered learning science research, usability heuristics, accessibility guidelines, and common trends across our platforms and others. After iterative cycles and feedback from the learning engineering team, each of the guiding objectives were tested during usability sessions, which confirmed there was no task delay and the experience was intuitive for the user.

The first goal was to create an easy mode of navigation between the progress panel and questions. The challenge was that students must be able to easily discover, navigate, and understand the connection between the questions, the text, and the progress panel. Nielsen's usability heuristics (1994) of user control and freedom, and consistency and standards were used to guide the design. Using a progress panel was consistent with other features in the platform and provided enough screen real estate to accomplish all of the objectives, and make additions or changes in the future. To provide students with control and agency, multiple navigation touchpoints were added so students could access the panel from multiple locations depending on their current course of actions.

Figure 1

The progress panel open next to the corresponding chapter of text.



each kingdom, organisms are further categorized into groups whose members share characteristics that distinguish them from members of other groups in the kingdom. These groups in turn are subdivided into smaller groups to show successively closer relationships.

As humans, we belong to a subdivision of the animal kingdom called *vertebrates* (animals with a nerve cord protected by a backbone) and, more specifically, to the group known as *mammals*. Two characteristics make us mammals: we have hair and we feed our young milk produced by mammary glands. However, we are further defined as belonging to the *primates*, along with lemurs, monkeys, and apes, because we share a suite of features that includes forward-looking eyes and a particularly well-developed brain. Humans, monkeys, and apes also have opposable thumbs (a thumb that can touch the tips of the other four fingers). Smaller details, such as tooth structure and skeletal characteristics, serve to divide the primates into smaller subgroupings.

Stop and Think

If a new organism were discovered in the rain forest, what characteristic would you look for to decide whether the animal was a mammal?

The second goal was to maintain clarity on question progress and status. One of the biggest challenges was on how to balance informing the student of their progress in terms of question completion while also surfacing accuracy information. The primary goal of the questions as formative practice is to give students a no-stakes opportunity to check their understanding of the content, allowing them to continue to answer the practice until correct. Given this central objective from the learning science perspective, question completion needed to be the primary status. However, when answering questions, students receive correctness information which should be clearly surfaced. Adding the red *x* and green *check* to the progress completion circles created a consistent and recognizable connection between the question answering experience and the progress bar, utilizing the recognition over recall heuristic (Nielsen, 1994) to help students better understand what the question markers represent.

The third goal was to show question progress in a manner that motivated students to complete questions. The organization of questions in the progress panel presented a challenge, as listing individual questions could take significant screen real estate while also overwhelm students when seeing hundreds of incomplete questions. The aesthetics and minimal design heuristic was considered when determining how to group and organize questions. The solution was to limit visible questions to the chapter level, and then group questions by activity enrichment. This question organization was also intended to help facilitate motivation in the chapter-level progress circle and question completion markers. The hope was to motivate students without relying too heavily on gamification features, which has mixed research results (Zainuddin et al., 2020).

Accessibility is always considered during the design process to ensure the solution will be functional and meaningful for all students. The W3C standards provide success criterion that are useful guides to check during the design process. For example, W3C success criterion states that the use of color should not be the only means for conveying information to students, as not everyone can visualize color (W3C, n.d.). To solve for this accessibility challenge, completeness became the contrast between a dark solid and a light gray to convey "filling in" without relying on specific colors. For correctness information, the *x* and *check* were included with the red and green color standards for correctness so those with a color impairment would have the symbol cues to follow.

Implementation

The implementation phase of the learning engineering process is when the solution is put into practice—in this case, used by students in natural learning contexts. As a feature of the e-reader, the progress panel could be released as part of a platform update and was targeted for August of 2022 to be available to a higher education institution who was engaging in a research study on the practice feature. Initial feedback on the progress panel feature was provided by students using a Public Relations textbook between August and October, 2022. The instructor created a point scale with a maximum of five points per chapter for completing a minimum of 80% of the available practice questions. As students worked through the textbook chapters, their use of the practice was recorded by the platform and the instructor was provided with data reports that showed how often students were using the textbook, as well as the percentage of practice students were completing per chapter. Given the formative nature of the questions, first attempt accuracy was not a component of instructor reporting or student grades—

only completion. After students had completed the textbook chapters required for the course, they completed a short survey to identify their perceptions of the questions as a study tool. This survey also included three items on the progress panel to identify how students interacted with this new feature. The survey link was distributed by the instructor during class, students were not required to complete the survey, and all results were anonymous.

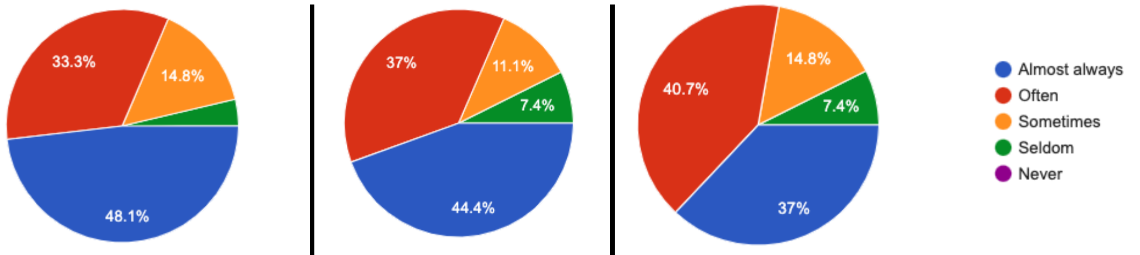
Results

Data analysis is crucial to the investigation phase of the LEP (Kessler et al., 2022), and both completion data and student surveys were used to evaluate the progress panel. Table 1 shows the final completion data from the instructor's data report (only 10 of 31 students shown for brevity). Each student's total percentage of practice completed is calculated for each chapter. On its own, this data reveals some interesting insights into student behavior. Many students did 100% of the practice for all assigned chapters, even in chapters with 40+ questions where they could have stopped at 80% of the practice and still received full points. This was particularly surprising to us, given that years of internal data analysis revealed that only about 5% of students will voluntarily complete practice when not required. This can also be seen in Step (chapter) 8; 9 of 31 students did practice in this chapter when it was not assigned. This high completion of practice—above what was strictly required—caused us to wonder if the progress panel could be partially responsible for this behavior. Lastly, several students (5, 6, and 9) repeatedly stopped doing practice at the low 80% range—exactly the minimum amount of practice needed to full points. This indicated to the team that students were using the progress panel to monitor the amount of practice they had completed in order to ensure they had done enough to receive full credit.

Table 1
Sample data report showing days used and percentage of practice complete for each chapter and the entire book

Total Questions		**18**	**10**	**27**	**10**	**67**	**48**	**43**	**14**	**19**	**256**
Name	**Days Used**	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 5**	**Step 6**	**Step 7**	**Step 8**	**Step 9**	**Book**
Student 1	8	100	100	100	100	100	100	100	0	100	94.5
Student 2	7	100	100	100	100	100	100	100	0	100	94.5
Student 3	10	100	100	100	100	100	100	100	100	100	100
Student 5	9	100	100	100	100	100	100	100	0	100	94.5
Student 6	9	0	0	0	0	0	89.6	83.7	0	84.2	37.1
Student 7	10	100	100	81.5	80	82.1	83.3	93	100	100	88.3
Student 8	11	94.4	100	100	100	100	100	100	0	63.2	91.4
Student 9	12	100	100	100	100	100	100	100	0	100	94.5
Student 10	12	100	100	100	100	80.6	81.2	83.7	0	100	83.2

Figure 2
The results of the three student survey items on the progress panel.



How often did you use the progress panel to monitor how much practice you completed?

How often did you use the progress panel to navigate to the practice questions?

How often did seeing the percentage of practice you completed for a chapter in the progress panel motivate you to complete more/all of the available practice?

The survey included three questions about how students used the progress panel and the results from the 27 students who participated are shown in Figure 2. The first question on how often students used the panel to monitor the amount of practice completed was a pleasant surprise, with nearly half of students responding "almost always," and another third choosing "often." Only one student selected "seldom," and this could potentially align with the small fraction of students were minimally engaged (student 6 of Table 1, for example). This question

confirmed that the progress panel was a helpful feature for students to know how much practice they had completed, even helping students to ensure they had done the minimal threshold of practice required to receive full points as observed in Table 1. While the exact percentage of students in each category shifted slightly, most students also used the progress panel to navigate to questions often or almost always. Given the importance of navigation as a feature during the design process, student responses to this question confirmed that the navigation feature was being used as part of the students' learning process and therefore was a valuable addition.

The third question asked how often seeing the amount of practice completed in the progress panel motivated you to complete more or all of the practice, and 37% of students chose "almost always" and another 40% chose "often." These responses help to confirm that the design of the progress panel was having an influence on how students were engaging with the practice—in many cases, motivating students to complete more than the minimum threshold of 80% of the practice. While Table 1 is only a representative sample, the student responses to this question on motivation can be proportionally mapped to the completion data seen for students.

Discussion: Iterative improvement

In this learning engineering process, the central challenge was to design a solution that showed students their progress and accuracy on the formative practice while also serving as a navigation tool to get to questions and the corresponding textbook content. The final solution was developed with input from a learning engineering team using established design heuristics and research from the learning sciences. In partnership with an instructor, the questions were assigned as part of students' course grade, providing the first opportunity to gather feedback on how this new progress panel was used. The data revealed that students were using it to monitor their progress, and sometimes even to stop at the minimum required percentage—a practical and necessary function of the progress panel. For the high percentage of students completing 100% of practice for chapters when only 80% was required, the student survey revealed that the progress feature helped motivate students to continue answering practice beyond that minimum threshold. The completion data and student surveys both confirmed the progress panel design was successful for each of the three original design objectives.

In this design challenge, the LEP facilitated team collaboration for the design, implementation, and analysis of the progress panel solution. While this initial investigation indicates that the progress panel is functioning as intended for students, it is also part of the LEP to continue to iterate and improve. For example, future design iterations may investigate if adding a static visual indicator of the progress panel on the e-reader interface could increase student engagement. Iterative improvements may also include other components of the LEP such as data instrumentation. Adding data events for interactions within the progress panel itself would help to study how students interact with the panel in the context of the rest of the experience. Continued research will further advance what is known about student motivation, formative practice, and effective design features.

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A Conceptual System Design for Teacher Education: Role-Play Simulations to Train Communicative Action With AI Agents

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Abstract: This research project focuses on enhancing student teachers communication skills, particularly for prospective teachers, using digital learning tools and framing communication accordingly to Habermas` differentiation of strategic and understanding-oriented communicative action. Specifically, we conducted an experimental study to compare the effectiveness of avatar-based versus video-camera-based interactions in training communication skills. Our findings suggest that the avatar-based approach may be more effective in some aspects than the other. Building up on these results, we are planning to develop an AI agent as a facilitator. This agent will provide feedback and guidance to prospective teachers to support the development of their communication skills. Overall, this research project aims to contribute to the field of teacher education by exploring the potential of digital learning tools to enhance communication skills training.

Theoretical background

For prospective teachers, in order to perform effectively in their professions, not only subject specific competencies are necessarily helpful but generic competencies are also equally important. It is also observed that subject-specific competencies are sufficiently available, prospective teachers often report a lack of generic competencies (e.g. communication competence). Communication skills are mentioned as a key learning outcome of higher education in national and international research papers (germany: Kultusministerkonferenz, 2019; international: OECD, 2013). In order, for prospective teachers to be able to cope with their everyday professional life, they use communication (Braun et al., 2016). Communication is not only needed in the classroom with pupils (e.g. teaching, classroom disruptions), but also among colleagues, school manager, and parents. Even if it is taught in study program, often, students feel insecure to transfer from teacher education to classroom and studies show that teachers feel inadequately prepared to apply generic skills. Especially in the teaching profession, they have difficulties with practicing (Dicke et al., 2016) and are confronted with the so-called “practice shock” (Stokking et al., 2003).

Communication competences represent an essential aspect of performance in social interactions. We define communicative competences as a person's ability to achieve goals in a socially appropriate manner (Habermas, 1984; Braun et al., 2018). Our theoretical framework is based on Habermas’ (1984) theory of communicative action. He differs between two type of communicative action, which are strategic and understanding-oriented communication. Communication can be used to directly reach a hidden conversation goal or remain open for argumentation (Habermas, 1984) - depending on the context, the choice of communication type is essential for achieving the goal.

To train prospective teachers on communicative skills, simulations are well suited (Chernikova et al., 2020). Simulation methods are a pedagogical tool with which learners can interact to mimic real life almost authentically (Cook et al., 2013). Role-playing represents one form of simulations and is considered an effective teaching method and their potential for teacher education has also been demonstrated (Braun et al., 2016; Crow & Nelson, 2015; Gartmeier et al., 2012). But there is also seen potential of role-play simulations in virtual learning environments in German higher education (e.g. Fecke & Müller, 2022; Kunze, Mohr & Ittel, 2016). To enable students of teacher education in developing their communication skills in a safe learning setting, we are developing a virtual learning environment (3D avatar; agent -based interaction) in which the learners can practice their conversation skills with an AI agent. The AI bot represented by an agent that take forward the conversation about a typical situation in the context of school with the learners. Such typical situations may include a conversation with a colleague (teacher-teacher interaction) in which, for example, one colleague confronts the other about a missed deadline, or a teacher-pupil interaction in which the student complains about his or her grade. They will be able to react intelligently to user’s interactions and can suggest various constructive alternatives of interacting (e.g. making counterexamples). The use of 3D AI agent in teacher education to train communicative action enhances teachers' interpersonal skills. The 3D AI simulations were effective in providing teachers with opportunities to practice and improve their communication skills, including active listening, empathy, and verbal and nonverbal communication. Moreover, the use of 3D AI agents allowed for personalized and adaptive training, as well as real-time feedback on the teachers' performance (Chen et al., 2020). These findings suggest that AI 3D chatbots have the potential to be an effective tool for training teachers in communicative action and improving their effectiveness in their profession. Habermas' theoretical distinction between communicative action and strategic action was used as a framework for designing our AI chatbot that can facilitate communication and collaboration in educational settings (Kanwar, 2021).

Research questions

Given this theoretical framing, this paper has two main objectives:

1. What are the specific advantages and disadvantages of the two different digital learning environments - videocamera-based interaction versus avatar-based interaction?
2. Building on the findings of the preliminary project: how can we develop an avatar-based AI agent? This question will be explored by presenting the initial results of our ongoing research in this area.

Procedure

In Summer 2021 (April to July) – in an experimental design – the performance-based simulations were conducted with professional trained actors and students of teacher education (n=61) in two different virtual learning environments (avatar-based and video-camera-based interactions). Before the simulations the participants were randomly assigned into avatar-based (n=29) and video-camera-based (n=32) interaction groups. Avatar-based interaction means, that the one's own person is represented by an avatar in a 3D-virtual environment. The participants and the trained actor were represented by an avatar and were able to interact with each other. The video-camera-based interaction took place in a conventional videoconference tool; where the trained actor had a role-play with students of teacher education on oral communication skills. In each learning environment, the students performed simulations to test their communicative competencies with professional trained actors in a two-way conversation. Here, the trained actors were simulated in several social roles, such as an equal colleague, a pupil, or a supervisor. In doing so, the students of teacher education remained in their role as future teachers. Also, the simulations were recorded by video. We collected quantitative and qualitative data from this experimental study conducted during a semester session of regular teaching course.

An external assessment was used to measure the communicative competencies: During the simulation, the overall assessment of the performance of communicative competencies was evaluated by means of standardized observation sheets by two silent raters based on 4 items rating, capturing the behaviour of students in the simulation.

In addition, self-ratings of communication skills were also used twice: the students filled in the questionnaire once before and once after the role-playing. With a total of 29 items and six subscales, students filled out a questionnaire of self-rated competencies of knowledge processing, systematic, presentation, communication, cooperation, and personal competencies (Braun & Leidner, 2009).

Also, focus groups (moderated group discussion) were conducted: here, the students of teacher education were asked to assess, among other questions about advantages and disadvantages regarding communication in the specific learning environment and the role of the tool used (avatar-based vs. video-camera-based) for the study. The analysis was done by summarizing qualitative content analysis (Mayring, 2015).

Results

Regarding the first aim, we compared the video-camera-based interaction with an avatar-based interaction. Following we presented an overview of the main results:

The quantitative analysis shows that in the avatar-based interaction, self-assessment correlates moderately with external assessment of communicative competence (correlations between self-assessment and external assessment is r=.618, p=.001), while this is not the case for the video-camera-based interaction (correlations between self-assessment and external assessment r=-.116, p=.549).

The focus groups provide a possible interpretation: while in the avatar-based interaction it is clear from the beginning that non-verbal communication is omitted and students can focus on the spoken word, the video-camera based interaction requires attention on non-verbal communication (Fecke & Müller, 2022). This makes it more challenging and leads to possible irritation. In the video-camera-based interaction, even the person is seen on the screen, but facial expression and other gestures are hard to understand via this transmitted social interaction. The participants in the avatar-based interaction also pointed out, that hiding behind the avatar made them feel more secure and it was easy to have the communication within simulated environment (Fecke & Müller, 2022). The results suggest that avatar-based interaction is more appropriate as an initial introduction to practice.

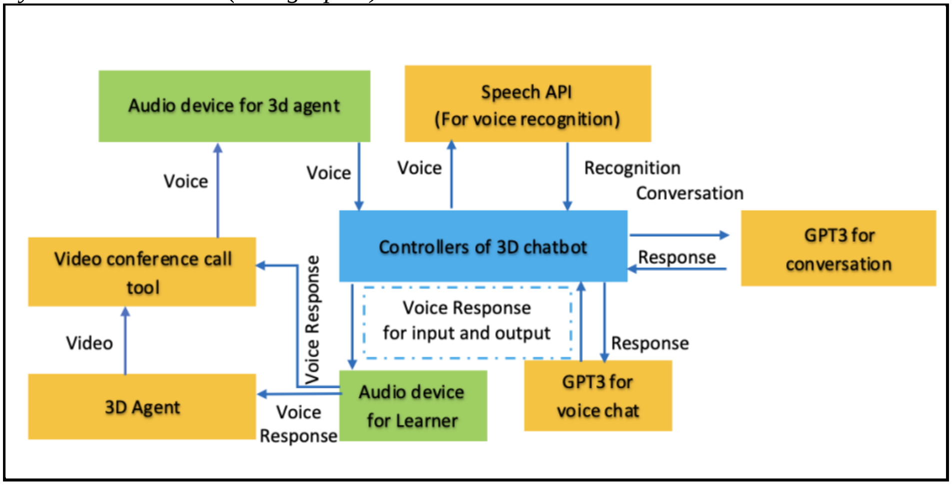
Based on the findings of the first research project aim, we are developing an avatar-based 3D AI bot to provide a rich and engaging training experience that can improve teachers' communication skills in a cost-effective and accessible way. To achieve this goal, we provide a brief overview of the technical implementation of the system below.

Technical procedure

The system architecture, as illustrated in Figure 1, comprises several key components that together create a platform designed to train students of teacher education in oral communication.

Figure 1

System Architecture (own graphic)



These components include video and audio routing, speech recognition and text-to-speech and speech-to-text APIs, GPT-3 as a generative AI model, a 3D AI avatar agent, and a controller for the agent:

- Video and audio routing: This involves using Loopback to redirect audio from the video conference tool to a virtual microphone. There are two audio routings required for this platform - one for learners and another for the 3D agent.
- Speech recognition and Text to Speech and speech to Text API: Google Speech API is used to convert audio into text, which is then processed using the GPT3 model to generate a contextual response. The response is then converted back into text as a response to the conversation.
- GPT3 as Generative AI model: The GPT3 model is a generative model used to generate a large volume of data with the input of small data sequences. It is widely used to train chatbots for business models and conversational chatbots for educational purposes.
- 3D AI avatar agent: This is a 3D animated agent that is a third-party plugin embedded with the model to mimic the auto-generated responses through the GPT3 model.
- Controller of the Agent: After training all of the individual modules, the chatbot controller plays the role of combining all modules by providing a centralized environment where the 3D avatar responds to all communication within due time. It ensures social communication skills in the native language German.

Overall, this platform aims to provide an effective and efficient way for students to improve their oral communication skills using advanced technology.

Discussion

The simulation of typical situations based on theoretical features in the professional life of a teacher has direct relevance for teachers who have already entered the profession.

Based on our findings in response to the first research question, it can be inferred that the use of avatar-based interactions in role-play simulations can be highly effective for providing initial practical experiences in higher education. Both environments (avatar-based vs. video-camera-based) provide more security, as these can be implemented in the protected setting at home (Fecke & Müller, 2022). It is worth noting that in the avatar-based learning environment, there may be limitations when it comes to the expression of gestures and facial expressions as these were not captured by the used avatar. In the video-camera-based learning environment, there is a great uncertainty about the appropriate use of gestures and facial expressions, as well as how they are perceived and interpreted by the others. Simulations in avatar-based learning environments can be used as a learning format in the sense of an introduction to practice and facilitate communicative competencies. Thus, the focus can first be on the spoken word before the adequate application of non-verbal communication follows, e.g. in a next step.

With the further development of this research project (research aim 2), a virtual learning environment can be created in which the participants can develop their communication competencies with a trained AI agent (3D avatar-based). The AI bot is represented by an agent that conducts the conversation on a typical situation in the context of the teacher interaction in schools with pupils, colleagues, supervisors or parents. In order to accomplish our research goals, we have outlined a technical overview of various tools and technologies that can be utilized to create an authentic human-centric learning environment using Artificial Intelligence to practice communication competencies.

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PlayData: Expressive Data Visualization Through Block-Based Programming

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Abstract: In this work we present PlayData, a web-based tool designed for young learners to create diverse representational forms for data, taking advantage of the flexibility offered by programming tools. PlayData was designed as a modified version of Scratch 3.0, presenting new specialized blocks for importing, analyzing, and representing data, and a table functionality embedded into the environment. Our design was guided by the premise that the tool should not require extensive instruction to get started with and encourage users to tinker with their data, trying out many ideas iteratively. In this paper, we describe PlayData's functionalities, and how they relate to the design principles that guided its development. We conclude by sharing lessons learned in pilot studies.

Introduction

Data literacy is rapidly gaining more relevance as bigger amounts of data are being generated and different types of data are becoming more accessible to wider audiences. As increasingly more diverse and larger datasets are publicly shared and used for decision-making, new educational approaches for data science education are needed to support the development of data-literate citizens (Finzer, 2013; Wise, 2020). From an educational perspective, it is essential to prepare students for a thoughtful use of data to make informed decisions, participate in the debates of society, and deal with questions from their daily lives. Working with data is also crucial in almost any discipline today. In science learning, for example, data is used as evidence for constructing arguments, supporting claims, and making sense of the world (McNeill et al., 2017). However, even if recent science and math standards require students to deal with data analysis by interpreting and representing data, most exercises in curriculum materials ask students to read visualizations created by others, and not to construct them by themselves (Börner et al., 2019). Along this line, recent studies show that most people cannot fully interpret standard data visualizations (Börner et al., 2016; Maltese et al., 2015), suggesting a need to incorporate more activities into k-12 classrooms to prepare students to be able to interpret and create multiple types of graphical displays.

Computational tools are useful to analyze large datasets and offer many representational possibilities. Furthermore, the use of computers can help make the work with data more authentic to students and afford new forms of representations that are more diverse and interactive than non-computer-based ones (diSessa 2004). However, middle and high school students often lack opportunities to work with data in ways that privilege exploration and meaningful engagement. Existing tools that combine data analysis and visualization with programming often fail to meet the needs of k-12 students, since they were not designed for educational purposes and have steep learning curves. In this work, we describe a new web tool for data visualization based on the Scratch programming language, called PlayData, along with the core principles that guided its development, and lessons learned from early pilot studies.

Background and related work

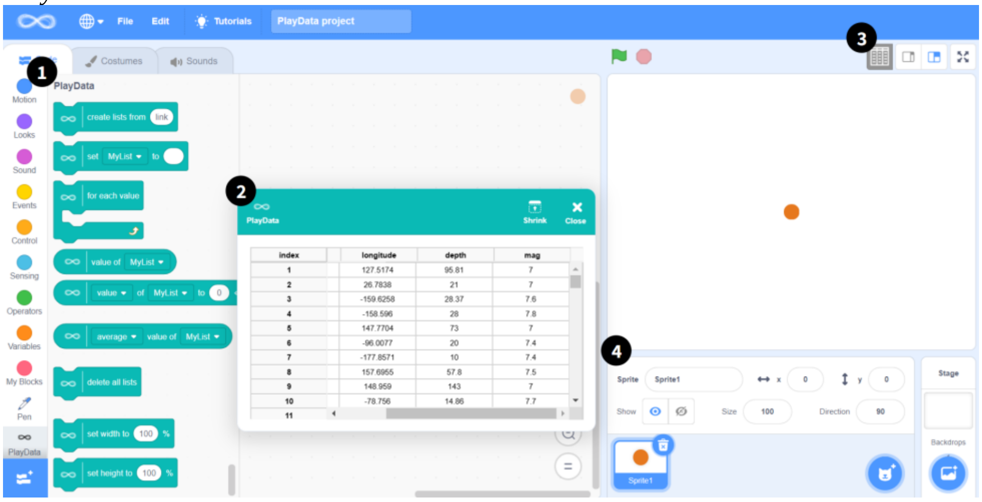
While most of the data science tools currently available are designed for the undergraduate level, many others have also been developed in the past decades to allow novices to engage with data analysis and visualization. Tinkerplots is an early data visualization and modeling educational tool developed for statistical data analysis (Rubin, 2002). The Common Online Data Analysis Platform, a more recent tool designed for young learners, is based on drag-and-drop features and allows users to create visualizations for data and to perform transformations on the data under analysis (CODAP, 2014). Although these tools were designed for school-aged learners, the kind of visualization afforded is limited to the templates available in the environment. A more flexible approach to working with data is to use block-based programming environments. DataSnap is an extended version of Snap! that provides an interface to import, process, and visualize big data (Hellmann, 2015). In the context of the Scratch environment, Dasgupta & Hill (2017) developed new blocks for personal and social media analytics, called Scratch community blocks, that allow users to access, analyze, and visualize data about their participation in the Scratch online community. While this variety of existing tools supports students in data analysis and visualization tasks, PlayData provides new expressive possibilities to engage with data. The tool was shaped to support both sensemaking and personal expression and draws on existing efforts to connect data literacy to the personal and social context of learners (Lee et al., 2021; Matuk et al., 2021; Wilkerson & Polman, 2020). In the next session, we describe the design process and principles that guided its development, differentiating it from other tools.

PlayData overview

PlayData was developed as a new Scratch 3.0 extension, targeted at middle and high school students. PlayData seeks to support learners in making sense of data through the creation of personal representations, taking advantage of the power and flexibility offered by the Scratch programming language. The tool comprises (1) new programming blocks to import, analyze, and visualize data, (2) a table embedded into the environment that allows users to see the dataset imported, which is opened through the table icon (3), and (4) new custom sprites and backgrounds that can be used in data visualization projects. These components are illustrated in (Figure 1).

Figure 1

PlayData environment



index		longitude	depth	mag
1		127.5174	95.81	7
2		26.7838	21	7
3		-159.6258	28.37	7.6
4		-158.596	28	7.8
5		147.7704	73	7
6		-96.0077	20	7.4
7		-177.8571	10	7.4
8		157.6955	57.8	7.5
9		148.959	143	7
10		-78.756	14.86	7.7
11				

Design principles and their translation into blocks

The design of the PlayData tool was refined over several iterations and informed by insights gained through workshops with children and through our own experience while using it. We decided to build the tool as a modification of Scratch, given that Scratch has been widely used in schools for introductory programming activities and its design principles are aligned with our vision around computing education. Our design was guided by a desire to scaffold a "messing about" attitude towards data (Hawkins, 1965), based on the premises that: (1) the tool should be intuitive enough so it doesn't require extensive instruction to get familiar with (low floors), (2) it should afford that many ideas can be tried out in a brief period of time – so one can create, test and refine visualizations iteratively to convey an idea, while the idea itself can change over time as the result of the multiple iterations (tinkerability). The translation of these principles into PlayData's custom blocks is described below.

Design principle 1: Lower the floor for working with data

Although Scratch was designed to facilitate the tinkering process (Resnick & Rosenbaum, 2013), the floors for working with data are often too high to allow fluid experimentation and open exploration. Mastering some of the concepts required to read datasets in Scratch can be complex for young audiences, and thus, creating an effective visualization can be challenging with the available blocks in the environment.

Design principle 2: Encourage open exploration

Another core aspect considered when designing the tool was that it should afford the creation of a variety of representational forms for the same dataset without users having to change large amounts of code. Our goal was to encourage exploratory approaches for working with data, making users feel comfortable to change the code and test new representational possibilities as their ideas evolve. Thus, PlayData allows the creation of diverse outcomes either by changing a few parameters inside the blocks or by making small rearrangements in the code.

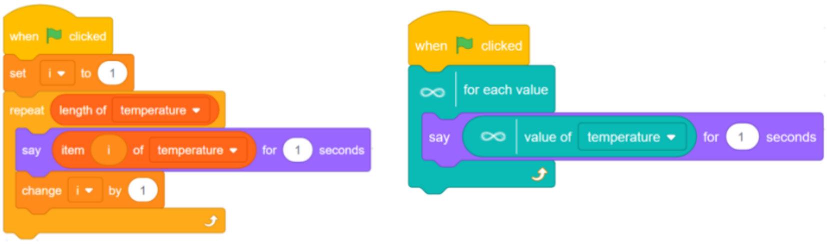
Translation of principles into tool's features

Adding data to the environment: In Scratch, users can add values into lists in three ways: (i) by manually adding values one by one, (ii) by using loop blocks with functions that return calculated values, or (iii) by importing .csv files from their computers. In either case, the process can be time-consuming, non-intuitive, or not flexible. Thus, we designed two new blocks to allow users to import data from multiple sources. The first block imports data from shared online files, such as Google Spreadsheets or .csv datasets available on the web. The second block can be used by directly pasting values copied from tables or spreadsheets. Once data is imported, new lists are automatically created, and can thus be selected from the dropdown menus in the PlayData blocks.

Iterating over the values: To read data in Scratch, users need to iterate over a list of values. To do so, it is necessary to start by creating both a variable and a list; the variable then needs to be initialized and increased by 1 in steps inside a loop block - a procedure to be repeated until the length of the items in the list is covered (Figure 2, left side). This process may seem intuitive to experienced programmers but can be quite complex for novices, requiring knowledge about lists that are usually not familiar to them (Aivaloglou & Hermans, 2016). In PlayData, all these steps are embedded into one single block, presented in Figure 2 (right side). This approach is similar to the one of Scratch community blocks (Dasgupta & Hill, 2017), which is restricted to data about participation in Scratch, while the PlayData block can be used with any type of data imported into the environment.

Figure 2

Code that iterates over the values of a list with traditional Scratch blocks (left) and with PlayData blocks (right)



```
when ⚑ clicked
set i ▾ to 1
repeat length of temperature ▾
    say item i of temperature ▾ for 1 seconds
    change i ▾ by 1
```

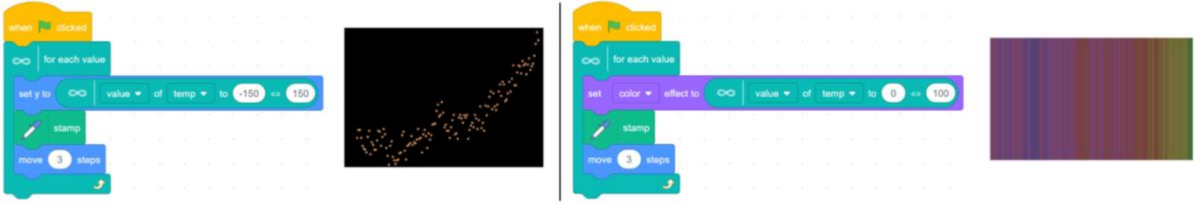
```
when ⚑ clicked
∞ for each value
    say ∞ value of temperature ▾ for 1 seconds
```

Looking at the dataset inside the environment: The table embedded into the PlayData environment allows users to quickly look at their datasets in a spreadsheet-like format, as shown in Figure 1. This is a central feature for an iterative process since users do not need to leave the environment to check their data and compare it with the visualizations created (Zhang et al., 1993).

Changing the scale of the values: One of the challenges of working with data visualization in Scratch is to adequate the original range of values to the range of parameters suited for the environment. For example, if one wants to plot the data in the X-Y axis, there is a need to change the lower and upper values to fit in the screen (which goes from -180 to 180 for the Y-axis, and from -240 to 240 for the X-axis). If one wants to map data to colors, the range of values goes from 0-200. To convert the original values to these new ranges, users need to perform calculations that can be unintuitive for beginners. To solve this issue, we developed a block that automatically converts the original values of a list into any desired range, encouraging users to explore multiple visualizations for their data in faster and easier ways. In Figure 3, in which we present an example that illustrates this idea of offering many representational possibilities using these blocks (two similar scripts producing distinct outputs).

Figure 3

Examples of visualizations created for the same dataset (global temperature anomaly since 1880)



```
when ⚑ clicked
∞ for each value
    set y to ∞ value ▾ of temp ▾ to -150 ⇔ 150
    stamp
    move 3 steps
```

```
when ⚑ clicked
∞ for each value
    set color ▾ effect to ∞ value ▾ of temp ▾ to 0 ⇔ 100
    stamp
    move 3 steps
```

Lessons from pilot studies

During the development of the tool, we ran several workshops (with middle and high school students, graduate students, and teachers), in different phases of its design. The duration of these workshops ranged from 1:30 hours to 10 hours. We collected data from these workshops through video recordings, log data and fieldnotes, and the insights gained in these experiences guided the design decisions described here and allowed us to understand how learners use the tool. Although we won't attempt to describe these results here in detail, they showed us promising pathways for developing activities aligned with the pedagogical goals of the tool.

By using PlayData, students engaged in authentic data visualization and design practices. These practices included translating ideas into programs, selecting parameters (such as the color scheme or the space between data points), inspecting the output and contrasting it to previous expectations, and adding annotations to provide context and better communicate the desired information.

However, there are also some open questions regarding the balance between procedural actions and engagement in sensemaking processes. Sometimes we saw learners creating aesthetically interesting visualizations without a clear understanding regarding the information that was conveyed through the representation - especially in small-duration activities that were not scaffolded to include elements such as asking a question before proceeding to the programming task. The study of if and how the sensemaking process around data evolves through interacting with PlayData is one of the things we are curious to explore in our next rounds of analysis.

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MedDbriefer: A Debriefing Research Platform and Tool to Support Peer-Led Simulation-Based Training in Healthcare

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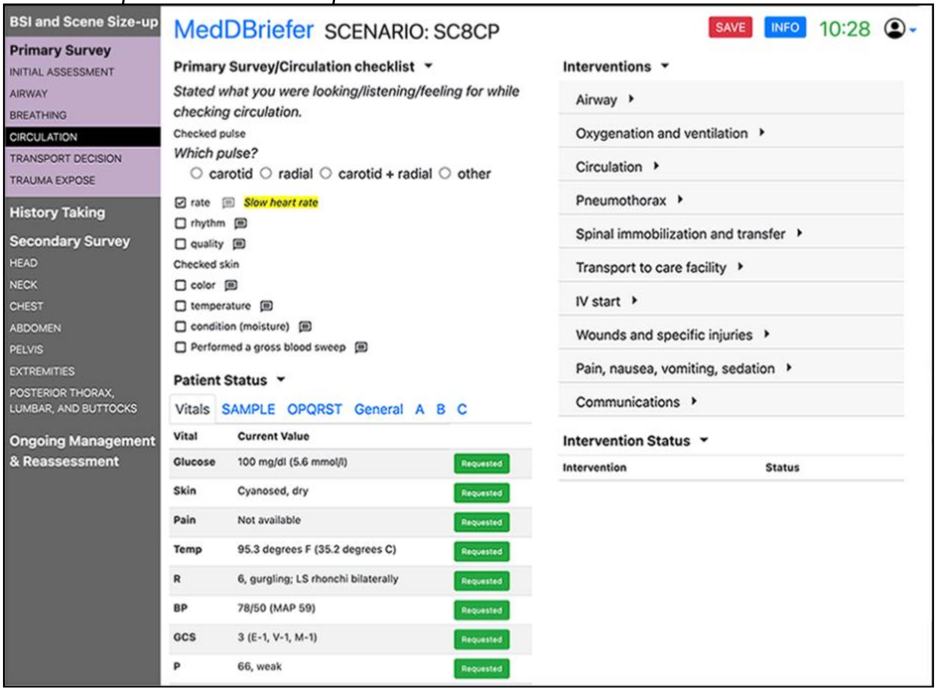
Abstract: MedDbriefer allows paramedic students to engage in simulated prehospital emergency care scenarios and receive an automated debriefing on their performance. It is a web-based tool that runs on a tablet. Although debriefing is purported to be one of simulation-based training's most critical components, there is little empirical research to guide human and automated debriefing. We implemented two approaches to debriefing in MedDbriefer and are conducting a randomized controlled trial to compare their effectiveness.

Introduction

Across the healthcare professions, students who struggle to acquire clinical reasoning and psychomotor skills rarely get enough simulation-based training (SBT) practice during course labs. Experienced SBT facilitators are in short supply. Many are themselves active practitioners (physicians, nurses, paramedics, etc.), which limits the time that they can devote to teaching. To address this problem, we are developing MedDbriefer, a web-based simulation tool that runs on a tablet. When fully implemented, it will allow one or more paramedic students to practice realistic prehospital emergency care scenarios and receive a debriefing on their performance (Katz et al., 2022). While one student treats a simulated patient as the leader of an emergency medical service (EMS) team, a peer uses the tablet's checklists to record the team leader's actions. (See Figure 1.) The system then analyzes the event log and generates a debriefing. If successful, MedDbriefer could help to reduce the shortage of EMS providers (e.g., Amiry & Maguire, 2021) and, ultimately, support training across the healthcare professions.

Figure 1
MedDbriefer's Observer Interface



SCENARIO: SC8CP

Primary Survey/Circulation checklist

Stated what you were looking/listening/feeling for while checking circulation.

Checked pulse

Which pulse?

○ carotid ○ radial ○ carotid + radial ○ other

☑ rate *Slow heart rate*
☐ rhythm
☐ quality

Checked skin

☐ color
☐ temperature
☐ condition (moisture)
☐ Performed a gross blood sweep

Patient Status

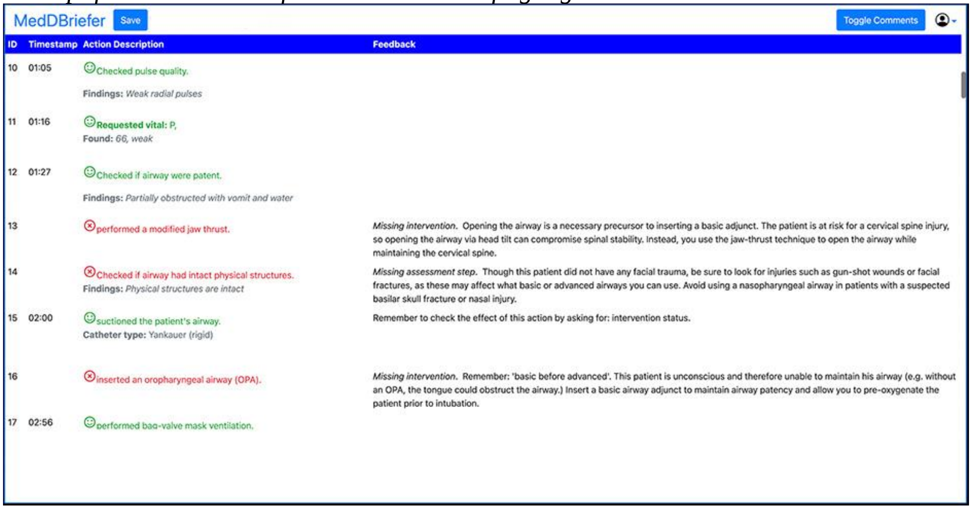
Vitals SAMPLE OPQRST General A B C

Vital	Current Value	
Glucose	100 mg/dl (5.6 mmol/l)	Requested
Skin	Cyanosed, dry	Requested
Pain	Not available	Requested
Temp	95.3 degrees F (35.2 degrees C)	Requested
R	6, gurgling; LS rhonchi bilaterally	Requested
BP	78/50 (MAP 59)	Requested
GCS	3 (E-1, V-1, M-1)	Requested
P	66, weak	Requested

Although debriefing is often deemed to be SBT's most critical component, little is known about how to guide human instructors and automated tutors in conducting an effective debriefing (e.g., Cheng et al., 2017). In addition to enabling students to practice scenarios, MedDbriefer provides a research platform to extend the field's knowledge about SBT, with a focus on debriefing. Toward that end, we implemented two approaches to debriefing in MedDbriefer. One approach reflects that taken in state-of-the-art tutoring systems for healthcare providers, such as vSim for Nursing (Laerdal Medical, 2020): a step-by-step textual recount of students' actions during a training scenario, with color-coded (green/yellow/red) feedback. (See Figure 2.) The other approach adapts one of several debriefing protocols that have been proposed to enable SBT instructors to conduct effective debriefings—namely, DEBRIEF (Sawyer & Deering, 2016). (See Figure 3.) Although several simulation researchers and practitioners have advocated the use of debriefing protocols, there is little empirical evidence to support this practice (Cheng et al., 2017; Sawyer et al, 2016).

Figure 2

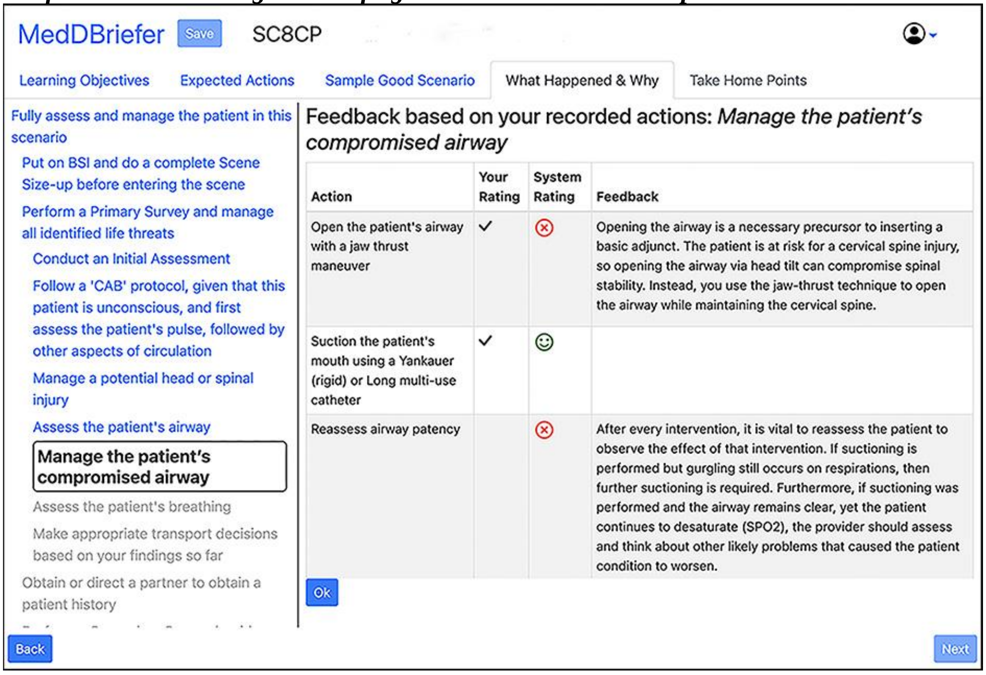
Excerpt from a MedDbriefer narrative debriefing log



ID	Timestamp	Action Description	Feedback
10	01:05	☺Checked pulse quality. **Findings:** *Weak radial pulses*	
11	01:16	☺**Requested vital:** P, **Found:** *66, weak*	
12	01:27	☺Checked if airway were patent. **Findings:** *Partially obstructed with vomit and water*	
13		⊗performed a modified jaw thrust.	*Missing intervention.* Opening the airway is a necessary precursor to inserting a basic adjunct. The patient is at risk for a cervical spine injury, so opening the airway via head tilt can compromise spinal stability. Instead, you use the jaw-thrust technique to open the airway while maintaining the cervical spine.
14		⊗Checked if airway had intact physical structures. **Findings:** *Physical structures are intact*	*Missing assessment step.* Though this patient did not have any facial trauma, be sure to look for injuries such as gun-shot wounds or facial fractures, as these may affect what basic or advanced airways you can use. Avoid using a nasopharyngeal airway in patients with a suspected basilar skull fracture or nasal injury.
15	02:00	☺suctioned the patient's airway. **Catheter type:** Yankauer (rigid)	Remember to check the effect of this action by asking for: intervention status.
16		⊗inserted an oropharyngeal airway (OPA).	*Missing intervention.* Remember: 'basic before advanced'. This patient is unconscious and therefore unable to maintain his airway (e.g. without an OPA, the tongue could obstruct the airway.) Insert a basic airway adjunct to maintain airway patency and allow you to pre-oxygenate the patient prior to intubation.
17	02:56	☺performed bag-valve mask ventilation.	

Figure 3

Self-assessment during a debriefing based on the DEBRIEF protocol



Fully assess and manage the patient in this scenario
- Put on BSI and do a complete Scene Size-up before entering the scene
- Perform a Primary Survey and manage all identified life threats
  - Conduct an Initial Assessment
  - Follow a 'CAB' protocol, given that this patient is unconscious, and first assess the patient's pulse, followed by other aspects of circulation
  - Manage a potential head or spinal injury
  - Assess the patient's airway
  - **Manage the patient's compromised airway**
  - Assess the patient's breathing
  - Make appropriate transport decisions based on your findings so far
- Obtain or direct a partner to obtain a patient history

Feedback based on your recorded actions: *Manage the patient's compromised airway*

Action	Your Rating	System Rating	Feedback
Open the patient's airway with a jaw thrust maneuver	✓	⊗	Opening the airway is a necessary precursor to inserting a basic adjunct. The patient is at risk for a cervical spine injury, so opening the airway via head tilt can compromise spinal stability. Instead, you use the jaw-thrust technique to open the airway while maintaining the cervical spine.
Suction the patient's mouth using a Yankauer (rigid) or Long multi-use catheter	✓	☺	
Reassess airway patency		⊗	After every intervention, it is vital to reassess the patient to observe the effect of that intervention. If suctioning is performed but gurgling still occurs on respirations, then further suctioning is required. Furthermore, if suctioning was performed and the airway remains clear, yet the patient continues to desaturate (SPO2), the provider should assess and think about other likely problems that caused the patient condition to worsen.

As a step towards addressing this gap in SBT research, we are conducting a randomized controlled trial (RCT) to compare the effectiveness of these two approaches to debriefing in MedDbriefer. This paper describes MedDbriefer and an initial field trial that we conducted to prepare for this comparative study.

MedDbriefer

MedDbriefer supports a "voice treating" approach to developing students' clinical reasoning skills. Voice treating entails verbalizing the assessment and treatment actions the healthcare provider would perform, how he would perform them, which actions he would delegate to a team member, etc. Although students often mime actions and use readily available equipment (e.g., a stethoscope) while voice treating, they can focus on identifying clinical problems and deciding how to manage them because they don't need to fully execute procedures.

Since MedDbriefer runs on a tablet, students will ultimately be able to use it to do practice scenarios just about anywhere—in a small meeting room, dorm room, etc.—without needing simulation equipment or a human instructor. A peer who is neither the EMS team leader nor a team member plays the role of "session observer", by using MedDbriefer's checklists to record the team leader's verbalized actions. As shown in Figure 1, MedDbriefer's *Observer Interface* (OI) provides two main checklists. The *assessment checklist* (Figure 1, left) is patterned after one of the "scorecards" used to evaluate EMS candidates during the National Registry of Emergency Medical Technicians' (NREMT) certification exam (NREMT, 2020). The *intervention checklist* (Figure 1, right) includes treatments and other actions that EMS providers commonly perform (e.g., transferring the patient to the ambulance). Interspersed throughout the checklist menus are prompts for the observer to issue to the team leader if he fails to provide sufficient detail while voice treating. For example, the Circulation menu displays a prompt for the team leader to specify which pulse(s) he is checking. (See Figure 1.) The system also provides feedback on the team leader's actions. For example, MedDbriefer displays a callout for the observer to issue when the team leader checks the "patient's" pulse (e.g., *Slow heart rate*, highlighted in yellow in Figure 1).

The chief difference between the two debriefing approaches that MedDbriefer implements is the extent to which they engage students in active reflection on their performance. In the narrative approach, the automated agent critiques each step of the team leader's solution (e.g., Laerdal Medical, 2020). Figure 2 illustrates MedDbriefer's implementation of this approach. In contrast, protocol-based debriefings encourage students to play a more active role in assessing their performance. This approach is illustrated by Sawyer & Deering's (2016) proposed adaptation of the US military's DEBRIEF protocol for simulation-based training in healthcare. DEBRIEF stands for **D**efine the debriefing rules; **E**xplain the learning objectives; specify the performance **B**enchmarks; **R**eview what was supposed to happen; **I**dentify what actually happened and **E**xamine why; and **F**ormalize the "take home" points. During a post-scenario discussion structured according to DEBRIEF, instructors prompt students to assess whether their solution met a set of performance standards ("benchmarks") and consider why it fell short of meeting particular standards.

In MedDbriefer's adaptation of DEBRIEF, the tutor summarizes the "Expected Actions" (Benchmarks) early in the debriefing session. During the "What Happened and Why" (Identify and Examine) phase, students are prompted to check off the actions they believe they performed and then compare their self-ratings with the system's ratings. (See Figure 3.). Feedback on incorrect actions is identical to that presented in the narrative version of MedDbriefer. (See Figures 2 and 3.). Abundant research demonstrates the superiority of active approaches to learning over more passive approaches (Chi & Wiley, 2014). Self-assessment is one form of active learning that consistently shows a positive association with knowledge and skill development (Andrade, 2019). Hence, prior research suggests that the DEBRIEF protocol-based version of MedDbriefer will predict higher learning gains than the narrative version.

Initial testing

At this writing, an RCT to examine this hypothesis is in progress. Approximately 40 students enrolled in EMS training programs are being randomly assigned to a debriefing condition (narrative versus DEBRIEF protocol-based; Figures 2 and 3). First, each student completes an online pretest. This test includes similar questions to those on the NREMT-Paramedic cognitive exam, which targets the clinical knowledge and reasoning skills needed for EMS practice. Next, students do eight scenarios that involve traumatic injury (e.g., due to a lawnmower rollover accident). The first two scenarios serve as a pretest; they are not followed by a debriefing. The intervention is comprised of the next four scenarios, which engage the student in debriefings. Students then do two posttest scenarios without a debriefing. The posttest scenarios exercise the same clinical knowledge and reasoning skills as the pretest scenarios. Students then take on online posttest that is isomorphic to the online pretest. Finally, they complete a brief survey with open-ended questions about what they learned, whether they think that MedDbriefer would be useful for EMS training and why, and how it could be improved.

To prepare for this trial, we conducted a small field test that followed the same procedure and used the same scenarios and instruments as those described in the preceding paragraph. Four recently certified paramedics (seniors in the university's EMS program) participated as team leaders during the scenarios. Peers trained to use the Observer Interface logged the team leaders' actions. All four participants received narrative debriefings after the intervention scenarios. Analysis of debriefing logs, feedback surveys, and screen recordings of observers' interaction with the OI revealed several changes that we needed to make before the RCT, for example: refinements to the algorithms that analyze session logs to generate a debriefing (Katz et al., 2022); clarifications to several feedback messages; and filling in some gaps in the OI's checklists—for example, to add cardiac monitoring by electrocardiogram to the intervention menus.

Table 1

Performance on pretest and posttest scenarios

	Multi-system trauma		**Difficulty breathing**	
Participant	**Pretest scenario**	**Posttest scenario**	**Pretest scenario**	**Posttest scenario**
P1	.76	.95	.80	1.0
P2	.62	.86	.50	.93
P3	.69	.83	.72	.90
P4	.86	.95	.79	.93

Although underpowered, this field trial suggests that MedDbriefer holds the potential to support learning. The fifth author performed a detailed analysis of each participant's data. For example, using the NREMT's trauma assessment checklist (NREMT, 2020) she scored students' performance on the pretest and posttest scenarios (#points earned/42 maximum). As Table 1 shows, all participants' scores increased from pretest to posttest—both on the scenarios that involve managing multi-system trauma and those that involve managing compromised breathing. Scores on the cognitive pre- and post-tests were mixed: Two students' scores increased from pretest to posttest, one student's scores stayed about the same, and one student's scores decreased. However, a closer analysis indicated that debriefing feedback contributed to gains on several test items. For example, one item targeted students' understanding that positive pressure ventilation should be avoided if a patient has a pneumothorax. Participants 1-3 missed this question on the pretest but answered it correctly on the posttest. They all received feedback that addressed this topic during debriefings. In contrast, Participant 4 answered this question incorrectly on both tests. She was the only student who did not receive feedback on this topic during debriefings.

Participants' feedback on the system, as expressed on the post-session survey, was highly positive. In addition to stating that the debriefing feedback was helpful (3 comments), the four participants agreed that, when fully developed, MedDbriefer will provide a useful tool for EMS training; for example, "When I was studying it was very difficult to find resources/scenarios that I could use for psychomotor testing by myself and with other students. This will be an amazing resource!" The data from the RCT will allow us to measure the extent to which MedDbriefer meets students' expectations and predicts gains in clinical knowledge and reasoning skills.

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Aide: A Conversational Agent Based on Inoculation Theory and Large Language Models to Empower Learners to Recognize Disinformation

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Abstract: Disinformation has been fueled in recent years, and inoculation theory offers an approach to supply the tools that will enable citizens to identify disinformation. It proposes that interventions can act like "vaccines" by exposing individuals to controlled doses of false or misleading information. This project draws on that theory to design a conversational agent that uses language modeling to surface strategies commonly used in disinformation. This paper lays out the motivation for the work, points to referential literature and related work, presents core design elements, and delineates future design directions based on testing data.

Introduction

The polyphony of online media and messages abetted a multitude of controversial—and, oftentimes, harmful—agendas, with deep implications for contemporary society (Marwick & Lewis, 2017). Educational researchers acknowledge the need to address the challenges posed by disinformation (Barzilai & Chinn, 2020), defined as the creation and distribution of false information with the intention to cause harm (Wardle & Derakhshan, 2017). This project seeks an answer to a part of that question: Aide is an attempt to support learners in recognizing features of disinformation. It uses large language models (LLM) to improve learners' ability to evaluate cognitive processes at play when we consume and distribute disinformation.

Aide is designed as a polyadic conversational agent (Zheng et al., 2022) to be used as part of a facilitated activity that guides the learner through analyses of strategies used in disinformation identified by previous research (e.g., Roozenbeek & van der Linden, 2019). This work builds on research that investigates disinformation through the lens of learning (Russo & Blikstein, 2022; Russo, Blikstein & Penalva, 2021): although it is a tempting solution to simply advocate for more efficient communication of facts, the present line of research proposes that there are intricate learning and cognitive mechanisms at play when we consume misleading or plainly false information.

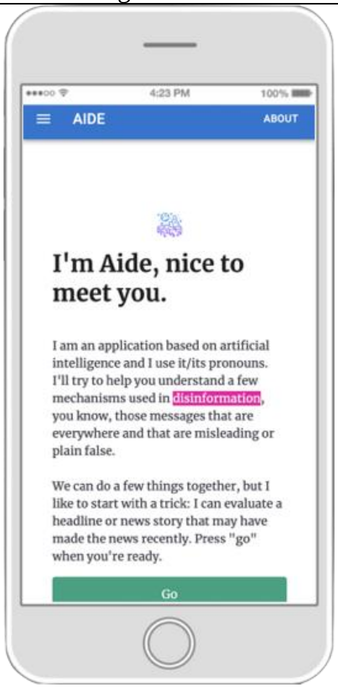
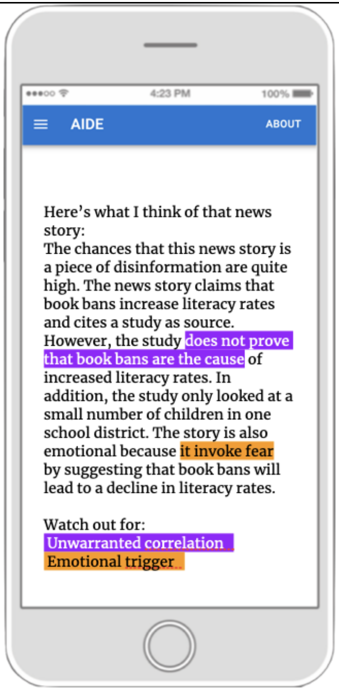
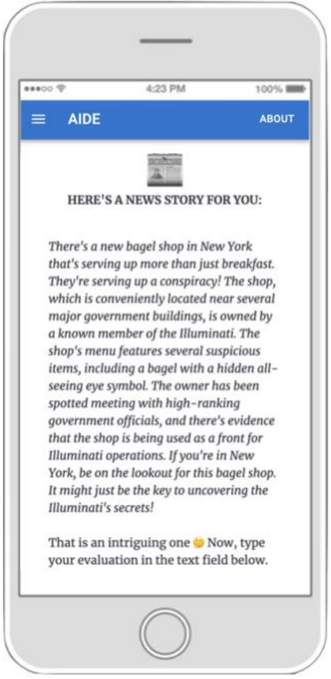
Literature review and related work

Contemporary explanations of disinformation and educational interventions to address the issue rely on analogies between the forms of the spread of false information and viruses (van der Linden, 2022). Researchers base that analogy on the networked nature of contemporary communication systems, which would present themselves as pathways for the proliferation of messages that explore both political motivation and a lack of attention from media consumers. That line of research motivates the expansion of interventions based on the "inoculation theory" applied to disinformation, that is, exposing learners to reduced doses of false information in a controlled "therapy" whose functioning is akin to that of vaccines. This type of intervention, researchers argue, would lead to the development of "cognitive antibodies" that promotes inoculation.

That "epidemiological" approach supports the development of interventions that (1) expose the learner to strategies used in the creation (rather than to specific examples) of fake news; and (2) engage learners in actively creating hypothetical examples of misinformation, instead of its passive consumption (Roozenbeek & van der Linden, 2018). Some of those interventions take the form of serious games, like Lamboozled! (Chang et al., 2020) and Bad News (Roozenbeek & van der Linden, 2019), whose approach has been found to be effective in learning about misinformation. Strategies highlighted in Bad News—e.g., conspiracy and emotion – have inspired the design of Aide. This app exposes the learner to disinformation in controlled doses, with the expectation that those work in accordance with the inoculation theory, that is, we expect that our intervention helps learners develop immunity against false information they encounter in the future.

Work on Computer-Supported Collaborative Learning (CSCL) includes evidence of interaction between the use of a conversational agent and students' conversational behavior improvement (Ai et al., 2010). Researchers observed enhanced learning outcomes with the use of direct support in tandem with conversational agents (Dyke, 2013). However, research connecting conversational agents and education seems to focus on the natural sciences. In this project, we propose an investigation into the use of conversational agents in the instruction of an essentially multidisciplinary topic with a deep connection to the social sciences.

Table 1
Selected screens of the prototype

Onboarding screen	Evaluation shown to the learner	AI-created story shown to learner
 **I'm Aide, nice to meet you.** I am an application based on artificial intelligence and I use it/its pronouns. I'll try to help you understand a few mechanisms used in disinformation, you know, those messages that are everywhere and that are misleading or plain false. We can do a few things together, but I like to start with a trick: I can evaluate a headline or news story that may have made the news recently. Press "go" when you're ready.	 Here's what I think of that news story: The chances that this news story is a piece of disinformation are quite high. The news story claims that book bans increase literacy rates and cites a study as source. However, the study does not prove that book bans are the cause of increased literacy rates. In addition, the study only looked at a small number of children in one school district. The story is also emotional because it invoke fear by suggesting that book bans will lead to a decline in literacy rates. Watch out for: Unwarranted correlation Emotional trigger	 HERE'S A NEWS STORY FOR YOU: *There's a new bagel shop in New York that's serving up more than just breakfast. They're serving up a conspiracy! The shop, which is conveniently located near several major government buildings, is owned by a known member of the Illuminati. The shop's menu features several suspicious items, including a bagel with a hidden all-seeing eye symbol. The owner has been spotted meeting with high-ranking government officials, and there's evidence that the shop is being used as a front for Illuminati operations. If you're in New York, be on the lookout for this bagel shop. It might just be the key to uncovering the Illuminati's secrets!* That is an intriguing one 🤔 Now, type your evaluation in the text field below.

Design components

The current iteration of this conversational agent is based on the findings reported in the literature above, on user testing with graduate students, and on feedback from supporting faculty. Although the sample does not reflect the intended population for the final solution, the data allowed for a preliminary assessment of usability design of a learner journey. Three main design decisions derived from preliminary testing are delineated below:

- **Disinformation strategies foregrounded.** Reflecting literature review, Aide exposes learners to techniques employed in creating disinformation, instead of training individuals to "detect" specific instances of fake news. This decision has been made in accordance with "prebunking" as a "prophylactic approach" to treat susceptibility to disinformation (van der Linden, 2022).
- **Mix of learner- and AI-generated news stories.** Active participation in the creation of "news stories" has been shown to be more effective in inoculating individuals than passive consumption (Roozenbeek and van der Linden, 2018). However, preliminary user studies demonstrated that learners need some level of scaffolding before they start creating their own stories. This justifies the use of a mix of sources for stories. The choice for AI-generated stories is justified by four main conjectures derived from previous prototype testing: (1) It affords scaffolding for the task of creating fictitious content *quickly*, (2) it helps surface hand-picked *mental processes* that might or might not be present in our judgment of new information; (3) it scaffolds heuristics for judging new information; (4) the ability to start debates from a perspective that is more likely to be from outside the learners' echo chambers.
- **Conversational tone.** Feedback on previous versions also pointed to the need for colloquial, less rigid language. A similar tone is found in previous work mentioned above. For this reason, the current iteration incorporates word choice that attempts to mimic natural conversations. It also employs emojis to complement the meaning of the written text.

Technical specifications

Aide is a react.js application that makes use of OpenAI's node.js package. User inputs are stored as variables that are passed as part of custom-made prompts. These prompts are then sent as requests to Open AI's API (see "${answerx}" in prompts shown in Table 2), which uses GPT-3 models to generate human-like text. GPT-3 is a pre-trained large language model (LLM) built upon 499 billion tokens extracted from the web (Dale, 2021). Table 1 shows screenshots of the interface and Table 2 describes the prompts in relation to each round of the conversation, their expected learning outcomes, and actions at the learner's and the interface's end.

Table 1

Distribution of actions by the learner and the system, expected learning outcome and prompts across stages

Round	Learner action	Aide's action	Expected learning outcome	Prompt sent to the API
1	Choose news story	Evaluate	Initial contact with disinformation strategies and general method of analysis	"How likely do you think that the following news story "${answer1}" is a piece of disinformation? Justify your answer by stating whether and why it uses rhetorical devices such as unwarranted correlations, conspiracy theories, overgeneralization, cognitive biases, and emotional triggers."
2	Evaluate a news story	Show a news story	Initial contact with disinformation strategies and general method of analysis	"Create a sensationalist short news story that an influencer would share. Use the words New York and bagels, and use an unwarranted correlation or a conspiracy theory:"
3	Choose keywords and evaluate news story	Create story	Visualize connections of a random word made possible through rhetorical strategies	"Create a sensationalist, slightly ironic, optimistic short news story using the word "${answer4}" Use overgeneralizations and unwarranted correlations."
4	Evaluate news story	Create news story (or pick one from the news)	Practice evaluation of information	"Create a sensationalist, optimistic, fake short news story that could be published by a newspaper. Use the words vaccines and rollercoasters. Use discredit towards science as a rhetorical strategy:"
5	Self-assessment	Show previous evaluations	Reflection on learning	NA

Initial learner testing

Testing data presented in this paper focus on learner experience and learner interface, reflecting the nature of a tech innovation paper. The team is conducting other types of evaluation. Testers were female undergraduate and graduate students (22 to 26 years of age), recruited via personal networks of members of the team. No financial compensation was offered for their participation. The team used a local implementation of Aide to conduct 1-hour interviews over Zoom. Participants were granted access to remotely control Aide's interface. Prior to interaction, researchers briefly assessed participants' knowledge about mis- and disinformation. During and after the interviews, the research team took notes; after the interviews, researchers watched the recordings and drew upon Zheng et al.'s (2022) meta-review to identify themes related to interaction and experience with AI-based conversational agents.

All 4 participants could navigate the interface without instructions. Nonetheless, they had difficulties finding the relationship between each page and what phase of the app they were at. This problem possibly occurred due to the lack of information on the landing page and the absence of guiding UI elements that made explicit the tasks that were expected from the learner. For example, one of the participants stated that "the first page says it will only present news, so I thought it would only focus on that. But it now asks me to evaluate and make a story." That reaction illustrates how design decisions on Aide might impact the visibility of the learning journey, engagement of the user, and, ultimately, learning outcomes. We address these issues in next iterations.

Another striking point about the interface and experience was that some participants felt that the app itself should offer explanations about concepts in the topic, rather than an instructor. Three out of four participants stated that it would have been helpful if the interface had made it clearer what “cognitive biases,” “overgeneralization,” or “unwarranted correlations” are. Since the app was designed as a facilitated experience, it was originally thought that a facilitator could guide discussions on those topics. However, possibly because the interface resembled “stand-alone” applications with which subjects were familiar, they expected explanations to be available as they navigate Aide. As a result, after these initial studies, we implemented a new feature to address it (see “highlighting feature” in Table 1).

Future design directions and conclusion

Testing shows that further research is needed on the social aspects of learning about disinformation, and how we could be incorporate those into Aide. Previous versions of this prototype attempted to address those aspects by including an interaction between more than one learner at a time. However, that component has not yet been fully realized in the design. Future testing should reconsider ways to include more human-human interactions, in addition to human-computer ones. Besides facilitation by an instructor, we conjecture that, through conversations with peers, learners can relate their lived experience with concepts presented by the application. Learner data has also shown that it is crucial to implement highlighting strategies (see Table 2) as a support for learning, which will make learning more visible. Finally, we also consider alternatives to GPT-3 and OpenAI to avoid dependence on a framework whose development and continued accessibility are out of our reach.

This paper presented Aide, a conversational agent designed to help learners develop their ability to identify disinformation strategies. Through this work, we expect to contribute to the inoculative approach against disinformation by proposing a solution that explores the affordances of AI based on large language models. We hope to enhance our understanding of how mental models influence our judgment of misleading or plain false messages. In the future, we hope that this understanding is used to devise interventions that help us act against disinformation at individual and systemic levels.

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Practice-Oriented Papers

Redesigning the MOOC “Learning How to Learn”

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Abstract: In this study we present the redesign process that produced a new academic version (in Hebrew, translated into Arabic) of the popular MOOC *Learning How to Learn*. During the design-based research we explored practices that implement evidence-based principles in the learning sciences in real-life digital learning, and created a course that not only teaches about learning but also practices what it preaches in its learning experience. Our practices address neural, cognitive-emotional, meta-cognitive and behavioral aspects of learning, and they include designing the course as a modular network, creating a local community of lifelong learners, and increasing embodiment in the media design. We present a model for a localized MOOC with maximal adequacy between the theoretical concepts that it teaches and its design, applicable to digital learning in other areas.

Redesigning a MOOC

Digital learning, and MOOCs specifically, increasingly benefit from learning-science-based design. Addressing the need to distribute knowledge on learning to students and other lifelong learners, we redesigned the popular MOOC L*earning How to Learn* and created a new, official academic version in Hebrew with full translation into Arabic, launched in December 2021. Our design-based research (Ariel, Millikovsky-Ayalon & Kimchi Felhorn, 2022) included a productive collaboration between practitioners (lecturer, teaching assistant and learning experience designer) who are also scholars in three different fields – Humanities, Neuroscience and Psychology.

Learning How to Learn (LHTL), developed by Prof. Barbara Oakley and Prof. Terrence Sejnowski, and available in the Coursera platform since 2014, was a central landmark in the attempts of educators and learning scientists worldwide to make the learning sciences accessible and applicable to the masses. It has become one of the most popular MOOCs in the world, with various translations (French, Spanish, Portuguese, Hungarian, Arabic, Korean) and new versions (Russian and Chinese – see Chen and Oakley, 2020 on the redesign of the Chinese version). Following Oakley’s approach, and with her support, our new version of the MOOC presents an academic adaptation which significantly deviates from the original in scope and design.

Our central premise was that a MOOC – particularly one on the subject of learning – should be designed according to the mechanisms of the learning mind and rely on evidence-based practices in the learning sciences (see also Najafi, et al., 2017; Gordon & Willtrout, 2021). Therefore, our aim was not only to present ideas *about* learning but also to implement them in the structure, the pedagogical methods and the overall learning technologies of the course. The original LHTL had already taken steps in this direction, and we expanded it to the overall course design and created an online learning experience that addresses an array of learning mechanisms. The process of redesigning LHTL, which lasted a year, entailed reverse engineering of the original course and iterations that prompted the course development (see figure 1). Our practices addressed neural, cognitive-emotional, meta-cognitive and behavioral aspects of learning, and they include designing the course as a modular network, presenting varied models of learners, increasing embodiment in the media design, and creating a section of active reading of academic articles. The redesign also addressed pressing issues in online learning, such as international versus culturally sensitive teaching, high MOOC drop-out rates, “transactional distance” and online versus blended formats. We will now briefly address three central landmarks in the MOOC redesign.

Redesigning the linear course as a network

While the original LHTL was linear, we decided to turn it into a network, in which the learning experience is modular and self-regulated. The transformation from a linear course to a network required us to treat the original LHTL as a flexible set of materials, reorganized in six central topics that we identified as central issues and concepts in everyday learning – time, attention, memory, emotions, language and body. Each topic comprises a lesson that can be learned in any order and pace, and connected to the other topics through an array of concepts that intercross them, so that the learners reencounter them throughout the course (for example, the term “meta-cognition” appears in each and every lesson; the term “spacing” appears in discussions on time, memory and attention). A course map and an interactive glossary facilitate learners’ orientation in the network. The modular course design resonates with the networked structure of the learning mind: it increases the connectivity between concepts throughout the course and enables learners to encounter them in different contexts and from various disciplinary perspectives, in a way that mirrors the mechanism of neural networks.

The networked design also presents an updated approach to the well-known problem of high attrition and drop-out rate in MOOCs. In recent years there is a growing consensus that the completion of a MOOC is not the best criterion for its assessment (Hayes, 2015; Lackner et al., 2015), and various alternatives are being considered, such as rewards for completion of small sections (Leach & Hadi, 2017). In our course, even if learners take only a few units they do not drop out "in the middle", as there is no "middle" in a network, and learning a single unit grants one a foothold in all the other units connected to it. Accordingly, instead of basing our assessment of the MOOC on the number of learners who complete it, the more important questions we asked concern learners' patterns of behavior in the course, the individual routes they choose, and the self-assessment of their own learning experience. In other words, the networked course design shifts the assessment from quantitative questions such as "how many" to qualitative questions such as "in what way". In a survey among approximately 150 students in 2022, we discovered that many of them can justify their personal modular route, and that the networked structure potentially enables them to develop awareness of their own learning motivations and helps them practice self-regulated learning. When the course is modular rather than linear, every element that the students wander through is the product of their choice, and the actual order of learning is led by an intrinsic rationale, which also potentially increases learners' intrinsic motivation and emotional engagement, which has crucial roles in online learning (Cleveland-Innes & Campbell, 2012; Dillon et al., 2016; Asikainen et al., 2018).

Localizing the course using diverse models of learners

The networked course design enables a flexible learning experience based on conceptual connectivity; however, online learning also relies on human connectivity – between learners and instructors, and between learners and their peers. Moore and Kearsley (2012 [1996]) developed the "transactional distance" theory according to which "distance is not simply a matter of geographic distance, but is a pedagogical phenomenon" (209). Thus, the geographical distance between instructors and learners can cause alienation, but can also function as an opportunity for pedagogical design that promotes a sense of community. Followers of the transactional distance theory demonstrate that it is a central issue in examining MOOCs, as these are usually based exclusively on distance learning (Weidlich & Bastiaens, 2018), risking blindness to the specific identities of the learners. As Chen and Oakley (2020, 5) note, sensitivity to cultural differences in MOOCs is essential: "We realized that, when it comes to MOOCs, simply providing translated video captions and Web pages were far from meeting non-English speakers' learning needs."

Therefore, in the Hebrew-Arabic LHTL we avoided using merely translated versions of the original American LHTL materials, rather creating a "glocal" learning experience – one that addresses global issues and universal learning paradigms, while also fostering local learning cultures. Creating a fair representation of Israeli culture is an impossible task, as it includes various – and often conflicting – voices and identities. This complexity, however, may also be seen as an advantage: from ultraorthodox ascetic religious learners to bilingual Hebrew-Arabic speakers and inspiring autodidacts, local learners present rich and diverse learning models. This resulted in our decision to include, throughout the course, encounters with different types of learners:

- *Fictional characters of learners* (such as Sherlock Holmes, Karate Kid, Charles Chaplin and Alice in Wonderland), presented at the beginning of each lesson according to its topic, and drawing the learners into a world in which their entire environment – including international popular culture – is immersed in learning.
- *Diverse local lifelong learners,* from elementary school pupils, through university students of various ages and sectors, to established scientists such as Nobel laureate Prof. Ada Yonath – are all interviewed in the course about their conceptions of learning and their learning habits. This mosaic of local learners creates the sense of a community that shares personal experience with the course learners, and allows for a more concrete understanding of abstract concepts in each lesson.
- *The course team,* authors of this paper. During the design process we, the academic team, documented our own real-life learning processes and included them as part of the course, becoming part of its community of learners *de facto*. For example, the course teacher presented a video blog of learning bass guitar from scratch for 10 weeks, while reflecting on concepts such as procedural memory, attention and motivation. Thus, our own position as learners did not remain backstage; it became transparent and visible to our learners, showcasing real-life learning dynamics and encouraging the learners to actively share their own, either online or in special blended sessions.

Designing videos using ‘embodied typography’

Following Oakley and Sejnowski (2019), and Clark and Mayer’s (2016) multimedia learning approach, which emphasize the principle of embodiment that eases the assimilation of complex information, we used a technique we call “embodied typography” in our media design. Embodied typography uses kinetic design that dynamically intertwines with the instructor, to visually demonstrate abstract concepts. Our premise was that a MOOC differs fundamentally from frontal teaching; it should not try to imitate a lecture and it should use alternative means suitable to the medium of short videos. Our solution, however, was to almost completely waive the power of visual images, instead choosing to utilize the elasticity of typography – instead of using illustrative images, we used illustrative letters, words, and abstract shapes. For example, when we mention the contribution of spacing to the learning process, the word “spacing” splits; when the concept “retrieval” (from long-term memory) appears, one letter as is ‘retrieved’ from the word. While not challenging the assumption that visual images help learners anchor and remember abstract ideas, or dismissing them as ineffective pedagogical devices, we claim that images often fixate memories on specific objects and are often too culturally specific. Typography enables the creation of abstract, clean yet accessible visual metaphors without committing to context-dependent images.

Throughout the course we use typography and abstract graphic metaphors repeatedly and consistently, to strengthen the networked course structure. In each appearance of a concept, we use the same design to represent it: for example, at each mention of a difficulty in learning (concepts such as stress, anxiety and procrastination) we use the same illustration of intertwined black lines that create a disturbing sense of entanglement. The word “motivation” is always followed by flying lines that illustrate a sense of action and energy. Thus, concepts throughout the course become mental models that create the expectation of consistency and strengthen long-term memory.

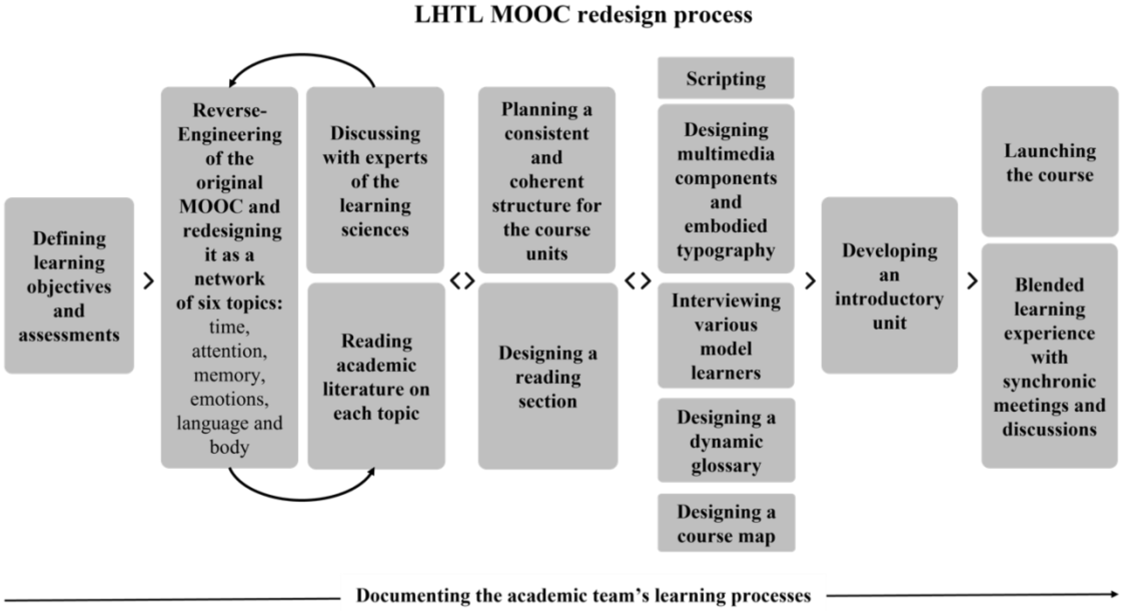
The redesign conclusion and its contribution

All the aforementioned practices, and many more that we implemented in the course, ensure that the theory of learning is reflected in every aspect of the course design. As one of our students commented in the assessment, “studying the course is like watching the backstage of your mind”. This tour into one's mind is not created by passively receiving theoretical concepts, but by a meta-cognitive learning experience, stimulated by the course structure and features, as well as by constant participation in interactive questions, discussions, and active reading.

The reverse engineering of the original course, together with various iterations we have implemented following conversations with experts and students, reading relevant literature, and experimenting with technologies, enabled us to constantly revise our premises and increased the course effectiveness and its value as a local version addressing a specific community. Iterations in MOOC design are not an easy task, as shooting the course units may fixate it and not allow flexibility, therefore the iterations started before the course launch. One example was the reading section design. While our far-reaching plan was designing a fully embodied reading that includes interactive guiding comments in the article along the reading, technological restrictions sent us to back to design a different reading experience. After the course launch, learners’ feedback helped us adjust and finetune specific areas in the learning experience: for example, we discovered that group meetings on Zoom between strangers do not promote their learning as expected, and we designed the blended sessions in different techniques and found alternative ways to create personal connections between learners, to address the issue of “transactional distance”.

We have learned about the possibilities and the limitations of MOOC technologies, and some of our wildest ideas had to be adapted creatively to more feasible practices. Thus, the process of *creating* the course became a learning experience in its own right and echoed the theoretical principles taught in the course. The result of our learning process is a MOOC format characterized by maximal adequacy between contents and design, open for the use of new international versions of *Learning How to Learn*. Our claim that learning-science based MOOC design significantly enhances it, also makes this model relevant to MOOC researchers and designers in other areas.

Figure 1
The MOOC redesign process



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#DryLabsRealScience: Redefining Practical Pedagogy Post-Pandemic

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Abstract: The COVID-19 pandemic posed specific challenges for STEM educators, namely the provision of meaningful laboratory experiences when access to equipment and facilities were restricted. #DryLabsRealScience is a community of practice that was formed to address these challenges, providing a free, open platform for sharing innovative, practical approaches to support the life sciences. The network identified datasets, augmented/virtual reality, simulations, and videos as the central and most effective approaches to delivering laboratory-focused teaching and learning. While all these approaches had been used pre-lockdown, the pandemic forced the adaption of these techniques to online delivery. In this paper, we describe the novel utilisation of these approaches to support student laboratory learning in response to the challenges faced by remote and blended teaching.

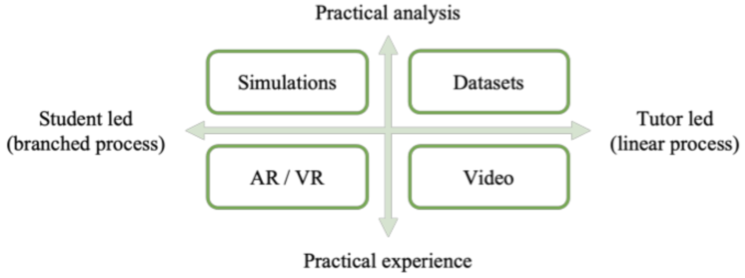
Introduction

When COVID-19 forced the closure of laboratory facilities, higher education (HE) had to rapidly re-evaluate their approaches to delivering practical-based degrees, with the main challenge being the replacement of sessions that developed kinematic psychomotor skills essential to STEM practitioners (Wilkinson et al., 2021). #DryLabsRealScience (#DLRS), a practitioner-driven community of practice, was established to address this issue, providing a free and open network for life science educators to share their innovative approaches to overcoming the challenges of pandemic-impacted teaching. What has resulted is a rich community of practice that enhances the delivery of practical laboratory and field classes in a much broader sense (Francis et al., 2020). Over 90% of participants in the network, which has an international reach of over 200 educators spanning higher, further and school education, as well as commercial education providers, highlighted that attending network events had allowed them to influence departmental policy for dry lab provision (Cramman et al., 2021). The evolving pedagogic approaches developed by the network have had a lasting impact on the practical class provision through the development of a blended educational model.

Approaches

Thematic analysis of the topics presented during #DLRS meetings has revealed four principal approaches: videos, simulations, augmented/virtual reality (AR/VR) and datasets. There is a clear overlap between these methodologies and combined approaches have become embedded as practitioners have embraced blended learning strategies. Each approach has a sound pedagogic underpinning as well as individual strengths and weaknesses that are presented as a conceptual framework (Figure 1). The four main areas of practice can be split along two axes. The horizontal axis describes the pathway for interaction with content: tutor-led (linear process), where a defined outcome is pre-set, and student-led (branched process), where the outcomes depend on the individual's actions. The vertical axis describes delivery as either a physical experience to replicate or enhance psychomotor components or as an environment to experience practical analysis through generating or manipulating practical outcomes.

Figure 1
A new conceptual framework for practical delivery



Videos

Educational videos have been integral to many HE courses, whether for traditional delivery, a flipped approach or as a mechanism for conveying information in blended/online courses. Videos have been shown to be an effective educational tool in various educational contexts (Woolfitt, 2015; Smith & Francis, 2022), including the supplementation of practical pedagogies through video exemplars and guides to practical techniques (Croker, 2010).

The COVID-19 pandemic placed an intense focus on the use of videos to help support the delivery of practical classes, initially remotely and subsequently in the blended learning model as facilities opened again. #DLRS identified three key stages of video usage in practical delivery (i) pre-lab (e.g., health and safety briefings, equipment demonstrations); (ii) replacement labs (e.g., live streaming a lab class, pre-recorded demonstrations); (iii) post-lab (e.g., data visualisation and analysis) (Turner, 2020).

Videos are not, however, a medium without challenges. They need careful design to ensure students are not cognitively overloaded and require elements of active participation from students to maximise learning gains and avoid them becoming a linear, passive medium for content delivery (Fyfield et al., 2019). Some specific active learning approaches highlighted in video usage by #DLRS contributors include:

- Deliberate errors are placed into the recorded demonstration, which the students then identify.
- Silent videos, where students are asked to record a narrative to demonstrate understanding.
- What happens next? Incomplete videos for students to identify the next step.
- Live streaming with students directing the actions of the demonstrator.
- Quizzes embedded into the videos require an attempt to be made before the recording can be resumed.

Simulations

A well-designed simulation replicates the sequence of interactions a user can expect when operating a system. Within the practical context of a laboratory, this manifests itself as the replication of techniques, methods, or equipment, in digital format. Where simulations differ from videos is the indeterminant branched endpoint that is dependent on the actions of the user. This permits students to experience multiple iterations of a method or technique that might otherwise be logistically impossible due to time or cost restrictions (Jones, 2018).

The use of simulations can be considered a form of inquiry-based learning, with students manipulating parameters within the simulated scenario, which can be recorded and analysed as a process in their own right to optimise the experimental design (Gormally et al., 2009; Pedaste et al., 2015). By passing ownership and control of the experimental optimisation to the students, they experience an authentic task that enhances critical transferrable skills, such as problem-solving (Bassingdale et al., 2021). Crucially, these skills can then be transferred to the physical environment, so students have already experienced what it is like to solve given problems and can focus on developing the kinematic psychomotor skills required to complete the task.

Virtual labs can bridge scientific theory from taught material to laboratory practice in the same way physical labs do. The ability to attempt multiple iterations of the experiment in a compressed timeframe can enhance the link (Francis et al., 2022). Students have reported that they develop an understanding of correct equipment usage, troubleshooting, accurate record keeping and data analysis and interpretation skills from simulated labs, which align closely with the learning objectives for face-to-face wet labs experiences (Bassingdale et al., 2021).

Examples of simulation usage from #DLRS members include:

- Data recording in an electronic lab book through a [Do][Explore][Act] framework.
- Interactive virtual lab usage to allow students to explore given scenarios (e.g., Labster (www.labster.com)/LearnSci (www.learnsci.com) resources)
- OpenSTEM labs (www.stem.open.ac.uk), online virtual labs from the Wolfson Foundation that provides remote access experiments and virtual simulations using real-time data.
- Virtual learning tools such as Benchling (www.benchling.com) incorporate an electronic lab book with an embedded suite of molecular biology analysis tools.

AR/VR

Augmented reality (AR) integrates digital information with the physical environment allowing simultaneous interaction between the digital and physical environment. Virtual reality (VR) creates a real-time, fully immersive simulated digital environment (Huang et al., 2019). AR is a more emergent pedagogical tool than VR, which has been implemented successfully in various educational settings, including HE (Huang et al., 2019). Several commercial providers facilitate the use of virtual laboratories, combining VR with simulations, videos, and interactive worksheets to produce rich, immersive, active learning environments for students. The use of AR in life sciences has been less well studied, but its potential is starting to be recognised (Barrow et al., 2019). Members of the #DLRS community became early adopters of AR and VR to supplement or replicate practical teaching, however, they acknowledged the barriers to adoption as a pedagogic tool. These include the cost of equipment, the skillset required by staff to develop and students to utilise resources and the institutional infrastructure, including student access to hardware. Some highlighted examples of AR and VR use include:

- 360º videos using ArcGIS StoryMaps to provide virtual field trips for students, allowing them to interact with multiple fieldwork sites.
- Virtual marine field trips created using ThinkLink, allowing students to navigate and explore coastal landscapes whilst conducting real-time experiments with embedded experimental tools and videos.
- Creating AR protein structures that aid students with visualising the crucial theoretical concepts from lectures in an interactive manner.

Datasets

Data generation and analysis is a critical skill developed during the laboratory experience. Pre-pandemic, many practical and field classes focused on generating data in numeric or image format, which were subsequently used for analysis and interpretation. Within the post-practical teaching environment, datasets are often subject to statistical analysis to reveal meaning. Therefore, the ability to manipulate and work with data, apply appropriate statistical analysis, and interpret meaning are crucial skills required of scientific practitioners. Within the #DLRS context, this has resulted in students generating datasets using simulations or tutors using coding strategies in R, C++, Python or HTML5.

An advantage of this approach is that each student can be assigned a unique dataset to work with, with algorithms providing the solutions to tutors based on the original input parameters. Through the, near, limitless datasets that can be generated, students can develop the key skills of data interpretation and analysis whilst mitigating against collusion and encouraging students to collaborate on processes rather than answers. Specific examples showcased to #DLRS include:

- Automatically generated datasets using R. Specific variables can be randomised to introduce set ranges and errors within the datasets. Unique identifiers allowed tutors to quickly access solution sheets.
- Interactive experiments coded using HTML5 allow students to generate datasets within a web-based environment. Answers can be inputted into automatically marked worksheets.
- LearnSci produces interactive, self-marking worksheets which can be embedded into virtual learning environments. The worksheets allow students to enter their own unique datasets and provide guidance and feedback as the student attempts questions providing a rich assessment for learning opportunity.
- CellProfiler has been used to perform High Content Image Analysis with students provided with existing images that were unique to each student.

The main pitfall of computer-generated datasets is the lack of ownership felt by the students with the data production and, therefore, more limited engagement with the analysis. Synthetic datasets, constrained within nominal parameters and ranges, may not provide the diversity of data, nor model experimental trends and errors seen in student-generated experimental data. However, the advantage is the reduced marking burden that can be associated with automatically marked worksheets.

Conclusions

The COVID-19 pandemic rapidly accelerated the adoption and evolution of pedagogical approaches that underpin practical delivery. Once educators were able to adapt to the remote and blended learning approaches, a rich and diverse range of strategies began to be described and adopted. At the start of the lockdown, many of these ideas were applied in isolation as educators struggled to provide a meaningful learning experience, however, we are now witnessing more joined-up strategies, with multiple approaches being integrated with each other to produce robust teaching and learning resources both pre- and post-practical. It needs to be noted that none of the approaches described here can fully replace the physical laboratory experience, as the kinematic skills developed in face-to-face environments remain the cornerstone of science-based degrees, confirming the findings of de Jong et al. (2013). However, where immense value is added is in the preparatory phase, allowing a scaffolded approach to student learning where they can link the theory of lectures to the application of laboratory practice prior to even setting foot in the physical space. Post-class, student learning of data analysis, interpretation and presentation can be enhanced allowing for a greatly enriched educational experience.

Although the strategies and approaches described here have been focused on biosciences, they are applicable to most other disciplines within and beyond STEM. Communities, such as #DLRS provide a valuable, open platform for the free sharing of ideas and resources driving teaching approaches' adoption, refinement, and enhancement. The networks will be able to adapt to future challenges, driving a long-lasting change to the pedagogic thinking around laboratory provision with the continued use of resources developed during the pandemic as a return to more traditional delivery methods ensues.

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Emerging Education Research Practitioners and Theory

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Abstract: Discipline based education research (DBER) seeks to understand how people learn and grow within a discipline. It is a highly interdisciplinary field requiring knowledge in the specific discipline in question, as well as education and related fields. DBER attracts many faculty practitioners who did not conduct their degrees or post-doctoral work in education. These practitioners often find themselves without formal support or opportunities for formal introduction to education research. We discuss how the Professional development for Emerging Education Researchers (PEER) program supports these emerging education research practitioners in learning the ropes in this new field. PEER's theory module is a recently created addition to the program, which is undergoing continuing development, and is our example of how the PEER program is adapting to participants' needs.

Introduction

Discipline based education research (DBER), a cousin field to the Learning Sciences, seeks to understand how people learn and grow within a discipline. Typically conducted at the university level and from within disciplinary departments or schools of education, DBER interests faculty with diverse research and disciplinary backgrounds. Some may have studied education research in graduate school, or pursued post-doctoral work in it, having prepared for research through training and practical exposure to ideas, theories, methods, and common practice within the field. Faculty may become interested in DBER after obtaining their faculty position (often, but not always, a teaching-focused position) (Bush et al., 2017) or after tenure and promotion. These faculty rarely have formal DBER training or practical experience, even as they may have varied experience as educators. As a result, they struggle to orient themselves to the field's understanding of theory, methods, and research practice and as they set up their research programs within the field.

The Professional development for Emerging Education Researchers (PEER) program was established to support these emerging DBER practitioners (Franklin et al., 2018). PEER offers workshops and mentoring to support emerging DBER practitioners in developing their education research skills and succeed in their personal education research projects. In this paper, we focus on one PEER module about research theory as a case of how the principles and design of PEER came together with lessons learned from participants.

Who are the authors?

In the context of PEER, our participants are practitioners. They are new to the practice of education research, and they engage as emerging DBER practitioners in PEER activities. This paper seeks to discuss how we support newcomers in engaging in the practice of education research. The first authors on this paper take the dual perspective of researchers on PEER as a program and practitioners (PEER participants); the following authors take the dual perspective of researchers on PEER as a program and PEER workshop facilitators. Just as a professional development program for teachers around improving classroom teaching counts their participants as practitioners of classroom teaching, we count the participants in our professional development program as practitioners for engaging in DBER.

We incorporate the research principles of PEER in our daily work, and study the PEER program in the hopes of making education research more accessible to disciplinary scientists. In our capacity as part of the PEER research team we work with the PEER coordinators and facilitators to better understand the needs of the program and its participants. Our research supports the development of the program, and helps to ground the program in participants' needs.

The philosophy and why of PEER

PEER is strongly grounded in two theoretical perspectives: responsive teaching, and communities of practice. Responsive teaching is a model of teaching in STEM education that places high importance on centering and responding to the ideas of students and the connections they are making (Robertson et al., 2015). PEER embodies this responsiveness at a workshop level by centering individuals' research interests and questions in its activities. Modular, multi day workshops are organized and constantly reevaluated to center participants' research interests and projects as a subject for development making practitioners the drivers of ideas.

PEER workshops also seek to develop a local community of practice among participants (Wenger, 1999). Many emerging practitioners are still developing their identity as education researchers, and a community of fellow practitioners is critical to supporting that development. As a theory of education, communities of practice highlight learning as engaging in shared practice (Wenger-Trayner & Wenger-Trayner, 2022). PEER's community of practice consists of practitioners and facilitators engaged together in researching education and instruction.

The theoretical grounding of PEER has led to four core guiding principles: research is *responsive, playful, collaborative,* and *communicative*. These four principles are explained in Table 1. Additionally, in keeping with these ideas, PEER takes a non-linear view of research as a practice. This nonlinearity encourages *playful* generation of ideas throughout the process, regular and planned *communication* of those ideas, *collaboration* with colleagues to share ideas and play with, and results in a research process that is *responsive* to the evolving needs and ideas of practitioners.

Table 1
The guiding principles of PEER, for professional development and research practice

Responsive	Research responds to the needs and ideas of researchers, subjects, and the community.
Playful	Research is play, engaging with each other's ideas in an actively positive way to encourage idea building and research development. There are no bad ideas, only incomplete ones.
Collaborative	Research is better with friends. More minds and perspectives mean more ideas to play with, and more research and collaboration opportunities.
Communicative	We communicate our research ideas at all stages of the project via different media (posters, talks, publications, etc.), and actively think about how we will do that.

The four principles of PEER do not only apply to research, but also to the program. Research is fundamentally a process of discovering and generating new knowledge, a process of learning. PEER is a professional development program, participants come here to learn and develop new skills in education research. Accordingly it makes sense to ground the learning and knowledge development that participants engage in at PEER in the same principles that we wish participants to adhere to in their research practice.

What is theory: Needs of emerging practitioners

Emerging DBER practitioners often struggle with the role of theory in education research, especially if their prior experience with theory is through a STEM discipline. In response to repeated and ongoing requests from PEER participants to train them about theory in DBER, we conducted research around emerging DBER practitioners ideas about theory and iteratively developed and tested a module to address their needs and concerns.

Participants have often expressed interest in learning about various theories, how to use a theory or multiple theories applied to the same data, or have even requested a module on "What is theory anyway?" Over the years, PEER coordinators had struggled to design a workshop module that felt like it addressed participants' needs and answered their questions in appropriate depth. Recent interviews with emerging DBER practitioners shed some light on what they wanted to learn about theory (Hass et al., 2022), for instance Ryan stated: "[There are so many] different theoretical perspectives that one can adopt when you're looking at your data..." and went on to say: "Where you just kind of do what you know and if you don't know it, you can't do it." The lessons learned from this research have allowed us to construct a new theory module.

Currently this module focuses on having participants discuss and think deeply about what they expect from theory in their projects. The module begins with a collaborative role play activity, and moves into alternating facilitator presentations and small group discussions about theory, interspersed with personal writing time. The module then moves into reframing research questions based on theory choices. It closes out with a large group question and answer session, and context discussion. This is a fairly common overall format for PEER modules, which focus on giving participants ample time to connect module content to their own research projects, with help from facilitators.

PEER's theory module

Facilitators present briefly (5 minutes) about big questions to consider when selecting among theories, responding to emerging practitioners' questions in a pre-workshop survey. Next a case study gives participants the opportunity to generate ideas about theory in a way that is *playful* rather than critical. The case study is a role playing session in which participants split into groups of 3 or 4 and are given a scenario to role play out. Members of the group take up the roles of Lauren and James (in a three person group one person is an observer). They then come back together for a group discussion about how the role play went, with Laurens, James', and observers taking turns reporting out. Participants are explicitly not given definitions of theory before the case study, and are intentionally given the case study at the beginning of the workshop before learning more about theory. The case study given to the participants is included below.

> *Lauren and James are thinking about collaborating on a paper to submit to Physical Review Physics Education Research about how to help students who are stuck while problem solving. They have video data and transcript of a small group of students problem solving in a lab. They are both new to Education research, and are struggling to choose an appropriate theory. So they reached out to a colleague who does this, whose first question was "What do you want theory to do for you?"*
> *They say they'll have to think about that more, and then head off to discuss theory together.*

Many participants express feelings of uncertainty about theory (a participant anonymously asked in a pre-workshop survey "Why do you even need a theory?"), but also feelings of uncertainty about their newness to education research (Mariah says in a pre-workshop interview "I was a little intimidated by that because I'm not like an education researcher…"). Building *collaboration* into the workshop gives emerging practitioners the opportunity to be confused about theory, openly and together, so that they know that they aren't alone. We also want to give participants space to discuss their own great ideas about theory (because it turns out they have lots) before we dive into other people's ideas about theory.

Emerging practitioners are also struggling to understand what role theory plays in research practice, as James says "I try and put myself in that researcher's shoes and understand how they're connecting the dots. And I try really hard to extend that all the way back to their theoretical framework…". After emerging practitioners have had a chance to think about what theory is, and their ideas about theory, facilitators give a presentation on the research process and theory's roles in a research project. PEER's nonlinear view of research means theory takes on different roles over the course of a project. Research is *responsive*, and as a project evolves and as researcher's thinking and perspective changes, theory must respond to those changes.

At this point, the theory module moves into a mixture of presentation from the facilitators, and question and answer. Facilitators respond to the concerns and individual ideas of participants, while also attending to and celebrating shifts in participants' thinking. Time is built in intermittently (usually about 5 minute chunks) for participants to do some generative writing, where they write about their ideas and how these ideas connect to their research plans. Generative writing is a philosophy of writing that takes the act of writing as generative, in writing things you come up with new ideas. Writing often and lots is good for producing, solidifying, extending, and exploring ideas. This supports *playfulness* by generating and recording new ideas to play with and share. It also supports *communicative* aspects of research by supporting the creation of posters, presentations, and papers later in the research process.

Next, facilitators discuss a method of categorizing theories, *responding* to emerging practitioners' wish for a way to map different theories and their purposes. The method is just one of many, and focuses on categorizing theories according to the level of their focus. Participants are given an activity where they work in groups to take a research question, and adjust it to suit different categories of theory. Then, they are asked to go back to their own projects and consider what their current research question says about what level of theory they might need. Again, notice that participants are encouraged to engage directly in the process of research as part of the workshop, and are invited to play *collaboratively* with the ideas presented to them.

The workshop ends with a practical discussion of how to find theory, in *response* to emerging practitioners' struggle to find relevant theories in the dauntingly vast literature. This last part of the discussion also includes time spent on the possibility of creating one's own theory, when that would be appropriate, and what it entails. Theory, like all parts of the research process, should be *responsive* to one's needs, so we discuss how to adapt and create theory when one needs to.

Implications for education researcher development

Paying attention to the needs of emerging DBER practitioners is important, as catching them early is an opportunity to help them grow in the practice and become engaged with our community. As a community this makes us more productive and our practice stronger. Alternatively, ignoring them leads to feelings of isolation and can drive them out of our community. It can also result in lower quality work within our practice.

Attending to emerging practitioners' needs means building a partnership, in which both our emerging practitioners and community members work together to build ideas. These partnerships lead to learning both for junior and senior community members, and bring benefits to all parties involved. Collaborations, publications, opportunities for mentorship, and building lasting friendships are all benefits that come with supporting emerging practitioners. Further these partnerships can lend insights into the values of our field, and also the behaviour and ideas that we take for granted (for instance the definition of theory, and the many different terms surrounding it). It is key, when building such a partnership, that all parties have the power and ability to set the agenda.

Finally, creating and iterating on the theory module has required us to look for the concerns underlying problems voiced by emerging practitioners. Though they often ask for particular theories, or particular questions about what theory is used for and where it comes from, deeper issues underlie these questions. For instance, concerns about legitimacy, acceptable practice within the community, and the friendliness of reviewers. Finding and understanding what these deeper issues are is important when attempting to support emerging practitioners in their growth.

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Pose Detection: Towards Ubiquitous Embodied Interventions

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Abstract: Incorporating embodiment into learning environments has increasingly been accomplished using motion-detection technologies to create extended reality (XR) experiences. While these XR experiences typically use specialized hardware (e.g., Microsoft Kinect), computer vision algorithms and embedded laptop cameras have advanced to the point where they can be incorporated into educational interventions and research tools without the need of expensive peripheral technologies. In this paper, we present a scalable research tool, The Hidden Village-Online (THV-O), that leverages these technologies in the form of a web-based, narrative-themed videogame. Preliminary pilot results indicate that this tool was able to replicate findings of a similar embodied cognition study that used software powered by the Microsoft Kinect. These results suggest that web-based XR experiences requiring only an internet connection and an embedded laptop camera, like THV-O, are mature enough to serve as a viable alternative approach for creating technology-enabled embodied learning experiences.

Introduction

Over the last decade, increasing interest in embodied cognition has seen the development of novel opportunities to learn through integrated and high bodily-engaged tasks (Skulmowski & Rey, 2018). Advances in computer-based motion-detection technologies have produced a variety of options to incorporate embodied experiences into learning environments (Georgiou & Ioannou, 2019), often leveraging a host of peripheral hardware such as the Microsoft Kinect (e.g., Abrahamson & Bakker, 2016; Rallis et al., 2018), virtual reality headsets (e.g., Johnson-Glenberg et al., 2021), and mixed reality devices like the Microsoft Hololens 2 (e.g., Walkington et al., 2022). One of these embodied learning environments, *The Hidden Village* (THV; Kirankumar et al., 2021; Nathan & Swart, 2020; Nathan & Walkington, 2017), uses 3D-motion capture to elicit and track players' cognitively relevant movements (Nathan & Walkington, 2017) that benefit players' mathematical reasoning about geometry conjectures. Benefits arise because players' are more inclined to generate embodied simulations of the potential transformations of geometric objects while they explain their reasoning as they formulate mathematical intuitions, insights, and proofs (Swart et al., 2020; Walkington, Nathan, Wang, & Schenck, 2022).

Though these studies suggest that players' geometric reasoning improved as a result of using this technology-based intervention, THV's reliance on dedicated peripheral sensor hardware limits its scalability and sustainability as a classroom activity and research tool for a number of reasons. First, rapid developments in extended reality (XR) technologies (i.e., augmented reality and virtual reality) caused several peripheral XR hardware projects to be discontinued, including the Microsoft Kinect, Oculus Rift, Google Glass, and Leap Motion controller. Continuing to use these outdated technologies requires researchers to seek costly and specialized software development to push forward their research agendas (Fogel et al., 2021). Second, peripheral hardware such as XR headsets can only serve one student at a time and purchasing enough to serve all their students is an expense that prevents many schools from widespread classroom adoption.

Fortunately, significant advances in the quality of embedded laptop cameras combined with open-source computer vision packages have enabled development of an easily accessible web-based version of THV that tracks and records players' movements without additional hardware or client-side software. As a proof of concept, we present *The Hidden Village-Online* (THV-O), a novel browser-based XR implementation capable of creating effective embodied learning interventions using ubiquitous consumer-grade technologies.

Methods

Technology

THV-O leverages players' movements for both navigation as well as core gameplay using consumer grade webcams and algorithmic-based software packages. THV-O uses the Mediapipe Holistic Pose Detection Algorithm (Lugaresi et al., 2019), which identifies key landmarks on a player's body (e.g., wrists, elbows, shoulders, and fingers). These landmarks are then used by THV-O to determine whether players have positioned their bodies in the correct poses (i.e., the directed actions). Graphics and interface for THV-O (alpha version) was implemented using ReactPixi for graphics and XState.js for state logic. To evaluate whether participants had adequately matched a pose, we wrote an algorithm to calculate the angle between a set of a participant's body parts (e.g., the angle between a participants left wrist, elbow, and shoulder) that compares it to the corresponding angle of the model's body parts (Figure 2, right).

Platform and flow

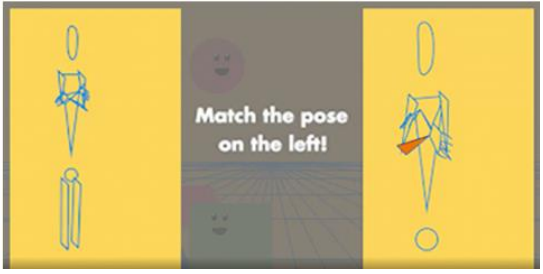
THV-O takes players through an eight-chapter story set in a two-dimensional world populated by different shapes. Using a webcam, the game detects participants' bodies in real-time and leverages the positional data to animate the player's avatar, effectively displaying a mirror image of the player in the fictional world of shapes (e.g., the avatar on the right side of the screen in Figure 1). In each chapter, participants read narrative dialogue between their character and one of the shapes, and then performed a task to “assist” the shape. Each task consisted of four stages: (1) Animation, (2) Pose Matching, (3) Intuition, and (4) Insight.

Figure 1
Player avatar in the world of Shapes

I'm Equila the Triangle, you're the Multi-shaper and this is the world of Shapes! In this world, we're all different shapes... but you... you are a very rare multi-shaper!

In the Animation stage, participants watched a 15 to 30 second animation of a model performing a set of directed actions (Figure 2, left). After the animation had finished playing, during the Pose Matching stage participants were prompted to move their avatar (using their own body) to match poses demonstrated by the model in the animation stage (Figure 2, right).

Figure 2
Player’s avatar (left) attempting to match model’s pose (right)

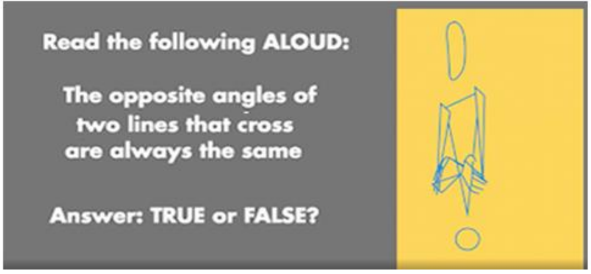


Match the pose on the left!

Next (Figure 3), during the Intuition stage, participants were asked to read a geometric conjecture aloud and assess whether that statement was always true or false. Lastly, participants were shown a final screen (the Insight stage) in which they were asked to explain *why* they believed the statement to be true or false. The conjectures and directed actions were used in previous studies that showed improved performance on the task when players performed the game-based directed actions (Nathan & Walkington, 2017; Walkington et al., 2022). The goal of the tasks was to investigate the influence of movements on cognitive states and, reciprocally, the influence of cognitive states on movement, a core tenet of the Action-Cognition Transduction framework (Nathan and Walkington, 2017). The directed actions for each conjecture were designed to be cognitively relevant to reasoning about the given problem. Collecting participants’ True/False responses for the Intuition prompts and multimodal explanations from Insight prompts were separated so researchers could evaluate whether participants’ answers changed as a result of engaging in grounded embodied reasoning.

Figure 3

Example geometric conjecture about which players reasoned



Read the following ALOUD:

The opposite angles of two lines that cross are always the same

Answer: TRUE or FALSE?

Preliminary pilot data

An initial pilot study of THV-O was conducted to test the platform's viability (Fogel et al., 2022). A convenience sample of university students (N=27, $\bar{x}$=21, n_{male}=15 [56%]) was recruited for the study. Participants were videotaped as they played through four conjectures (four chapters) on the THV-O platform, with presentation order of conjectures determined using a Latin-square factorial design. Video recordings of participants' gestures and transcriptions of their verbal reasoning were qualitatively analyzed.

Preliminary data from this pilot experiment revealed that people using THV-O performed spontaneous gestures representing mathematical concepts across 74% conjectures that were completed. Moreover, the results suggested that making *dynamic gestures* that simulated the various transformational states of the mathematical objects under investigation during their explanations was associated with more correct insights (a replication of Nathan et al., 2021).

Discussion

In this work, we discuss using web-based XR interventions utilizing embedded webcams and computer vision algorithms to replace embodied interventions that relied on costly peripheral hardware. We demonstrated the viability of this approach through THV-O as a proof of concept to serve both researchers and educational intervention designers. While the platform utilized motion-capture data to power the gameplay experience, integrated data collection was not developed in THV-O's current iteration as a result of the limited resources available for prototype development. Fortunately, browser technology enables the collection and saving of data used by researchers to answer fundamental research questions. Thus, future iterations of THV-O will support data collection functionality enabling researchers to record participants' speech (audio), actions/gestures (video), as well as body position (motion-capture accuracy, time, attempts).

Though this approach shows the potential of technology-enabled embodied educational interventions, it is not without limitations. Changing the angle or height of the web camera influenced how well the algorithm was able to determine whether participants had adequately matched a pose. As a result, the height of the camera influenced THV-O's ability to compare the calculated difference in angles of a participant's body to the angles of the model body for a given pose. Improving the pose matching experience by reducing the algorithm's sensitivity to camera placement is a goal for future work. Additionally, many of these types of highly performant open-source computer vision algorithms currently only detect a single individual at a time. Thus, researchers may be unable to investigate the benefits of collaborative embodied learning, as was possible with the Kinect sensor array (Walkington et al., 2022). Finding alternative methods to study collaboration using THV-O will require utilizing new algorithms to detect and track multiple participants in the same frame. Nonetheless, the current study highlights some preliminary benefits for using embedded webcams and computer vision algorithms to deliver embodied learning experiences over the web. Moreover, it offers a new and promising method for developing a scalable, low cost educational intervention and research tool.

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Humanitarian Aid Project as a Source of Building a Community of Practice in the Educational Institution

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Abstract: This paper analyses the process of conducting the Humanitarian Aid for Ukraine initiative in an educational institution and defines the learning outcomes of the project. We used learning paradigms of communities of practice and service learning to describe and indicate essential steps of the project. The result of this practical work is an instructional guide to a humanitarian project within an educational organisation. This paper documents best practices, suggests improvements and reflects on the educational value of the activity to its participants and the hosting organisation. All the process is described by the characteristics of community of practice: domain, community, and practice, which make it easy to replicate in other educational institutions.

Introduction

The classical educational process is going through many transformations and redefinitions at present. Despite these innovations, people tend to think of an educational process as something constructed in advance by educational specialists with predetermined objectives and learner trajectories (Earle, 2002). In this paper, we would like to address the following question: how does learning take place when it is not thought of and designed in advance but rather occurs due to an external event? The current paper explains how a highly dedicated community created a learning opportunity for itself by successfully managing a fully-fledged humanitarian project in a crisis situation.

On February 24, 2022, a full-scale Russian invasion of Ukraine began. A Humanitarian project, called The Humanitarian Aid for Ukraine initiative, was launched at the end of February 2022 at Learning Planet Institute (LPI) – the institute for interdisciplinary research in Paris that hosts one bachelor program, three master programs, a doctoral school and numerous researcher fellows (1). The community coordinator – the main initiator of the project – is a second-year Learning Sciences student of the EURIP Graduate School (Ecole Universitaire de Recherche Interdisciplinaire de Paris - Learning Planet Institute / Université Paris Cité (2)). The project was created in cooperation with the Association of Ukrainian Scouts in France (Plast – Scouts Ukrainiens de France) and the Embassy of Ukraine in France (Ambassade d’Ukraine en France).

As civic activities are at the core of the EURIP graduate school and Learning Planet Institute (for example, Imhotep – the association created to build efficient health communication (3), Learning Planet Youth Council – the communication platform for young activists around the world (4), and many other student and research community initiatives (5), the board of Learning Planet Institute and EURIP supported the humanitarian action for Ukraine.

It is noteworthy to mention that humanitarian aid, in the form of material donations, has proven instrumental in enabling numerous countries to surmount natural and man-made disasters (OCHA, 2022). Such donations are frequently gathered and transported by small non-governmental organizations (NGOs) adept at functioning locally (Ibidem).

This project is an example of the successful creation of a community of practice and implementation of the concept of service-learning on the institutional level. Service-learning means integrating civic initiatives and volunteering into student curriculum and education programs (Levesque-Bristol et al., 2011). Communities of practice, according to Wenger, are the following:

> Communities of practice are groups of people who share a concern, a set of problems or a passion about a topic and who deepen their knowledge and expertise in this area by interacting on an ongoing basis (Wenger et al, 2002, p.4).

The community of practice can give newcomers the necessary skills and make the experience of its members personalised. The community of practice is also a fertile ground to explore new concepts and implement new strategies while mutually learning and improving. To sustain the community of practice, there should be a bond of communal competence and deep respect for particularity and experience. (Wenger, 1998).

The communities of practice are based on the following dimensions (Snyder & Wenger, 2010, p.100):

- **Domain** – defines the identity and concerns of the group. It is necessary for the group to share a passion for the domain.
- **Community** – the relationship between the members and the feeling of community should be strong, The members' expertise levels should vary. A "community coordinator", along with the core group, should take over the leadership of the community.
- **Practice** – the practice of the different groups in the community should share and develop the knowledge of practitioners. Practice contains a range of tools, frameworks, methods, stories and activities connected to learning and innovation.

Project overview

The experience explained in this practice-oriented paper can serve as a generalised blueprint for further usage in collaborative learning. In the paper, we would like to describe all the processes, from the generation of the original idea to the implementation of the active phase. For that purpose, as Snyder and Wenger suggested, we will focus on the following characteristics – the domain, community, and practice, that define the project as a community of practice.

In the case of our project, the domain is humanitarian aid, the community – volunteers concerned by the situation in Ukraine, practice – tasks, activities and learning methods used for the project.

Domain

The initial idea of opening a collection point of humanitarian aid resonated with the needs of Ukrainians and the will of Parisians to engage in humanitarian action. Indeed, the first phase of the project was the need for action that arose from the Russian invasion of Ukraine: more than 7.7 million internally displaced people and more than 15.7 million people requiring humanitarian assistance with food, hygiene, medical and other supplies (United Nations, March 2022). Within the first three days after the beginning of the full-scale war in Ukraine, numerous concerned people in Paris were working on ideas of launching projects to help civilians affected by the war.

As one of the authors of the paper is also a member of the Plast – Scouts Ukrainiens de France Association – the branch of Ukrainian scouts located in Paris. This association has connections with numerous NGOs in Ukraine and collaborates closely with the Embassy of Ukraine in France. Hence it was decided to launch the project in cooperation with the Plast – Ukrainian Scouts in France and the Embassy of Ukraine in France.

Several master's students of the EURIP graduate school for interdisciplinary research proposed the project to the board of the institution at the end of February 2022.

The *main tasks* were the following:

- Opening a humanitarian aid collection point at the Learning Planet Institute: collecting, sorting, packing and sending donations (food, hygiene, baby care products, medicines and equipment for civilians) to Ukraine.
- Organising the team of volunteers from the EURIP graduate school and partnering organisations.
- Designing and maintaining the learning program for the volunteer community members.
- Sustaining active communication within the Learning Planet Institute community and French media to raise awareness about the problem and current needs in Ukraine.

The first author of the current paper was responsible for the project deployment and coordination.

Community

During the first three days, the community coordinator was in charge of the reception of donations, stock management, logistics, and communication with donors, local activists, and the media. 3-5 volunteers on site were responsible for sorting and packing donations. Due to the significant growth in the number of donations and people willing to help over the first days, the decision to enlarge the project scale was made. That is why we developed the learning system to create and sustain the community of volunteers. The learning system included the following elements:

- Communication channels for volunteers dedicated to asking questions, offering improvements and giving feedback.

- Workflow guidelines that depend on the task (welcome point, sorting, packing, community management, logistics, etc.).
- Community-building events (regular common lunches, feedback sessions, outdoor activities and discussions for volunteers).

The community of volunteers grew from 3-5 people to more than 100 volunteers in the peak phase of the project (the first two months), and 50 community members stayed active from the beginning of the project until the end of the active phase (4 months in total). The community included: students and researchers from EURIP graduate school, Learning Planet Institute staff members, and people related to partnering organizations.

It is worth mentioning that during the first days of community building, as volunteers were learning how to run the humanitarian aid project and giving multiple pieces of feedback, the team implemented changes to upgrade the practice to enhance the equity, well-being and efficacy of volunteers. That makes the project an example of a co-constructed learning community in which diverse perspectives were included.

Practice

Therefore, among all changes implemented within the first week of the project, one of the most significant was the implementation of management positions for experienced volunteers, which included:

- *Project coordinator:* workflow and logistics management, communication with partners and media, reporting, event organising, and cooperation with recipient organisations in Ukraine.
- *Communication manager:* social media management (content creation, communication with the online community of donors, partners, and volunteers), scheduling visits of media representatives.
- *Responsible for volunteers:* managing shifts schedule, planning the shifts, distributing the work between volunteers, resolving issues of the volunteers, and providing learning materials.
- *Stock manager:* administering the stock spreadsheets, registering each categorised box of donations to the system, creating delivery notes with detailed lists of items sent and delivery vehicle and driver details, preparing custom clearance documents for drivers, and managing the work of senior volunteers.
- *Senior volunteers:* responsible for several categories of donations: food, hygiene, baby care, equipment products and medicines (requirement: medical diploma holder). Those volunteers managed the work of junior volunteers regarding the reception, sorting and packing processes.

Community members were assigned management positions depending on their expertise and availability throughout the week. The volunteers met regularly at the collection point, and they were trained by senior community members that had already gained experience by being involved in the project workflow since its early stages. During the regular feedback sessions and informal gatherings, community members repeatedly reported an increased sense of belonging that improved their well-being.

Learning outcomes

Based on all the processes explained above, various competencies were acquired as part of the project. Thanks to the regular feedback sessions with volunteers, we derived the following learning outcomes:

- *In entrepreneurship:* conceptualising and creating a project idea, calculating necessary resources, and establishing the project lifecycle.
- *In project management:* building processes in the team, establishing roles and responsibilities, organising the logistics system, creating shifts and schedules, and writing reports.
- *In communications:* creating visibility in social media, creating content, communicating with activists, media representatives, and public speaking.
- *In event management:* organising formal and informal events for volunteers and stakeholders, organising a final gala for the community of volunteers and project stakeholders.
- *In education management:* designing a learning and mentoring system for new volunteers.
- *In self-development:* gaining the capacity to work in conditions of crisis and psychological instability, understanding the value of self-support and giving a hand to others.
- *In professional development:* providing volunteers with recommendation letters to facilitate their employment-seeking, validating the project as a master internship for the project coordinator.

Conclusion

During the active phase of the project, organisers succeeded in building a community of practice of more than 100 volunteers and establishing partnerships with more than 40 organisations in France (local governments, schools, education communities, logistics companies, various enterprises, NGOs, etc.) and more than 15 NGOs in Ukraine. Within the four months of the project, the team successfully sent more than 75 tons of humanitarian aid, which translated to 45 different vehicles and 6754 boxes packed by volunteers coming from numerous countries of the world (Ukraine, France, USA, Poland, Italy, China, India, Sri Lanka, Peru, Russia, and others).

The project also allowed the students to regularly interact with researchers and employees of Learning Planet Instituteas well as with volunteers and activists from outside of the institute. Learning outcomes of the project impacted several domains, such as entrepreneurship, project management, communications, event management, education management, self-development, and professional development.

Improvements

According to the related literature, it would be beneficial to implement such projects as integral parts of the bachelor's and master's programs curriculums (Owusu-Agyeman & Fourie-Malherbe, 2021; Boland, 2014; Kingston et al., 2014). However, for the organisers of the initiative mentioned above, it was essential to keep the project open to the participation of the employee and research community of the institution and ensure inclusivity for the volunteers not affiliated with the institution.

To conclude, the example of this project deployment and coordination would be helpful for the other institutions willing to engage in civic activities and implement communities of practice and service-learning.

Endnotes

(1) https://www.learningplanetinstitute.org/en/about [access: 15.10.2022]
(2) https://eurip.u-paris.fr/ [access: 15.10.2022]
(3) https://imhotep-sante.org/home/ [access: 15.10.2022]
(4) https://www.learning-planet.org/2022/08/16/youth-council-2022-2023/ [access: 15.10.2022]
(5) https://livingcampus.learningplanetinstitute.org/en/vie-etudiante [access: 15.10.2022]

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International Society of
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Transformative Learning: Space as a Third Pedagogue

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Abstract: Empirical works on transformative learning have investigated transformative learning processes and outcomes across various learning activities and learning contexts. However, not much is known about Wimmer (2009)'s notion of 'space as a third pedagogue'. This paper discusses the theoretical constructs of transformative learning to inform the design and implementation of formal and informal learning activities on board a hospital ship. It proposes a conceptual framework to investigate the theoretical assumptions of transformative learning processes and outcomes in such a unique learning context where an academy, a floating hospital, mariners, and a crew taking on different roles live, work, study and thrive together in this shared space. In particular, the first insights on space as a pedagogy, invites learning sciences researchers and practitioners alike, to a scholarly discourse on the significance of extraordinary learning spaces that could have a significant bearing on transformative learning processes and outcomes in a self-contained community of learners.

Introduction

Transformative learning has its root in young adult learning, adult education, and lifelong learning where scholarly works, empirical studies and instruments of measures investigated transformative learning experiences across a variety of educational and social contexts of learning. Mezirow defined the process of transformative learning within the constructivist lens as "the social process of constructing and appropriating a new or revised interpretation of the meaning of one's experiences as a guide to action" (Mezirow 1994, p.222). According to Mezirow (1991), the social construction of new meanings through new experiences are susceptible to influences by the social as well as other co-existing structures e.g., political, institutional, economy. On the same token, these respective dynamics are instrumental in modifying established meanings and known values when learners consider them to be dated or dysfunctional. Further, Mezirow (1994) also posits that learners go through critical teaching and learning moments that are connected to their past lived experiences.

The theory of transformative learning has witnessed a substantial amount of empirical studies across various disciplines and scholarly work such as transformative learning review in arts-based learning (Blackburn Miller, 2020), technological adoption for teacher professional development (Schols, 2012), adult educators and teacher training (Christie, Carey, Robertson, & Grainger, 2015), and transformative experiences for international graduate students in educational and non-educational activities (Kumi–Yeboah & James, 2014). These empirical works investigated different cognitive activities that facilitated transformative learning as well as transformative processes and outcomes but with similar end-goal i.e., learners will become more critically reflective of belief systems, social and/ or cultural values and they will be able to re-define and/ or reframe a problem/ issue through transformative learning. However, Wimmer (2009)'s notion of "'space' as a 'third pedagogue' in arts education programme, which to date, received little attention in empirical research. Hence, this paper discusses transformative learning: foregrounding 'space as a third pedagogue' with a focus on the adult crew members living and working in a self-contained community on board a hospital ship.

Transformative learning experiences, processes and outcomes

Transformative learning experiences: Instrumental and communicative learning

Mezirow (1981) identifies two domains of learning that are central to transformative learning, namely, instrumental and communicative learning. These two channels of transformative learning provide critical platforms for questioning, weighing and evaluating known assumptions and beliefs which ultimately lead to a perspective shift (Cranton, 2006; Mezirow, 1991). Instrumental learning "controls and manipulates the environment" with a focus to improve 'prediction and performance" whilst communicative learning focuses on how learners communicate their ideas, feelings, needs and desires (Mezirow, 2003, p. 59). Of equal significance would be the nature and types of transformative learning experiences which triggers instrumental and communicative learning.

According to Cranton (2006), there are three dominant perspectives on transformative learning experiences. One is the cognitive/ rational perspective that has its focus on rationality, critical reflection, and discourse where the construction of new meanings and/ or revised interpretations works towards personal goal for autonomy and independence (Mezirow, 1991). Learning activities that facilitates cognitive/ rational processes would encompass critical reflection, action, experience (critical life events), disorienting dilemma, and discourse. The second perspective is coined as beyond rational/ extrarational perspective which places emphasis on the emotional, imaginal, spiritual that reach beyond rationality (Stuckey, Taylor, & Cranton, 2013). And the third is the social critique perspective which drew its theoretical arguments from 'ideological critique, unveiling oppression, and social action' as the context for transformative learning (Stuckey, Taylor, & Cranton, 2013). These transformative learning activities often lead to collective social actions.

Transformative learning experiences: Space as a third pedagogue

As forementioned, research on space as a third pedagogue remains scarce. Learning and teaching spaces are a 'third pedagogue' because they affect the very foundational elements that determines learning behaviour and learning success in transformational self-directed learning and the ability to concentrate and/or receptivity (Leiber, Carlos, Bruckmann, & Rosa, 2021). On a similar strand, Talbert and Mor-Avi (2019)'s study on abstract active learning classroom exemplifies the importance of designing learning spaces to optimize the practice of active learning and amplifies the positive effects in learners from young learners to higher educational level learners. The practice of active learning can be understood in Nohl (2009)'s works on "initial spontaneous action" and "renew spontaneous action". And on the concept of change in 'meaning perspective', spontaneous action and transformative learning provides another lens to view Mezirow's (1994) notion of a change in one's frame of reference - meaning structures. A change in meaning structures implies more permanent changes in how one manages life transactions. In this context, Nohl (2009)'s concepts of phases of transformative learning where the "phase of initial spontaneous action" precedes the "phase of renewed spontaneous action" seem to suggest that the transformative learning experiences as well as the learning spaces could be instrumental in framing the processes and outcomes of transformative learning.

Transformative learning processes and outcomes

In the process dimension, Schols (2012) reiterates that critical reflection is pivotal to bring about the desired transformative learning outcomes – reframing problem/ issues as aforementioned. A transformational change in one's frame of reference is best explained by Mezirow's (1991) notion of reflective thinking where he accentuates three types of reflective thinking: content reflection, process reflection and premise reflection. Content reflection refers to the critical investigation of the content or the description of a problem; process reflection is about weighing and engaging the different strategies and approaches in solutioning; and premise reflection takes place when learners start to question the basis or premise problem itself (Schols, 2012). Apart from reflective thinking, communication and creative thinking are also essential transformative learning processes. Communicative learning enhances learners' communication skills such as conveying one's ideas and presenting one's works and creative thinking processes are fostered through improvisation, imagination, and creativity (Blackburn Miller, 2020). On the concept of creativity, Guilford (1967) postulates that there is essential four categories in creative thinking, namely, originality, flexibility, fluency and elaboration.

In the outcome dimension, Cranton (2006) posits that content and process reflection could possibly bring about initial perception change but it is premise reflection that critically transforming one's world view, beliefs, and values. To which Mezirow (1994) likened such a transformational change to a process change in one's frame of reference – meaning structures (meaning perspectives and meaning schemes).

Method

Participants, design and implementation

The new Mercy Ship - Global Mercy is the largest civilian hospital ship with six operating theaters and advanced medical training facilities. Global Mercy has presently more than 300 adult crew and about 60 children onboard, representing more than 50 nationalities. Crew serve in various positions e.g., surgeons, nurses, medical personnel, ship engineers, academy teachers, housekeeping, dining, and galley staff. The total number of crew on board the ship at any one-time changes owing to on-going recruitment when short-term crew depart. All adult crew serving on the hospital ship for more than three months are required to attend a full-day 8-hour course - "Equipping to Serve (ETS)". All year-round informal learning activities include the weekly community gatherings and social activities. These activities are not mandatory but often see high attendance and community engagement.

The theoretical constructs of transformative learning experiences, processes and outcomes are encapsulated in Figure 1. This theoretical framework provides the premises to discuss the design of transformative learning activities and the transformative learning processes and outcomes of the crew living and working together in a self-contained community on the hospital ship. The learning activities in the ETS course serve not only as an induction for the crew into the community but also to equip and to empower crew to live and work effectively as a self-contained community. Table 1 provides an overview of the learning objectives and transformative learning activities for each of the five thematic sessions. On the average, we have about 8 to 10 crew for each ETS training course. ETS is usually held in the guest lounge: conducive for both plenary and small group discussions.

Figure 1
A Framework for Investigating Transformative Learning Experiences, Transformative Processes and Outcomes.

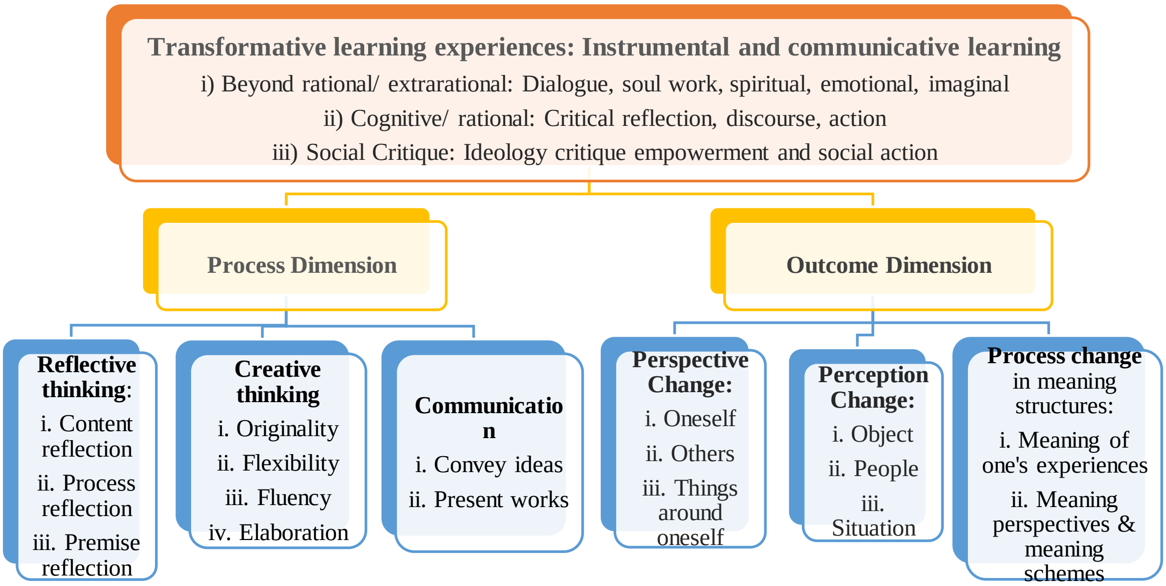

Table 1
Overview of Learning Objectives and the Transformative Learning Activities.

Learning Objectives	Transformative Learning Activities
To know the hospital ship's mission and vision statements, and her four core values.	Plenary presentation by chaplaincy Small group work & presentation on concrete examples of the four core values in relation to the individual, community & organizational level
To develop an awareness of ship safety and security and one's role in the community.	Plenary presentation by the captain Individual activity cards for reflection and response
To appreciate cultural differences on board the ship and understand change and transition.	Plenary presentation on hot vs cold climate cultures, change and transition by staff development Small group discourse on experiences with and responses to the different cultures & challenges
To identify the core tenets of the Philosophy of Service (i.e., serving west African nations).	Small group work on philosophy of service model Socratic discussion: Partnership vs Paternalism
To develop an awareness of the hospital work and medical capacity building (MCB).	Plenary presentation, video clips, Q &A by hospital director and MCB projects director.

Initial findings

All ETS participants are asked to complete an evaluation survey consisting of two demographic questions, one Likert scale item (on the five thematic sessions) and two open-ended questions on what they like about the sessions and what can be improved. At the recent ETS evaluation survey, 8 out of 9 participants indicated that they found the thematic sessions insightful and the small group discussions facilitated critical moments of reflection on past lived experiences esp. the philosophy of service and volunteering on a hospital ship with more than 50 nationalities. However, findings on perspective changes were derived from informal channels of conversations over time e.g., during social activities, sharing of testimonies and/ or when crew are departing. Firstly, they experienced a process change in meaning structures as they started to question their existing frames of reference pertaining to personal life and work undertakings. Secondly, the transformational change (perception, perspective or change in meaning structures) that occurs, lies not so much on the acquisition of new information and knowledge, but rather, on the shared vision (serving the African nations and patients) and a shared living and working environment i.e., space as a third pedagogue. The shared living and work space plays significant role to bring about a transformative change in their perspective and perception of previously perceived worldview. We attribute that to the interaction with the affordances of the environment as well as the social actors in these spaces that have evoked new lens and viewpoints over time leading to a change in learners' perception and perspective.

Conclusions and future works

This paper essentially provides a conceptual framework to both discuss and to investigate the theoretical constructs in the transformative learning experiences, processes and outcomes of a unique self-contained community on a hospital ship. The initial formal and informal findings provide some first insights into 'space' as a third pedagogue: not only the learning activities in the formal learning space (e.g., course training room), but the day-to-day transactions at the individual and the collective level in this shared living space – the hospital ship. Future action-research could investigate the different types of transformative learning activities, and the measure and extent of transformational changes these transformative experiences evoke over time. Qualitative research will also provide more in-depth study on Nohl (2009)'s concepts of "initial spontaneous action" and "renewed spontaneous action" as they have implications on a mere perception/ perspective change or a more radical change in one's frame of reference and meaning structures and understanding space as a third pedagogy. Align with this year's theme on "Building Knowledge and Sustaining our Community", this practice-oriented paper aims to initiate some scholarly conversations on space as a third pedagogue in transformative learning in other emerging learning/ working spaces such phygital spaces, remote learning/working propelled by the recent pandemic.

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A Community of Practice to Bridge Research and Practice in Science Education

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Abstract: Communities of practice (CoPs) have been used to support practitioners' efforts to adopt new teaching methods. In this paper, we summarize how our team facilitated knowledge transfer by forming and leveraging several CoPs that shared the common objective of implementing Inquiry-Based Labs (IBL) in science curricula. Over two years, our team members played the role of linkage agents in the CoPs to bridge the gap between education research, by sharing our own research findings, and practice, by collecting feedback directly from IBL practitioners about their challenges with implementation. As various needs of the members were well met – to be informed, to share thoughts, to belong – the CoPs have since evolved into stable, sustainable entities. Through these powerful social interactions, CoP members themselves have become linkage agents, connecting us to the larger community that would otherwise not engage with our research and thus further bridging the gap between research and practice.

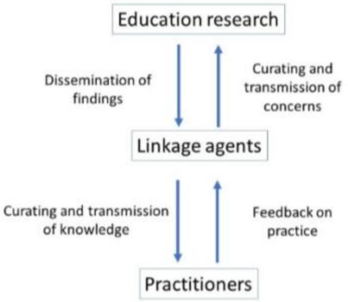
Introduction

Advances in education research are often unacknowledged by practitioners, notably those teaching in the domain of Science, Technology, Engineering and Mathematics (STEM) at post-secondary institutions (Ma et al., 2019). Despite overwhelming evidence regarding the effectiveness of numerous teaching approaches, many practitioners have difficulty adopting these classroom practices (Marion & Houlfort, 2015). Faculty report a number of barriers impeding their ability to change such as time, their personal identity and beliefs about instruction, departmental and institutional culture, and the lack of incentives to change one's teaching approach (Brownell et al., 2013; Henderson et al., 2011).

It is well documented that knowledge transfer in education is difficult to achieve (Becheikh et al., 2010) and the ability for practitioners to mobilize and apply new knowledge into practice is challenging for a number of reasons (Hemsley-Brown, 2005). Traditionally researchers resort to presenting their innovations, along with supporting evidence for their effectiveness, through conventional means of dissemination, however, such approaches have proven ineffective in inspiring practitioners to adopt new instructional strategies (Henderson et al., 2011). On the other hand, the literature does reveal several successful approaches for encouraging change. Such strategies are characterized as having i) focused objectives, ii) coordinated efforts by the individuals involved, iii) structures to provide time for work on these objectives over extended periods, iv) mechanisms for performance evaluation and feedback and v) the explicit intent to change faculty perceptions (Fullan et al., 2018; Henderson et al., 2011). Furthermore, questioning of the status quo, having a clear plan of action, being able to actively recruit new allies, and drawing personal confidence from collaborating with others are other hallmarks of successful change strategies (Fullan et al., 2018). Finally, linkage agents, or individuals who can function as intermediaries between researchers and practitioners, can prove useful in communicating the immediate needs and concerns of practitioners to researchers, as well as relaying research findings back to practitioners in a feedback loop (Becheikh et al., 2010), thus ensuring knowledge transfer is achieved.

Communities of Practice (CoPs) can serve to circumvent the challenges associated with knowledge transfer. Rooted in change theory, CoPs provide forums for faculty to share their concerns about teaching, to collaboratively design possible solutions to these challenges, to learn about best practices and, consequently, to participate in educational reform (Abigail, 2016; Gehrke & Kezar, 2017). Through a mix of knowledge sharing, knowledge-creation, identity building and social interaction, CoPs can be positive vehicles for engaging faculty in adopting novel practices (Abigail, 2016). A CoP composed of members acting as linkage agents can provide a mechanism through which knowledge transfer is more easily facilitated (Henderson et al., 2011). We started a number of CoPs to promote interest in our team's larger research on what types of scaffolding best support the development of scientific thinking in students exposed to Inquiry-Based Laboratory (IBL) instruction. The objectives of this project were to: 1) profile Quebec-based college (cegep) teachers who used or were interested in implementing IBL approaches, 2) identify the forms of scaffolding that best supported learning using an IBL approach, 3) assess whether there exist disciplinary differences in the implementation of IBL pedagogy, and 4) conduct design-oriented research to assess the development of the scientific process. We identified three key areas where our CoPs could address our research needs: a) the recruitment of qualified participants who teach either chemistry, biology, or physics; b) the need for both physical and temporal spaces through which we could consult with our participants routinely; c) the creation of a social community where participants could support or inspire each other in the practice of using IBL instruction. Consequently, the CoP is part of a feedback loop where our research team acts as a linkage agent, i.e., by communicating our findings to a captive audience, then later receiving feedback from IBL practitioners to further inform our research (Figure 1).

Figure 1
The role of linkage agents in facilitating knowledge transfer



Educational context

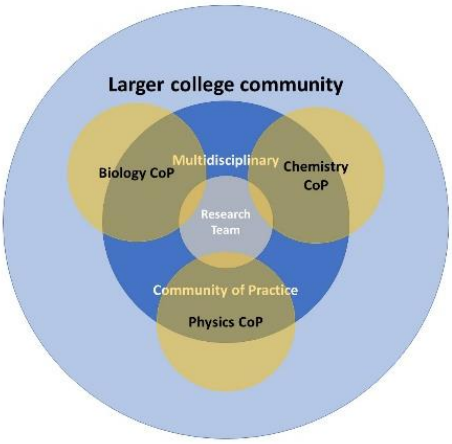
The educational context for this study is at the post-secondary level in the province of Quebec, the structure of which is unique from the rest of Canada: STEM-bound students must complete a two-year college or cegep degree (corresponding to grades 12 and 13) consisting of general education courses (literature and language, philosophy or humanities, and physical education) and domain-specific courses notably in chemistry, biology, physics, and mathematics. This degree is prerequisite to attend university STEM programs. There exist ~60 cegeps all teaching the same Ministry of Education-mandated program, either in French or in English. Colleges have the freedom to set their own program planners, grids, courses, etc. albeit within certain limitations, meaning that local programs and even departmental cultures vary from institution to institution. Instructors are discipline experts having at least a bachelor's degree in the discipline they teach, but most having a master's degree. Some teachers may have an education degree, but this is not mandatory to teach in the cegep system. Consequently, cegep instructors lacking such a background may be incapable of identifying with educational research.

Our research team is comprised of cegep teachers. We are both researchers and practitioners, which facilitates the implementation of an action-based research program. Our research questions are embedded in our teaching concerns and are developed to generate results that are both rigorous and applicable in a classroom. Aware of the difficulties of knowledge transfer in education, we planned this research project to be situated close to common concerns facing science educators, anticipating that our research questions and results would then be meaningful to them and their teaching practice.

The start of the multidisciplinary CoP

At the start of our research project, we invited science teachers from both French and English colleges to a large online meeting. Although the context was to discuss the common challenge of implementing the new cegep Science program slated to start in 2023-2024, the meeting served the dual purpose of forming a large, multidisciplinary community of practice (MCoP) that shared a common concern (Figure 2). At this meeting, we presented how our IBL research both aligns with the learning objectives of this new program, as well as also how this paradigm can help address shared challenges educators face in STEM education. To foster social connections between the participants, we asked them to discuss several topics raised during our presentation in small, disciplinary groups ("breakout rooms"). As Wenger (1999) describes, such participation is key to successfully forming a CoP as it provides both action as well as connections between members. The strategic use of breakout rooms also provided opportunities for reflection on the potential advantages of using IBL in the new Science program, enticing attendees to reach out to our research team about knowing more on IBL or even to become research participants. Finally, attendees of the MCoP were invited to join a mailing list, keeping them appraised of our research and of other meetings or workshops offered by our research team.

Figure 2
Organization of our Communities of Practice (CoPs)



Creation of discipline-specific CoPs

Following the creation of the MCoP, our research team invited members to join smaller, discipline-specific CoPs (DCoPs). DCoPs were composed of a small number of core participants who were always present at each meeting (Table 1). Topics for each DCoP meeting were set by coordinators who were members of our research team – i.e., linkage agents. Although many discussions were about IBL, multiple topics were discussed per session. Members were surveyed before meetings for their suggestions of discussion points and these persons often acted as moderators for these topic discussions. This bottom-up approach ensured that discussions were always meaningful to the participants and validated the time and effort required on their part to partake in the DCoP.

Table 1
Number of participants in CoPs meetings

	Chemistry	Biology	Physics
First gathering of MCoP	46	21	16
Typical DCoPs meetings	15	12	8

Modes of engagement

To facilitate attendance, both the MCoP and DCoPs operated in either of the following formats: completely online, which proved beneficial for connecting members both during and after covid pandemic isolation, or co-modal with members being present either in-person or via web-conferencing software simultaneously. These flexible modalities afforded members who could not make face-to-face meetings, or were uncomfortable doing so, access to the DCoP. Furthermore, Web 2.0 tools or group management software were used to store shared resources, to store recorded meetings or to continue asynchronous discussion between meetings.

Knowledge transfer via linkage agents

Given that it was the theme of our larger MCoP meeting, IBL was the focus of first meetings with the DCoPs. Members of our research team acted as linkage agents by not only presenting from existing literature the history and theoretical framework of IBL instruction, but by providing practical knowledge about how STEM instructors could successfully implement it. IBL-experienced DCoP members shared success stories affirming the literature findings, which in turn encouraged non-practicing DCoP attendees to reflect upon the merit of using IBL-based pedagogy. For those that opted to try implementation, both the time and effort needed to do so were considerably reduced through the sharing of expertise and ready-made resources offered by DCoP members. For new practitioners, this support also helped them gain the confidence to see the implementation through. Seeing value in what they were gaining, individual MCoP/DCoP members asked our team to host additional IBL workshops for their local departments or programs. These motivated CoP members helped bridge a gap between our research team and the wider cegep community who otherwise would not have engaged with our research (Figure 2). In so doing, these members not only became champions of change, but through interactions with us have become linkage agents themselves by connecting other practitioners to our IBL research.

Outcomes and future of the CoPs

Through our team's desire to challenge the status quo re: STEM lab instruction, we formed sub-groups of individuals willing to engage with our research and ultimately put it into practice. The CoPs provided the time and social support required for our participants to address the common goal of learning about and implementing IBL pedagogy and in so doing, helped move our research forward. However, what is worth noting is that our DCoPs have since evolved into self-sustaining entities that now address pedagogical questions beyond our original mandate. The self-selection of the members ensured we recruited individuals who were initially invested in a common goal, but our willingness to have members contribute their own pet topics of discussion ensured continued viability of the DCoPs. Additionally, multidisciplinary concerns continue to be addressed via larger gatherings of our MCoP where concerns and solutions raised there funnel back into discussions at the DCoP level. Consequently, members of the various CoPs are now positioned as members of the community that can connect us to other practitioners that would otherwise not engage with educational research. Technology also facilitates the exchange of resources between members and helps keep the CoPs socially connected.

It cannot be understated that our tiered CoP structure benefits from our research team's continued involvement as linkage agents who can connect practitioner concerns to the educational literature, and vice versa. We would recommend to those taking part in action-based research to consider leveraging CoPs as a means for ensuring knowledge transfer takes place, as well as to connect faculty, who would otherwise not engage with the educational research, to learn about it as well as its implementation in practice.

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Deepening the Integration of Computational Thinking and Science Through Decoding in a Middle School Summer Program

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Abstract: In this paper, we describe DecodeNYC, a summer program for New York City 7th and 8th graders at the American Museum of Natural History (AMNH). The goal of DecodeNYC was to support students' learning of Lyme disease ecosystem dynamics and computational thinking through experiences with an online computer modeling and simulation platform called StarLogo Nova. In DecodeNYC's curriculum, the well-established "Use–Modify–Create" learning progression was augmented with a newly described practice known as "decoding", wherein learners make explicit connections between mechanisms in code and the scientific processes they represent. We describe the DecodeNYC curriculum and share findings from an exploratory study of the curriculum's impact on student learning. We close with a discussion of how research findings informed revisions to curriculum and instruction over the course of three years of remote and in-person implementation and a summary of the benefits and drawbacks of this approach from a practitioner's perspective.

Introduction

The ability to model and simulate the behavior of complex systems has been foundational to understanding phenomena across disciplines. Thus students' attention to relationships within complex systems and manipulation of systems through modeling and simulation are authentic to scientific practice. Engaging in these activities anchored in science phenomena is encouraged by the Next Generation Science Standards (NGSS, 2013), particularly practices of developing and using models and using mathematical and computational thinking. Working with scientific models offers learners an opportunity to engage in computational thinking (CT), a set of thinking skills, habits and approaches that are integral to solving complex problems using a computer and widely applicable in the information society (Wing, 2006).

However, research shows that dynamics of complex systems are difficult for middle school students to grasp (Gotwals & Songer, 2010), and ecosystem dynamics are particularly challenging to teach at the middle school level (Yoon et al., 2018; Grotzer et al., 2017). Educators can engage students more easily in specific NGSS practices, such as asking questions, planning an investigation, and analyzing data, but find it difficult to engage students in constructing models and CT practices (Davis et al., 2017).

Several studies have tackled this issue by developing and testing curricula where students can gain an understanding of complex systems through a learning progression in which students use a model, then modify it, and then create their own model. The progression of "Use–Modify–Create" (UMC) (Lee et al., 2011) is well-established as a trajectory to engage students beyond surface level understandings of models. Recently, however, scholars in collaboration with practitioners using the UMC progression observed that when CT was taught, its relationship to the scientific phenomenon in question was being overlooked (Lee et al., 2022). For students to gain a better understanding of how the code represents scientific processes, they must engage in the additional step of "decoding," mapping the relationship between mechanisms in code and the scientific processes they represent. For DecodeNYC, we developed and implemented a curriculum centered around decoding, with learners applying this skill at each step of the UMC progression. This focus encourages students to see models as representations of the real world and as powerful tools for scientific sense-making rather than mere computer games.

Decoding in practice

StarLogo Nova: A tool for decoding

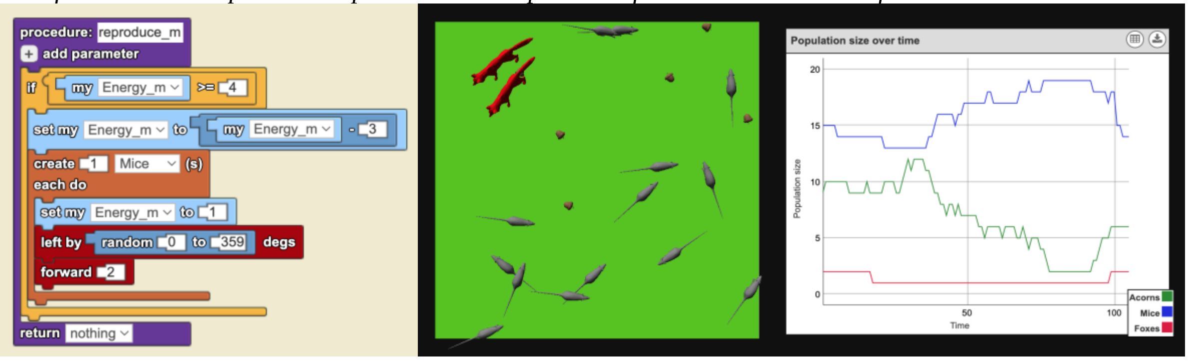
It is important to use a learning tool with features that support decoding. Participants in DecodeNYC used, modified, and created computer models using StarLogo Nova (SLN), a free browser-based computer modeling and simulation platform created by the MIT STEP Lab. SLN was developed within the constructivist tradition to enable users to control the behavior of thousands of agents at the same time, making it a valuable tool for modeling complex adaptive systems such as ecosystems that consist of many interacting parts. SLN has three primary areas: an information area, a simulation area called "SpaceLand", and a modeling area called the "Workspace". SLN enables connections to be made between the code in the Workspace and the execution of that code as simulation in Spaceland, providing an avenue for learners to practice decoding and mechanistic reasoning.

Two SLN models were developed for DecodeNYC in collaboration with an ecologist at Columbia University (Diuk-Wasser et al., 2021): A model of acorns, mice and foxes intended to exhibit population dynamics (Figure 1) and a model of mice, ticks, and deer that represents the tick lifecycle as well as the spread of Lyme disease-causing bacteria in the environment. Additionally, simplified models were created to help students experiment with and learn key SLN concepts.

An example model is shown in Figure 1 below. The code specifying agent behavior in the acorn-mouse-fox model includes an "Energy_m" variable whose value is reduced during movement and reproduction and increased during nutrient consumption. Behaviors such as reproduction and death occur only if this energy value reaches a certain threshold. The agents in Spaceland reflect these behaviors, moving, generating new agents, and being deleted as dictated by the biological constraints encoded in the Workspace. The corresponding graph helps learners keep track of population sizes over time and recognize trends.

Figure 1

Code for the mouse reproduction procedure and Spaceland from the acorn-mouse-fox SLN model



```
procedure: reproduce_m
+ add parameter
if  my Energy_m >= 4
  set my Energy_m to  my Energy_m - 3
  create 1 Mice (s)
  each do
    set my Energy_m to 1
    left by  random 0 to 359 degs
    forward 2
return nothing
```

UMC in the curriculum

The curriculum for DecodeNYC followed the UMC progression, with students primarily using SLN models in the first third of the program, modifying them in the second third, and creating their own models in the final third. During the first half of the program, students used and modified the acorn-mouse-fox model to solidify their understanding of population dynamics and energy flow in an ecosystem. Subsequently, students used and modified the tick-mouse-deer model to learn about the Lyme disease ecosystem and test different interventions for Lyme disease remediation before spending the last several days creating their own code to add a new species into a tick-mouse-deer model.

In order to encourage and support students in making explicit ties between code and science, the curriculum designer created numerous opportunities for learners to employ decoding, both to extrapolate from what they saw in the code to what they knew about the scientific phenomena and in the other direction, from science to code. Some decoding-focused activities across the UMC progression include: After learning the basics of SLN code blocks, students were asked to decode functions from the acorn-mouse-fox model of the type shown in Figure 1; Midway through the program, students completed a series of pair programming challenges wherein they needed to modify and debug broken models by adding values, rearranging blocks, or adding new blocks to the code; Finally, as a concluding activity for the program, groups of students worked together to create their own models based on the tick-mouse-deer model that incorporated a new agent representing another animal in the ecosystem.

Impacts

Decoding in student work samples

In our study we analyzed student work such as Google form data to search for evidence of students linking between coded mechanisms and the scientific processes they represent. Decoding was evidenced when students described the code's function in terms of scientific concepts rather than effects on the agents in the model. For example, after working in groups to decode procedures from the acorn-mouse-fox model, students were asked to respond to the prompt: "explain in simple English what your procedure does." Some responses demonstrated mapping between code and the phenomenon modeled: "When an animal has no energy left it dies", whereas others did not: “Create one acorn and scatter it xpercent of the time.” Later, after completing each of the programming challenges in the second third of the program, students were asked to respond to the prompt, “What is one thing you learned or noticed while completing Challenge [X]?”. While many student responses were reflective of increasing knowledge of the StarLogo Nova tool and specific code block functions, some revealed ecosystems understanding using decoding. For example, one student responded as follows: “I noticed that when the turtles reproduced they didn't loose [sic] energy so they kept reproducing.” This student is drawing on their understanding of energy flow in ecosystems in their analysis of the code. Students also demonstrated decoding in their responses to reflection prompts after “modify” activities.

As the program continued, more students used mapping to scientific processes (or decoding) to solve computational challenges, even when *not* specifically prompted. In the concluding “create” activity students applied their decoding skills without being instructed to do so. Notably, students decoded both from code to scientific phenomenon and from phenomenon to code. For example, one student remarked:

> since the spider is a hunter, at some point, if the spider has one or less energy or some certain amount of energy or less, it will hunt the ticks at double the speed as the regular real walk. And it's hunting the ticks, which means we're going to use detection blocks.

This speaker noted the spider is a “hunter”, or predator, drawing on their knowledge of ecology. Then they acknowledged that the spider might change its behavior based on its available energy, and finally specified the particular SLN code block that would be needed to encode the hunting behavior.

KS-CT survey: Evidence of decoding skill

In addition to the embedded assessments in the curriculum, changes in students' decoding ability, understanding of science concepts, CT, and mechanistic reasoning was captured with the DecodeNYC KS-CT pre- and post-survey. The DecodeNYC KS-CT is a multiple choice instrument that draws items from a previously validated version of the KS-CT and five ecosystems items from the Harvard-Smithsonian Center for Astrophysics’ MOSART instrument (Sadler et al., 2010). The KS-CT survey was administered to participants before and after completing the DecodeNYC program as well as by a control group of students who did not participate in the program. The DecodeNYC program had a statistically significant positive impact on students' learning. From pre to post test, students in the treatment group (n = 18) increased their KS-CT scores by an average of 2.44 points out of a total of 19 points whereas students in the comparison group (n = 10) increased their KS-CT scores by an average of 0.2 points out of a total of 19 points. Results were statistically significant (p = .002 for sign test; p = .004 for signed-rank test) and the effect size (Cohen’s d) was 0.66552 (between medium and large). The scale with the largest increase was decoding (mapping code segments to the scientific processes they represent); the average score on this scale increased from 8.5 (47% correct) to 14.25 (79% correct). The average score on the ecosystem scale increased from 57% to 66% correct.

Student feedback

Three focus groups of four students each were conducted at the end of the first run of DecodeNYC to capture thoughts and feedback from participants. In discussions with the program’s evaluator, students organically mentioned decoding and how it enhanced their experience. For example, one student said:

> Well, coding helps in the ecology aspect because you're able to use the coding to prove different aspects of that ecosystem. Like we were trying to show the infection rate of Lyme disease in our ecosystem that we created in StarLogo Nova. And it was really easy to see it because it was just right there, and we were able to figure out what aspects of the ecosystem were creating it by just looking at our code.

The general consensus among students who had been exposed to coding in school was that DecodeNYC was “way better” because the coding had a specific purpose, in this case learning about the Lyme disease ecosystem. This suggests that a decoding-centered curriculum is not only an effective way to integrate computational thinking and scientific learning, but it is also a rewarding and motivating experience for young learners.

Conclusion

Participants in the DecodeNYC program were faced with a challenging task: They were expected to learn a new coding interface; learn how to use, modify, and create agent-based scientific models; develop mastery of ecosystem and population dynamics concepts; and apply all of those skills to a complex disease ecology system. Thanks to the decoding skills they developed during the program, the students rose to this challenge, demonstrating increased understanding of each of these components in surveys, focus groups, and student work samples.

Developing and implementing this program has revealed for our team of practitioners the value of decoding as a core skill for the integration of computational thinking and scientific inquiry. We have found SLN models to be an excellent tool for guiding students through this process and consider decoding a crucial addition to the UMC framework. As we revised the DecodeNYC curriculum over the course of the three years of implementation, we refined the opportunities for student decoding at each stage. We added additional decoding-specific prompts to reflection worksheets and created specific activities to address gaps in understanding.

One possible drawback to decoding-centered curriculum design is that students may not get a deep enough exposure to CS constructs (loops, conditionals) to be able to effectively modify or create new programs. Students are encouraged to see the code as representing a real-world phenomenon rather than a logical unit unto itself. We hope future work will elucidate how best to teach students to read code for information about processes.

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Practitioner-Researchers Engaged in Practice Situated Design-Based Research: The Challenge of Positionality

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Abstract: This paper explores the challenge of positionality as both limiting and liberating in the context of a design-based research PhD study carried out by a practicing teacher in a real world second level education setting. The study outlined here, in order to explore this issue, sought to enhance our understanding of academic buoyancy in second level students (N=255) and to produce an adaptable and/or adoptable model emergent from three iteratively refined Design-Based Research Design Cycles. Lessons learned from this journey are presented for other practitioner-researchers to consider as they grapple with positionality as part of their practice situated Design-Based Research journey and strive to ensure that what they produce is replicable as actionable knowledge.

Introduction

Applied research in the field of the Learning Sciences often employs Design-Based Research (DBR) sometimes referred to, in a European context, as Educational Design Research (EDR) (Sandoval, 2013). This approach to problem solving in educational contexts has fast gained a reputation as being a robust methodology of choice for researchers in the field of teacher education and teachers who wish to carry out research in their classrooms as part of continuing professional development (McKinney & Reeves 2013). This is hardly surprising as the cyclic and iterative processes involved in DBR are aligned with the authentic design of educational environments; hence, there is a natural alignment between design research and research in education (Kelly et al, 2008). Indeed, it is underlying premise of DBR studies, rooted in second level classroom practice, to generate actionable knowledge (Flynn, 2018) and to develop artefacts that advance theories capable of leading learning in naturalistic settings (Flynn et al., 2022). In this respect, DBR is a methodological approach that supports an investigation of learning by those who are best positioned to determine its effectiveness or otherwise - teachers.

However, there is an element of carrying out DBR, particularly for in-service teachers completing PhD studies, that presents a challenge to the adaptability or adoptability of the output of the study and that is positionality (Flynn et al., 2022). Positionality is the role that the researcher has chosen to adopt within a given research study and that position influences how research is conducted, its outcomes, and results (Rowe 2014). Being the researcher and the practitioner integrates theory and action, putting theory into practice, while addressing the issue by working together with those who are experiencing the issue, in this case presented here - the second level student. The challenge of positionality for practitioner-researchers addressing complex problems in their classrooms is explored in this paper, framed by the research study in question. In keeping with the research methodology employed, the overarching research aim of this study was twofold: a) to enhance our understanding of academic buoyancy in second level settings; and b) to iteratively design and refine an innovative pedagogy that supports the enhancement of academic buoyancy in the context of the real-world messiness of second level classrooms. This paper presents insights on the challenge of positionality from the perspective of a full-time in-service teacher carrying out a DBR, PhD study on how to enhance academic buoyancy (Martin & Marsh 2009) in second level students (n=255), within the naturalistic context of that teachers ’classroom.

What was designed and what was done to date

Academic buoyancy generally refers to a students ’ability to respond to everyday challenges in an academic setting, and plays a significant role in how individuals respond to the challenges they will experience within and outside formal educational settings (Martin & Marsh, 2009). The multi-cycle study presented here sought to iteratively design and refine an innovative pedagogy that supports the enhancement of academic buoyancy in the context of the real-world messiness of second level classrooms. As the lead researcher is a practicing teacher, convenience sampling was employed within the lead researchers own school setting across three DBR design cycles for the recruitment of participants (N=255). All participants were female with an average age of 15.5 years. The participating all female second level school is located in a rural setting in the West of Ireland and the school management team were supportive in facilitating this research study. The designed intervention was aimed at students enrolled in a yearlong elective programme called the Transition Year (TY) Programme. The TY Programme is intended to act as a bridge from a relatively passive academic environment in the first three years of second level education to a more self-directed learning experience in the final years where enhanced academic buoyancy would benefit students (Clerkin, 2016).

Informed by a multi-ontological conceptual framework that included key design informants of collaboration (Stahl et al., 2014) engagement (Yu, Martin et al. 2019) and reflection (Lousberg et al., 2019) an initial pilot, semester long, module was developed for implementation by the lead researcher with her own class group. The intervention, a twelve-week long module, required students to attend and engage with pedagogically informed activities for one hour each week. For the pilot study, and subsequent iterations, in the initial sessions with the students the researcher used a negotiated content development approach to ensure the intervention catered for the diverse needs of the participants in the school. Employing this negotiated process allowed the students to address social issues in school and also enhanced the likelihood of engagement by the participants. The pilot study was completed in Autumn 2020, a second iteration in Autumn 2021 and the final application of the intervention, or Design Cycle III, was in Autumn 2022. A mixed methods data collation and analysis strategy was developed to ensure comparison across design cycles (Flynn et al., 2022). In consultation with the author, an Academic Resilience Scale (ARS-30) (Cassidy, 2015), was employed as a design effectiveness informant. The ARS-30 is based on a three-factor measure of student ability to bounce back from academic setbacks, and to deal with academic adversity. The scale also provides a measure of the efficacy of interventions in terms of developing the students ’academic resilience and buoyancy skills. In conjunction with this, the Academic Buoyancy Scale (ABS) (Martin & Marsh, 2008) which comprises four items to check the extent to which students can deal effectively with hurdles in everyday academic life. At the beginning of the module of intervention and then again at the end of the module, students were asked to rate their academic buoyancy on the scale. These results, as well as structured end of class reflection sheets and unstructured reflective journals, were triangulated to provide feedback on the effectiveness of each cycle. The qualitative data collected, in particular, allowed the researcher to adjust the design from iteration to iteration so that the experience of the participants was enhanced. Essentially, the very nature of unification in qualitative data relies upon incremental efforts made during the research process to ensure reliability mechanisms are woven into every step of the research process (Morse et al. 2002). This approach to reliability is vital in the current study as the initial implementation phases of research were conducted by the researcher who is also the practitioner. Ongoing reflexivity throughout researcher/practitioner research is necessary (Holmes, 2020).

Hence, the positionality of the researcher is an important factor in this study. The researcher/practitioner acknowledges their personal position and how it might have the potential to influence the participants. DBR ideally enables the development of robust effective interventions, and cognisant of this, the concepts of validity and rigour were established throughout all cycles of this research. The rigour of a study may be measured by the degree to which the researcher is transparent about the design and role in the research process. The quandary resides in the fact that a researcher brings their own lens to a study. Design Cycle I and Design Cycle II, for the most part, developed the researcher’s agency and influence in bringing this module to fruition in the school. The researcher acknowledges their personal position and how it might have the potential to influence the participants. In order to mitigate this issue, for the third iteration of the intervention, the researcher/practitioner took a step back from delivering the module and recruited four other teachers to take charge of the rollout of the intervention. Therefore, interpretations are not wholly derived from one source, thus adding credibility to the findings.

Implementation

Second level classrooms are complex social environments with different groups of people from different backgrounds with varying levels of experience (McIntyre, 2000). In such contexts, standardised educational interventions might be considered as, at times, unworkable. In contrast design research methodologies are popular as they allow for innovation and careful evaluation. The iterative nature of DBR in particular allows for a design process where results of the first cycle are evaluated, the impact understood and, where necessary, adaptions made before moving on to Design Cycle II. Similarly, adaptions made from Design Cycle II to III. It became clear in the early stages of Design Cycle I that students needed to play a pivotal role in the design and development of this module through their participation in a consultative, student-centered learning experience. The participants themselves emphasised this inter-connectedness as being essential to their engagement in this dynamic learning experience in their reflective submissions. This empowering process of co-creation in the initial stage of this cycle promoted student engagement throughout the module as the process provided an authentic and rigorous approach to incorporate the student voice in the module, with the underlying view of promoting engagement. Design Cycle I was implemented by the lead researcher with a group of 84 female students. A key recommendation emerging from the results of this cycle was the need for further instruction in the area of reflection. The researcher believes the value of deeper more critical reflection by participants is vital to progression in becoming more aware and efficient in dealing with future setback for the participants. At this point, the researcher realised that the position adopted by a researcher affects every phase of the research process. While it may have been advantageous to mitigate this issue further in Design Cycle II by the researcher limiting their participating to the re-design aspects only, instead the researcher worked together with one other teacher to roll out the module, again over a 12-week period with 75 female participants. This cycle involved greater instruction in the area of reflection. Arising from the quality of reflections in Cycle I, it was decided to incorporate three lessons on reflection in the module of intervention for Cycle II. Design Cycle III had 96 participants. Considering what was best for the study in relation to researcher/practitioner positionality, it was decided to pass on the implementation of the module to four teachers in the department allowing the researcher to take a back seat and focus on coordinating the implantation of the intervention. The maturity of the design in Design Cycle III allowed the researcher/practitioner to transition from that position to that of purely researcher. Findings from each of the first two Design Cycles show positive results in the participants buoyancy levels, and this held true for the final Design Cycle. The researcher/practitioner, having engaged in a reflexive approach, is confident of a reduction in bias. Having removed themselves partially in Design Cycle II and completely in Design |Cycle III, the researcher accepts that this is not a guarantee to eliminate bias completely, however, being detached from the participants is on the right path to report on the findings without bias. The time-consuming nature of DBR provides a challenge with many competing priorities for practicing teachers. Securing teachers to commit to rolling out the intervention can also be a challenge to overcome. The timing of making this transition from researcher/practitioner to researcher is critical.

Lessons learned

Lesson No. 1: Practitioner/researchers must carefully consider positionality at the outset of a DBR study

Some authors use the terms practitioner researcher/design researcher/action research interchangeably, noting an important characteristic of this type of research being that the practitioner/researcher is the doer of the research (Bartlett & Burton, 2005). In this study it is the teacher in their classroom and not an outside researcher conducting the research. Put simply, it is research done by teachers for teachers. By employing DBR and thinking carefully about the concept of positionality from the outset of the work, the difficulty of putting theory into practice is mitigated in this instance, and a creative space exists where both module content and teaching methods can be modified. With an important goal of the Learning Sciences being to better understand the cognitive and social processes that result in the most effective learning for the student, this knowledge is used to redesign classrooms and learning environments so that people learn more deeply and more effectively (OECD 2008). Practitioner research has a valuable contribution to make in advancing teaching and learning in the classroom.

Lesson No. 2: Recruit colleagues early - you don’t know when you will need them to help

Wenger describes communities of practice as groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly (Wenger-Trayner et al., 2014,). These communities are designed to bring people together with the intent of engaging in collective learning. The need to find supportive academic partners and to form a collaborative relationship with them became evident during the second phase of data collection for this DBR study. Going into Design Cycle III, the researcher had a cohort of four teacher colleagues who agreed to take over the delivery of the intervention. In hindsight, these teachers could have been involved earlier in the research journey as critical friends which may have informed development of the research.

Lesson No. 3: Timing is everything - know when to hold and know when to fold

From the outset of this paper the authors have highlighted the challenge of positionality as it relates to a teacher who is conducting research in the naturalistic context of their classroom. Indeed, the first lesson learned is that greater attention should have been paid to how much of a factor this can be in a DBR study such as this. In order to achieve an intervention workable in a real-world classroom setting, and one which can be taught by all teachers, it is important that the researcher distances themselves from the module rollout and passes this role to other teachers. The timing of this is critical. In the first instance the researcher/practitioner must know how long to hold onto the reigns to ensure the intervention is ready for others to work with. At the same time, they must be willing to fold responsibility for the delivery and pass it to others to test. It is in this instance that the role of researcher/practitioner transitions to that of researcher, the final design must pass its final test without its creator.

Conclusion

In this paper we have outlined the challenge of positionality in DBR studies carried out by practitioners in their own real-world classrooms. The DBR study outlined here, in exploring this issue sought to enhance our understanding of academic buoyancy in second level settings and to iteratively design and refine an innovative pedagogy that supports the enhancement of academic buoyancy in the context of the real-world messiness of second level classrooms. The authors conclude that interventions refined in such contexts require a careful consideration of the influence of positionality on the reliability of any final output and the role that design maturity plays in mitigating this issue. Finally, the authors suggest that in developing a community of practice around a situated DBR study, as described here, it is possible to use the act of addressing positionality as a transition point from being practitioner/researcher to researcher and address challenges to the reliability of a Design-Based Research PhD study.

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Design and Implementation of Capacity Building Programs for Senior Education Functionaries in India

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Abstract: Capacity building programs equip education systems to be better prepared for the unknown future by enhancing the skills of its members. These programs are customized and contextualized based on the needs and role of the participants. This paper details the aspects of design and implementation of one such capacity building induction program for District Educational Officers in India. By exploring the characteristics of the program, the learnings present the components to build an effective capacity building program for senior functionaries who are new to the system. To make learning effective for this particular group, it needs to be social, collaborative, situated in authentic contexts with learners as active constructers of knowledge. The happenings should be relevant, it should ground new experiences and connect to the prior knowledge of the participants. These foundation principles of learning with concrete example of the induction program will promote informed creation of impactful and meaningful learning experiences for senior education functionaries.

Introduction

According to United Nations (UN), capacity-building is defined as the process of developing and strengthening the skills, instincts, abilities, processes and resources that organizations and communities need to survive, adapt, and thrive in a fast-changing world. The UN also mentions that an essential component in capacity-building is transformation that is generated and sustained over time from within; transformation of this kind goes beyond performing tasks to changing mindsets and attitudes.

The effect of the pandemic has pushed the education systems around the world to rethink their existing practices and work towards a paradigm shift to prepare themselves for the unknown future. This preparation has been translated into developing and implementing capacity building programs for stakeholders across the education sector at both the state and national level. In India, department of education of the respective state government plans and administers capacity building programs in the form of upskilling, Professional Development (PD) training for teachers, head teachers and educational officers. These programs are done in collaboration with universities, State Council of Educational Research and Training (SCERT) and District Institute of Education and Training (DIET). The ultimate focus is to improve student learning outcomes by training stakeholders in a particular skill or competency; or building their capacity in their roles to function effectively.

The programs are designed for senior education functionaries such as principals, educational officers at the state and district level offer capacity building in leadership, academics and administration. The influence of such programs is directly on the team of the educational officers which either has other officers or teachers and head teachers depending on the organizational hierarchy. The impact of senior functionaries at the classroom level is difficult to trace and measure, hence there is minimal focus on design and implementation. However, there is a dire need to examine the learning design in such large-scale capacity building programs for senior functionaries as it is crucial in shaping the culture, beliefs and mindsets of the entire education system. This paper details out the design and implementation of a capacity building program for District Educational Officers (DEOs) in an Indian state by the University.

Theoretical background

The sociocultural theories on learning emphasized the idea that knowledge is constructed and is a social process (McMahon, 1997). Aligning to this, the learning sciences research also states that learning needs to be situated, social and distributed (Fishman et al., 2022). The central idea of situativity is that learning is more effective when situated in authentic contexts (Fishman et al., 2022). The authentic contexts can involve using video and other representations of practice, using educative curriculum materials, and using cognitive and digital tools. The social and distributed nature of learning can translate into building communities of practice, creating knowledge building communities, coaching, mentoring, design-based research and research-practice partnerships. Community of practice refers to the creation of a learning environment in which the participants actively communicate about and engage in the skills involved in expertise (Lave & Wenger, 1991; Wenger, 1999). Such a community leads to a sense of ownership characterized by personal investment and mutual dependency (Collins & Kapur, 2022). For any Professional Learning Communities (PLCs) to be effective, the participants need to discuss problems of practice, engage in collective sense making, have collaborative conversations, contain shared values and norms and reflective dialogues. This study draws from these principles of learning for analysis of the design and implementation to understand the practices that enable impact in capacity building programs.

Context

Senior education functionaries comprise of Joint Directors (JDs) of the department of education, Chief Educational Officers (CEOs), District Educational Officers (DEOs), Block Educational Officers (BEOs), SCERT and DIET principals and faculty. They are primarily involved in administration, management, and leadership duties along with providing academic support. The senior education functionaries start their career as a teacher and with experience move up the ladder to various designations. By the time a person becomes a JD he/she has been in the system for many years. The system observed that this long journey to leadership positions is a hindrance to fresh ideas, perspectives and innovations. Hence, as a step to bring in young and energetic people directly into the leadership position, the state government introduced a direct recruitment system where qualified candidates working as teachers apply out of their own volition and passion, go through an assessment process and directly become BEOs/DEOs.

The state Department of School Education in collaboration with the university designed and implemented a six-month orientation program for 20 DEOs who were directly recruited in the year 2021. It was piloted in July 2021 and completed its course in January 2022. It is important to note that the DEOs who were recruited before this cohort were expected to learn on the job and were not provided any induction from the state. The utmost significance of this program is that these 20 DEOs are in the age range of 30-40 and will be a part of the system for the next 20-25 years. They have the authority to shape the future education system of the state. DEOs function as an inspection authority, authority for opening, closure and renewal of schools, appointing and approval authority of government, government aided and private schools. They are responsible for primary, middle, high and higher secondary schools. The vision of the induction program was to develop a cohort of DEOs who would be academically oriented to the educational policies and objectives of the state and the country, administratively adept with all aspects of the role and be able leaders capable of providing vision, guidance to the system and accountable to the aims of the Department.

Design

The program was designed collaboratively by the School Education department of the state and the University. The objectives of the program are to:

- Deepen the understanding and appreciation of DEO’s roles and responsibilities
- Build capacity and capability to effectively perform the roles and create the desired outcomes
- Respond effectively to the everchanging contexts
- Explore interlinkage between personal vision, values, and practices with the profession

To achieve these objectives, the broader content domains of leadership and management and education perspectives were chosen. Under the domain of leadership and management, the themes assigned for each month were Leadership, Task management, Understanding self, People management, Driving improvement and change. Each theme covered multiple topics, for example, the theme of understanding self included topics such as Personal Vision, Values and Drivers, Direction, Goals & Norms and Communicating with Effectiveness. The education perspectives domain comprised of topics like Introduction to the study of childhood in the Indian context, Reimagining Schooling, Child Development and Learning, Assessment, Quality of Education and Parent’s aspiration.

The program was conducted in the medium of English and consisted of three modes of engagement: Workshops (face to face Sessions and expert talks), Webinars (online expert-led and assignment-based) and Field Projects (research projects and school visits). The six-month timeline of the program was divided in a way to provide equal weightage to both the content domains and field projects. The workshop was for 4-5 days a month adding up to a total of 25-30 days. The short courses or webinars were for 150 hours, and the field projects were for 60 days. During the program, each DEO trainee was allocated a mentor who were DEOs who engaged with the trainees in conducting the field projects effectively. Feedback was collected consistently in both formal and informal ways. Through informal WhatsApp group, emails and face-to-face workshops DEOs and the resource persons discussed, shared, and addressed specific concerns or clarifications. Formal feedback google form was designed by the university faculty and shared with the participants on the last day of the program.

Implementation

The program chose a blended integrated approach where three modes of engagement were executed simultaneously every month. The specific theme chosen for each month reflected in all three modes of engagement. The content domain of leadership and management was entirely implemented through workshops. The webinar sessions were on topics from the domain of education perspectives. The focus of the field projects was a combination of both the domains.

The workshops session was augmented by talks by field experts, school observation visits and debrief, project presentation and feedback. Each workshop was a rich combination of illustrations from the field and exercise and discussion-based sessions. Different exercises were designed to provide DEOs with personal space to think critically and reflect. The small-group discussions ensured that they step out of their comfort zone and concretized the ideas developed during the program. The activities of the orientation workshops were aimed to deepen understanding, to reflect and develop strategies for personal and systemic transformations. Each session had visual inputs in terms of PowerPoint presentations.

A key part of the orientation was the focus on building academic perspectives on schooling, children, teaching- learning and assessment. To bring this aspect a series of webinars was a crucial element of this blended program design. Each webinar was delivered by experts from the university and anchored by the resource people facilitating the program. Each 90-minute webinar explored perspectives around the chosen topic and was interspersed with discussions and assignments. The anchor interventions tied the topic to the overall workshop themes and to specific aspects of the DEO role. The rationale for assigning field projects was for the trainee DEO to get an in-depth understanding of the various systems, processes, resources, and people they would be engaging with in their role. Each project had clear guidelines for research focus and presentation. The DEOs presented their projects during the workshops to the resource persons, field experts and mentors and received specific feedback. The field project findings were woven into the session topics by the facilitators. This helped in situating the research findings and data in specific contexts and was relatable to the roles and responsibilities of the trainees.

In the face-to-face sessions held every month, a component of talks by field experts, local school observation visits followed by in-depth debrief, IT and legal sessions were organized. Each of these engagements were enriching experiences that added significantly to DEOs' experience and preparation to hit the ground running when they took charge officially. The informal forums inputs on webinar facilitation, language clarity, timings were addressed on a timely basis. The workshop discussions on session feedback enabled the resource persons to incorporate feedback into their presentations. The google form captured the DEO trainees' opinions and feedback on all workshop sessions, webinars, projects, learnings, critical inputs, and ways to improve the program. Currently, as a continuation of the program, the faculty from the university are visiting DEO offices across the state to observe and analyze the status of the directly recruited DEOs and provide suggestions, recommendations and assistance.

Learnings

The conversations with faculty of the University on the collaborative program designing process, the implementation experience along with the participant feedback presents key reflections on components that build effective learning experience in capacity building programs for new senior education functionaries. The program design enabled interactions and bonding between a group of 20 officers who were at the starting point of their journey. This combined state of professional life along with the sense of purpose empowered the DEOs to learn from each other. The program was built in a way that there was collaboration, peer-learning and group projects. DEOs, when they start their role will have their own team and might become isolated carrying out their responsibilities. Hence, building this team spirit and tight knit community right at the beginning paves way for Professional Learning Communities (PLC). PLCs promote reflection, sharing, collaboration and support which is essential to their job role. Learning experiences are effective when learning communities of trust and respect are established with the inherent belief that learning is social in nature.

The varied modes of engagement ensured that the program has a balance of theory and practice. The workshops and webinars introduced new concepts to the participants. The field projects equipped the participants to understand the ground reality and gave them a trailer of their roles and responsibilities. The participants looked at the ground reality from the lens of the concepts that they learnt during the sessions. This provided relevance, meaning and preparedness towards their role. At the same time, they also got the essence of the challenges and difficulties. DEOs were able to grasp reality and place themselves in the context before they started. Through this it is evident that learning experiences need to be situated in authentic contexts (Fishman et al., 2022) for it to create impact. The workshops and webinars of the program provided ample opportunities for participants to discuss, question, share and reflect. Active engagement throughout the program empowered the participants to learn from the reflection of their experiences during school visits. They constructed meaning by connecting the concepts to practice. During the discussions, the participants were able to discuss their personal vision and goals in the role of a DEO and find meaning. Apart from this, the sessions pushed the participants out of their comfort zone to explore current realities of schools and classrooms in the state. These sessions involved collecting qualitative and quantitative data through observations, interviews and engaging with state database. They developed skills such as critical thinking, data interpretation and analysis, reasoning and prioritization. When the learners are actively engaged in construction of meaning and knowledge (Chi &Wylie, 2014), powerful learning occurs. Learning becomes more effective when learners are encouraged to ground new experiences and concepts in perceptual and motor experiences, language and prior knowledge (Nathan, 2021) like the examples stated above.

Overall, learning experiences are effective when they are collaborative, situated in authentic contexts, allowing learners to actively construct knowledge, ground new experiences and connect to prior knowledge. These components are essential when building a capacity building program for senior education functionaries. Through this program, the DEOs started their journey with clarity, vision and support. The program enabled them to set expectations and direction from the beginning and build a more equitable and just culture in their work. The sustained impact of the program can be witnessed post 6 months from the end date. This impact is seen as results on the field and from observations during the visits of the faculty. Interactions with JDs of the state reveal that the mindset, beliefs and attitude of the DEOs who underwent the program are progressive, futuristic and upholding the values of the state. During the visits, the faculty witnessed transformation happening in smaller pockets in administration, leadership, management and academics.

Relevance

The paper is highly relevant as education systems around the world are encouraging young people to join the system which has had its traditional roots for centuries. It is necessary for the system to provide induction for the people to navigate through the existing conventional practices, have the courage to break the shackles and pave the way for the future. It is essential to prevent the newly joining people to either follow the old ways or lose trust in the system. Designing capacity building programs with the foundation of principles of learning sciences results in active, impactful and sustained transformation. The aim of these programs is to provide training to get the participants started in their professional journey and over a period, create PLCs and support systems which makes them self-sufficient. Such programs as detailed out in this paper can be researched on for their impact and can be scaled up across systems. While this program is specific to educational officers, the design and pedagogy of it is transferable to any discipline.

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Identity Inquiries: From STEAM Self-Portraits to Identity Mapping

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Abstract: This paper outlines how an elementary STEAM educator presents, reflects, and enhances identity inquiry practices for students as they build and share knowledge together over multiple years. Utilizing a consistent, integrated approach to STEAM learning in the classroom coupled with annual self-portrait development and reflection, salient themes arise in how young people can guide each other in the reformation of roles in science, technology, engineering, arts, and math and how to engage civic action in their developing worlds.

Introduction

Sociocultural theories of learning include identity as a central component of learning (Lave & Wenger, 1991; Wenger, 1999). Research in STEM education - including research in science, engineering, and mathematics education, as well as in the explicitly interdisciplinary STEM education field - has widely taken up identity development as a meaningful construct for examining children's participation and experiences in STEM learning (Avraamidou, 2020; Capobianco et al., 2015; Carlone & Johnson, 2007; Graven & Heyd-Metzuyanim, 2019; Patrick & Borrego, 2016). Research shows that conceptions of what it means to be a scientist or mathematician are heavily informed by dominant stereotypes of mathematicians and scientists as old white men (Carlone & Johnson, 2007). When these stereotypes are not upended, challenged, and dismantled in elementary school, minoritized students entering middle school risk diminished participation in their formal STEM learning spaces (Archer, 2010). Elementary school is a critical time for children to have opportunities to challenge and reinvent traditional notions of STEM identities and reimagine what science is and can be.

Purpose and research questions

This paper explores the ways in which an elementary STEAM teacher (science, technology, engineering, arts and mathematics), now also a novice researcher, worked to support student identity development through instructional tasks in a connected and continued fashion with students in Pre-k through 5th grade over multiple years. As such, many students participated in a STEAM identity development task every year for multiple consecutive years. Through an approach incorporating STEAM self-portrait drawings coupled with age-appropriate writing reflections and technology integration as a beginning of year tradition, students created work that offers insight into their journeys of human development, including their emergent written and artistic literacies and, here, of primary interest, their identity development connected to civic engagement.

We conceive of these tasks as *identity inquiries* - an investigation of what it means, or has meant, to oneself to be a person who participates in a community or discipline. We propose that these identity inquiries may serve as a way to surface and thereby challenge stereotypes about who participates in STEAM disciplines, what that participation looks like, and the possible roles of STEAM in our world. Likewise, they can evidence young learners' emerging and changing understandings of themselves as participants in STEAM and in their own communities. Looking at student identity inquiry work produced and collected over five years, our analysis then asked: *1) How is STEAM represented in relation to civic learning or civic participation? 2) How do students challenge stereotypes through STEAM integrated civic learning and participation?*

Background and context

First author, Scarlett Calvin, has been teaching STEAM integration enrichment classes across PK-5th grade classrooms for the last six years at a small public/charter elementary school in a central Texas city. Aligned with the school's mission to "develop students into lifelong learners through rigorous, research-based curricula, individualized instruction, high expectations, and a nurturing environment that includes parental and community involvement and serve as a model of an exemplary educational program for diverse learners," the STEAM self-portrait project has been presented to students during the beginning of every year as a preliminary activity to activate prior learning, uncover interest and involvement with the natural world, and to tap into student ideas of applied integration with math, science, and expressive content driven by student experience. The activity is introduced by asking students to "draw themselves doing anything STEAM related". We collaboratively discuss what STEAM is, practice naming the disciplines, and students are encouraged to interpret the assignment freely.

While drawing their portraits, they are asked to respond to a series of written questions, to probe prior ideas involving STEAM experience and the importance of STEAM learning.

In Spring 2022, Calvin became a participating teacher-researcher in the Transdisciplinary Civic Learning Collaborative (TCLC), a multi-sited, multi-disciplinary group of elementary and secondary teachers and education researchers working on designing and implementing transdisciplinary civic learning units at diverse school sites that may arm students with tools to develop empowered STEM and civic identities. While the learning units designed differ substantially across school sites, they share a student-facing guiding question developed collectively across sites: *How do we leverage our individual assets and identities to collaborate, imagine, and sustain healthy communities?* Noting that the first portion of this guiding question references individual identities, and agreeing collectively that in order to support meaningful civic engagement, we must start with the self, teachers across the TCLC designed and conducted varied forms of what we have now come to refer to as *identity inquiries* across sites and classrooms.

When Calvin joined TCLC, we realized some of her oldest students had been participating in identity inquiry for much of their elementary careers. In realizing this work could shed light upon TCLC goals, we began digging deeper, uncovering themes contributing to developing the notion of reimagining STEM learning spaces for innovative young students. In addition, Calvin used TCLC's big guiding question to enhance the identity inquiry task for 4th and 5th-grade students who had already been participating in this campus tradition to further expand their engagement and journey within this realm of elementary student identity inquiry development and set them up for success in navigating participation into potential STEM-affiliated careers. In Fall 2022, 4th and 5th graders created digital identity representations highlighting ties to relevant communities they are a part of and issues that face those communities. They then presented works in a collaborative setting to reflect, challenge, connect and build upon ideas.

Data and analysis

Data for this analysis included approximately 220 STEAM self-portraits created by 44 children throughout their 1st – 5th-grade years from 2018-2022 and 88 civic identity webs created by 4th and 5th-grade students in 2022. All students take STEAM courses, with the data samples reflecting the racial demographics of the school (65% Hispanic/Latinx, 16% Black/African American, 13% white, 2% Asian, 4% two or more races). The analysis examined (a) how students chose to physically represent themselves within (b) what they represented as a "STEAM" affiliated setting, and (c) how they meaningfully integrated STEAM and civics concepts. Calvin initially coded looking for themes. She then shared these themes with the team and we settled on three macro-themes for further exploration. In analyzing each of these themes and summarizing our findings we attend to setting, tool and artifact use, and the culmination of each in relation to broader community problem-solving potential and civic identity development. Selected student work products are presented and examined in Findings to illuminate both commonalities and variation within each of the themes.

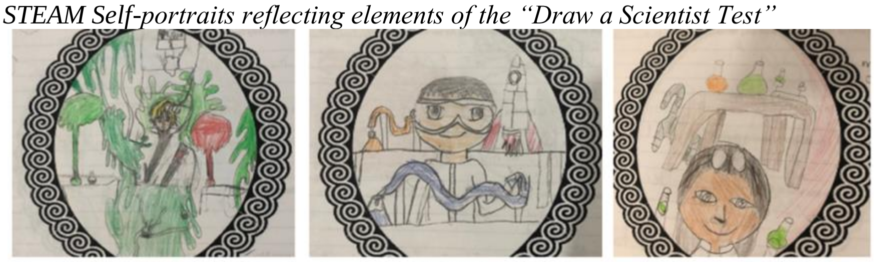
Findings

Data revealed evidence of stereotypes and dominant conceptions of STEAM largely resonant with dominant conceptions of science. We also identified concurrent evidence of students challenging these stereotypes as well as civic identity mapping as a space for building forms of resistance through relevant multimedia and connected culture. Findings are presented in three sections; each section shares evidence from student work to illuminate themes found across data, shedding light on how students can make sense of, develop, and collaboratively reinvent stereotyped notions of STEAM using elements of civic learning and participation.

Stereotypes and dominant conceptions of STEAM

Across the data, students of every age, created drawings with standard or commercialized versions of scientists reflecting themes well documented in the "Draw a Scientist Test" literature (Chambers, 1983) such as "the scientist as a man who wears a white coat and works in a laboratory... wears glasses... and is surrounded by equipment … a jungle gym of blown glass tubes" (Mead & Metraux, 1975, p. 386). Similarly, Figure 1 shows three samples created by students depicting themselves as scientists wearing lab coats (1.1, 1.2 & 1.3) and goggles (1.2 & 1.3) with short hair (1.1 & 1.2) and light skin (1.1, 1.2 & 1.3) provoking the imagery of white men. Tables, faucets, and wires (1.2 & 1.3) indicate indoor lab work with green liquid (1.1) and beakers (1.2 & 1.3) that denote explorations with potions, slimes, or explosions. It is difficult to discern a context where the students are working, or what problems within the community they intend to solve, if any. Students depict having fun with science, shown by smiling faces, but do not explicitly connect context to the broader sense of community connection or future problem solving.

Figure 1
STEAM Self-portraits reflecting elements of the "Draw a Scientist Test"



1. Slime and explosions Scientist
2. Labs and Beakers Scientist A
3. Labs and Beakers Scientist B

Challenging stereotypes and dominant conceptions of STEAM

In contrast to the decontextualized scientists noted above, another theme of student work of all ages included evidence of complex STEAM integration tied to community engagements including, but not limited to, mechanical engineering in construction settings, robotics in makerspace settings, ecological film making, animal rights initiatives, and more. Figure 2 portraits reflect student interaction within various applied learning settings, solving community problems in relevant contexts, using technological tools, while integrating STEAM content. Figure 2.1 shows a digitally created scientist on the roof of a neighborhood home, installing solar panels with tools. A majority of the work is created using geometric shapes pieced together in meaningful ways to create a portrait of a student using solar energy science to solve the relevant problem of increased energy consumption in her neighborhood community. Figure 2.2 is a digital drawing of a scientist engineering a house with a green drill tool next to a large growing crop and a red "garden" sign above a raised garden bed containing various foods. This student poignantly uses elements of gardening and health science to give meaning to the building of which she's engineering for her community to solve food sustainability and scarcity issues. Figure 2.3 shows a hand-drawn scientist collecting plastic in a basket in an aquatic setting. She includes a tree depicting elements of life to show the diversity of ecosystems and the importance of conservation. All three drawings appear to challenge traditional physical depictions of what scientists can be as they are portrayed outdoors in many different styles, shapes, and colors but most notably, connecting the self to community and solving issues of passion.

Figure 2
Challenging stereotypes through integrated STEAM learning and community engagement.

1. Solar Panel Installation in a neighborhood setting
2. Engineering a home in a community garden setting
3. Ecological Conservation in an aquatic setting

Building resistance through virtual STEAM identity mapping

Through collaborating with the TCLC around the idea of identity inquiries, Calvin conceptualized an extension assignment for 4th and 5th grade students following STEAM self-portraits. The extension assignment, *Virtual Identity Maps,* was presented to students to take the STEAM self-portrait project to the next level to include self-reflection and community engagement but also advocacy and cultural ties, to reimagine what STEAM can be, representing future generations. Students were encouraged to add relevant pictures, reflective writing, and broadly consider a series of questions including *1) What makes me unique and special? 2) What do I care about in the world, and what would I change? What kinds of communities am I a part of or wish to be a part? 4) How can I make the world a better place?* Students created a diverse range of media reflecting a number of issues, visuals, cultures, contexts, and STEAM content. In addition, students reflected themselves as scientists in ways they conceptualized, often resisting stereotypic forefronts, instead creating portfolios of complex ideas, goals, aspirations, and connections to communities. Figure 3, one example from the extension assignment, evidences a plethora of global issues, STEAM disciplines, personal expression, and problem-solving. Rather than teasing these apart, we suggest it is more meaningful for teachers and researchers to learn from and celebrate the holistic vision and organized intent of a young student, reflecting upon their developing identity in relation to their call for change utilizing STEAM knowledge and skills, empowerment, and self-actualization.

Figure 3
Identity map integrating STEAM, writing, culture, and advocacy

Discussion and implications

Looking at elementary-aged students' expressive and self-guided work, we see that it's possible to meaningfully create and inform the future of STEAM knowledge and roles through experience with continual and consistent STEAM and civic identity inquiries. As indicated in the findings, a range of identity development can be noted for students of all ages, setting the stage for meaningful cooperative learning, sharing, and apprenticeship within situated learning contexts (Lave and Wenger, 1991). While it's evident some students reflect stereotypic notions of science, their interaction and experience within the classroom context can inform and reinvent STEAM related learning and issues through the interaction of others. Additionally, the use of media in probing civic issues related to identity development can better aid students in communicating relations and dreams associated with civic participation in communities they are developing. Through identifying these themes, future goals for additional research within the data will examine questions like 1) How do students guide each other in resisting stereotypes? And 2) How can longitudinal reflection and connected creation set the conditions for learner insights into their own developing identities, minds, and futures with STEAM?

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Designing and Implementing a Societal-Context Course for Physics Undergraduates

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Abstract: Through a self-study research-practice partnership, we discuss the design, implementation, observations and lessons learned from active learning integration in an upper-level university course. This one-semester course on physical science in contemporary society aims to empower physics undergraduates to develop transferable skills and 21st century competencies through design elements including a student-driven curriculum, student-led classes, an open-ended final project, and ungrading. The class was judged to be a success based on student outputs of final projects, student-designed classroom activities, and student reflective writing.

Pedagogical objectives

We live in a global, interconnected world in which science plays a vital role, as illustrated recently through the COVID-19 pandemic. Yet physics is often taught as an objective discipline, impervious to societal concerns. How do we prepare physics students to grapple with vital questions regarding complex relationships between physics and society? In this self-study, we examine the design and implementation of a university course on physical science in contemporary society. Each year, roughly forty third-through-fifth-year physics undergraduates take this one-semester course, which fulfills the ethics requirement for physics specialists at a large research university. This study examines the depth of learning and the efficacy of our student-driven course design. In particular, we aim to engage students equitably, mitigate any resistance to a nontraditional course format, and empower students to critique and ameliorate the culture(s) in which they live (including physics, academia, and beyond). Learning goals include: (1) to explore relationships between individual people and physics; (2) to explore relationships between society and physics; (3) to communicate effectively.

This self-study is a research-practice partnership that focuses on a second iteration of the course taught by the practitioner (Sealfon) with observations and analysis provided by a trusted observer (Burron). The practitioner’s first iteration was half online and half in-person due to the COVID-19 pandemic. Previous iterations of the course, not taught by the practitioner, were less student-centered and involved less active learning.

Theoretical framework

Active learning has been recognized to be a superior form of educational practice overall, resulting in superior student understanding of content (Kolloffel et al., 2011; Muukkonen & Lakkala, 2009; Song & Looi, 2012) regardless of the testing methods used (Haak et al., 2011). For our working model of active learning, this study uses SALTISE's definition of active learning activities which include: inquiry-based learning, problem-based learning, project-based instruction, concept mapping, and debates (SALTISE, n.d.). We pair these categories of instructional methods with Chi et al.’s ICAP Theory (Chi et al., 2018) that conceptualizes the success of active learning through the products of the students. In ICAP, the goal of active learning is to connect the ideas that are presented in class to ideas and concepts that are in the students’ lived experiences. These connections serve to avoid “encapsulated or inert knowledge” (Chi et al., 2018, p. 1728) which aids in subsequent retrieval and enactment of the knowledge. Chi argues that manipulation of new knowledge, and interacting with other students using that knowledge, entrenches that knowledge within existing knowledge schemas.

Pedagogical changes can be difficult to evaluate and enact without the ability to have feedback of some form. We address this issue by using the “self-study” methodology which allows practitioners to critically examine their pedagogical practices, evaluate the success of that pedagogy, and to have a trusted observer to act as a check to potential self-bias (Loughran, 2004; Russell et al., 2020).

Data sources

This self-study draws from seven sources of data: logs of classroom observations, post-class reflections by the instructor, student works and feedback, the class syllabus, assignment documents, and interviews of the instructors. These multiple data sources help to triangulate the effectiveness of the observed and assigned active learning pedagogies. The trusted observer observed 30% of the course and took notes on the sequence of events, the reactions of the students, and any publicly-facing student works. After each class, the observer collected a reflection from the instructor for later documents analysis. We also collected mid-semester student feedback via an anonymous, optional, online survey, which about half the class completed.

Course design and implementation

The practitioner sought to design a successful student-driven course with an enrolment of 30-40 students who are accustomed to traditional lecture courses with solo problem sets. Most students were not used to expressing themselves in class, articulating their own learning goals, working collaboratively, or designing their own project. The challenge was to balance structure and independence. Active learning at this scale would be most feasible with learning assistants (Barrasso & Spilios, 2021; Otero et al., 2010), yet institutional constraints prohibited this. So the practitioner opted to engage the students themselves, as they are upper-year undergraduates, in the facilitation of classes.

For the facilitation assignment, students signed up to facilitate one hour of class in groups of up to four. In the first iteration of the course, the practitioner chose the topics and students simply signed up; in the second iteration, the practitioner engaged the students in co-creating the list of topics. The practitioner provided a guided "Facilitation Worksheet" for each group to complete to scaffold the steps they would need to design an effective active-learning lesson. The practitioner then reviewed each completed Facilitation Worksheet, added comments and suggestions, and met with each group to discuss their lesson plan and what would make it successful in the classroom before each group's facilitation. In the most recent iteration, the practitioner discussed and finalized students' facilitation grades, based on both preparation and in-class facilitation, during a debrief meeting with each group. The facilitation assignments helped students develop their communication skills, gave each student a turn in the spotlight (with support and with a group of classmates), and enabled dynamic class discussions around a wide range of important topics. To set the stage for productive discussions, the practitioner invited the class to co-create a list of class discussion norms on the first day of class, which groups would revisit before class discussions.

These peer-led classes were paired with weekly writing assignments. In the first iteration, the writing assignments were based on pre-class readings and due before class, helping to establish a common knowledge base for the class discussions. However, these assignments proved too onerous and time-consuming, and the resulting stress compromised learning and quality. In this iteration, we assigned each facilitation group to write a coherent one-page summary of the background readings for their topic with citations to original sources. This summary was shared with the class one week in advance, and students completed a brief online pre-class quiz based on these summaries, reducing the burden for the rest of the class to arrive prepared. We shifted the focus on writing skills to weekly post-class assignments, in which students were asked to complete a reflection that applied what they learned in class to a different real-life situation and connect it to their experiences. This writing prompt was supported by insights from Chi et al. (2018) who emphasized the importance of connections between new knowledge and older knowledge to encourage retention. The students' reflections then allowed teaching assistants (TAs) to engage with the students about critical thinking, appropriate writing skills, and bringing the student's self and opinions (a difficult proposition for this student population) into their writing. We used ungrading (Kohn & Blum, 2020) to encourage growth in writing abilities. TAs gave students weekly feedback on three criteria adapted from the VALUE rubrics (Association of American Colleges and Universities, 2009): (1) identify and communicate a position or perspective; (2) analysis and integration of knowledge; (3) writing syntax and mechanics. TAs also provided a mid-semester estimated grade. Towards the end of the semester, students completed a self-assessment of their growth in the three criteria as demonstrated through their written submissions. They then met with their TA for fifteen minutes to discuss and finalize their post-class writing grade.

The last major component of the class was a final project, enabling students to delve more deeply into a class topic. The practitioner based the final project structure on Jim Martinez's assignments that engage students in interdisciplinary, open-ended, creative projects (Martinez, 2017). Students could work in groups of up to five on any topic that involves a complex issue and pertains to relationships between society and physics. They could consider creative formats for their final product beyond a typical paper or essay (e.g. podcast, video, play, blog, research proposal, etc.). Three stages helped scaffold the final project, and the practitioner provided feedback after each stage. In the last few weeks of class, students shared their learning from their projects with the class; these project presentations were graded in part on how well presenters engaged the class in active learning. This course iteration included a phase of peer feedback and self-evaluation after groups submitted their final products, and final project grades were finalized in a meeting between the practitioner and each group.

Results and discussion

A principal concern of the practitioner was that some students in the previous iteration “phoned it in” when facilitating active learning activities with the class. In these cases, the students simply read off slides that summarized papers the class had already read. Though the feedback from the previous iteration was favourable, especially regarding presentations that were interactive, concerns about this “phone it in” behaviour prompted redesign. To combat this behaviour, the practitioner engaged with her presenting students in design meetings, provided scaffolds for active learning instructional planning, and changed the weighting for the presentations from 10% to 30% of the total grade.

Though students were initially reticent, the class became accustomed to the alternative delivery format and then eventually started to enjoy the activities. Students demonstrated impressive knowledge development through their oral comments and the thinking they summarized on their whiteboards. However, some facilitation groups were more successful than others at preparing adequate background knowledge with their classmates. This challenged these groups' ability to engage the class in deep discussion because of the inadequate, or unbalanced, background information limited nuanced discussion of the topic. For future iterations, we propose separating out the facilitation group’s preparation assignment into two parts, with the summary of the background readings for the class due earlier than the rest of the lesson plan. This would allow more time for the practitioner to give feedback on gaps, or biases, in the background summaries.

We also used ungrading on writing assignments to discourage students from ignoring feedback and focusing only on the grade. This process proved incredibly successful as students’ writing improved in nearly all cases, and nearly all students appeared to be taking the feedback into account in subsequent submissions. While early writing from students was poor, with few exceptions, nearly all students approached the VALUE rubric’s definition of mastery-level writing after five or six assignments. For students who were slow to respond to the ungrading feedback, the use of a non-binding midpoint grade appeared to influence these students to pay attention to the feedback and subsequent submissions showed a marked improvement. Survey data also supported that students engaged with the TA feedback across weeks.

Student surveys showed a universally positive opinion of the class, with students praising the work of their classmates, the feedback from the TAs, and the practitioner. For example one student wrote:

> “The in class discussions, especially when they were global, i.e. involving the whole class. It provides students an opportunity to interact with their colleagues in a personal and meaningful way, a rare and valuable experience that most other classes just cannot provide.”

Students also pointed out that the class was unique in their experience and that they appreciated the opportunity to think and interact with the issues. For example:

> “I've been able to talk to more people that are studying similar things to what I am so I am able to get more exposure. This class has allowed me to make more connections, see their perspectives on issues and inform me more broadly on physics.”

One student, who admitted to initially not wanting to take the class, commented that they now believe the class should be obligatory for students in the physics program.

Conclusions and relevance

This class design seems to have worked well, even with a population of students that tends to be reticent about writing, speaking, or engaging with social issues.

Given the surprising success of ungrading for student feedback, future work employing ungrading in post-secondary classes may be useful, especially in instances where the growth of the students’ abilities can be iterative (e.g., in a writing context, weekly assignments, or science lab reports e.g. Etkina et al., 2008).

Using the ICAP framework to emphasize connections between physics and social issues, as a direct learning outcome for writing, appears to have deepened the students’ understanding of the relevance of physics within a social context. Making connections integral to the learning objectives, though it may feel artificial, does seem to deepen student connections to the topics presented, as reflected in mid-semester survey responses that reference this advantage and in the growth of student achievement in this area.

As having students design and implement lessons worked very well in this context, further work to incorporate student-led learning in physics classrooms may show similar results. Though students may initially resist this educational style, the evidence shows that most, in our case all, eventually appreciated it.

Students also commented extensively on the social aspects of the class and how other students were helpful and accommodating. This type of co-creative course design and facilitation may help with pro-social aspects of post-secondary learning in fields that are not perceived as human-centric (Holmes, n.d.; Segarra et al., 2018).

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Designing Inquiry Based Labs for College-Level Biology Students

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Abstract: We report on a practitioner-researcher crafted semester-long biology inquiry-based lab approach which implemented a new script based on conceptual progression. Students were required to make decisions in well-scaffolded contexts relating to each component of the scientific process separately, but progressing in an order supporting the knowledge and skills to be learned, from experimental design and statistical/procedural methods, to formulating hypotheses, and ultimately drawing conclusions. In each module, students took up agency for a single component, but scaffolded within an exploration of the entire scientific process, including reflecting on how their work integrated into a full pre-prepared journal article. The progression concluded with students completing a small comprehensive project on their own. Results were encouraging, as students met the significant challenge of the final project, meaning our approach could serve as a model for other biology instructors. Further research will explore the success of the various scaffolds employed.

Objective

Inquiry-Based Labs (IBL) is an instructional approach based on social constructivism and aimed to promote the learning of scientific practices and processes. It focuses on engaging students in the thinking and procedures by providing them with opportunities to make decisions as part of the laboratory component of a science course. It is a departure from traditional verification/confirmation labs that often look like recipes from cookbooks, leaving little room for students to use skills and knowledge that are central to scientific experimentation and analytical skills (Holmes & Bonn, 2013). Increasingly, higher education science programs are questioning the effectiveness of using traditional labs (Holmes et al., 2020). The effectiveness of IBL arguably relies on appropriately scaffolding decision making and supporting the knowledge construction used in task completion (Hmelo-Silver et al., 2007).

To date, most theoretical and empirical research with IBL has been based on types of single labs (e.g., Blanchard et al. 2010), and there is little evidence-based information to guide the design and development of a college-level biology IBL curriculum. This paper reports on a semester-long IBL that explores a new script for IBL based on a "*conceptual progression*", instead of that proposed as typical implementations, as described in other studies.

Background and design

The literature has used two dimensions to classify the IBL approach: (1) the amount of instructor guidance (decision-making autonomy/agency afforded to students), and (2) the stage in the scientific process selected for the decision-making activity (research question, methods, results analysis, discussion). Science education researchers (Blanchard et al., 2010; Buck et al., 2008) have classified IBL implementations into typologies based on the intersection of these factors, which associate higher levels of inquiry with increased student decision-making (agency), but which constrain and prescribe the stages where this decision-making takes place. According to these typologies, lab activities with lower levels of inquiry (i.e., higher levels of instructor guidance) all encourage student agency only in the late stages of the scientific process (drawing conclusions), while providing strict guidance throughout all early stages. Inquiry levels are then constrained to progressively and sequentially increase backwards through the earlier stages (analyze data, design methods, formulate hypothesis, ask RQ). Essentially, per these typologies, students are only afforded agency to make decisions for first steps of the scientific process when they can complete an activity requiring them to make decisions throughout the entire process. While this *backward progression* seems typical of IBL described in the literature, it arguably does not reflect an ideal conceptual progression for IBL and overlooks the interdependent nature of each stage of the scientific method. Furthermore, those studies categorize individual labs in isolation and do not explore sequencing across a course, a critically important aspect to practitioners.

The semester-long IBL intervention on which we report sequenced lab modules by the specific knowledge and skills to be learned, following what we believed to be an ideal conceptual progression and unconstrained by the backward progression identified in other studies. Each module required students to make decisions associated with its particular learning objectives, while prompting them to integrate the associated knowledge into the larger process of scientific experimentation. In this way, students were progressively required to consider each component of the scientific process separately in a well-scaffolded context, and finally to put their understanding of each component together in a more comprehensive small project. The IBL was the product of a practitioner-researcher partnership, with both collaborating equally and extensively to adapt existing lab activities within the framework of our ideal conceptual progression model.

Context of the IBL case study

The IBL case study was set in a college-level General Biology I course (first year university equivalent, first biology course in the Science program), the institution situated in the province of Quebec, Canada. It consisted of five lab modules, each focusing on a particular aspect of the scientific process, which is the key characteristic of our approach. We also designed a variety of scaffolds to support the task completion. Typically, these scaffolds were embedded in the module as part of the instruction, or as background information, rubrics and models of high-quality performances.

Importantly, one of the scaffolds used in this IBL case study is embedded in the affordances of an online platform called OCLaRE (Online Collaborative Laboratory Reporting Environment). This is based on a “writing-to-learn” pedagogy (Reynolds et al., 2012) with structural features and templates that format the components of a typical lab report into the layout of an authentic scientific journal article. In our IBL modules, we used these affordances in a “complete-the journal article” activity, which required students to reflect on their choices for the particular aspect of the scientific process when viewing their section of the article within the context provided by the entire paper.

Lastly, the design team collected all student output, including lab reports within the online platform, which together we consider the biology-focused performance data. To assess the implications of this design on learning we developed a suite of instruments: a pre-post-test to assess changes in scientific reasoning (George’s Ice Cream, adapted from McDermott, 1995), an epistemic belief questionnaire (Topic Specific Epistemic Beliefs, Strømsø, et al., 2008), and a survey and interview questions on perceptions rela(ted to the course and levels of confidence.

Design of the IBL case study

The first IBL module was significantly more elaborate than the other four because it developed skills needed throughout the rest of the semester. It focused on providing opportunities for decision-making related to analytical skills, specifically aimed at developing the ability to design simple experiments and use simple statistical methods. The curriculum develops these skills first because we consider them the bedrock upon which other components of the scientific method are built. For example, the appropriate statistical/analytical tools to use depend on the study design and data collected, and proper interpretation of results for the purposes of drawing conclusions is challenging without understanding these two elements together. Simultaneously, a proper scientific hypothesis needs to be testable, so students must be able to conceive of how a hypothesis could be tested before they can formulate one. Thus, in module 1 students made choices to design an experiment to test a hypothesis about sugar content in peaches, to run a statistical analysis using data provided, and ultimately to produce a results section for a scientific article,

IBL module 2 was on measurement protocols and data manipulation, module 3 on using background information to formulate hypotheses, and module 4 on drawing conclusions and inferences from results (see Table 1). These modules were adapted from current lab practices and were thus presented in an order which reflected the content and regular lab activity progression of the course: in module 2 students designed a study to determine whether particular plant and animal cells were different in size, in module 3 students used detailed background information to formulate a hypothesis about the pattern of inheritance for a particular fruit fly gene, and in module 4 students used results of an experiment to draw conclusions about which evolutionary mechanisms had led to changes in allele frequencies for a gene in controlled fruit fly populations. However, the order of the interventions also reflected what we view as a logically coherent progression for scaffolding development of scientific skills, by first establishing the fundamental understanding of design and analytical methods, building upon this to formulate testable hypotheses, and finally considering the entire process and drawing conclusions. Collectively, these four modules represent the main components of the scientific method, but also map to the four sections of a traditional scientific publication.

The final component of this five-part curriculum, IBL module 5, was an open-ended task which required students to write a full scientific paper. This was based on a SimBio simulator called “How the Guppy Got Its Spots”, which itself is modeled directly on a classic paper in evolutionary research (Endler, 1980). The simulator roughly reproduces the environment where the research took place, including the tools Endler used to run the experiments. Given Endler’s research question, students had to formulate a hypothesis, design an experiment using the simulator to test this, analyze the raw data output, and draw conclusions. Scaffolding the IBL, students were provided with a full grading rubric, support documentation that accompanies the simulator, and the actual Endler (1980) publication that the simulator is modeled on. A social annotation assignment, using an online platform, was generated for the latter.

Elaborating on the conceptual progression model (see Table 1), it’s important to note that the decreased number of decisions associated with modules 2-4 belie the complexity of the reasoning and knowledge resources required to complete these modules. For module 2, students needed to consider and describe procedural constraints associated with taking measurements of cell sizes, as well as assumptions about cell shape that would be required to manipulate data for the purposes of comparison. These constraints/assumptions were not explicitly provided but were critical to assess confidence in the results and conclusions. For modules 3 and 4, the background knowledge required to formulate a hypothesis or interpret results and draw inferences was quite complex for students at this level. Scientific inquiry is rooted in a deep understanding of the subject matter, and the final tasks associated with these two lab modules required students to draw heavily upon fundamental conceptual knowledge from the course.

Table 1

The five-module (Mod.) curriculum outlining the conceptual progression model of students’ decision making

	Student choice	Mod.1	Mod. 2	Mod. 3	Mod. 4	Mod. 5
Introduction	Form hypothesis from background information			x		x
	Write introduction			x		x
Methods / Design	Design experiment from RQ and hypothesis	x	x			x
	Incorporate replication into design	x	x			x
	Systematically vary independent variable	x	x			x
	Write methods		x			x
Analysis, Discussion, and Conclusions	Select appropriate analytical approach	x				x
	Interpret data and draw inferences				x	x
	Write results	x				x
	Write discussion and conclusion				x	x

Implementation script

The workflow of the first four IBL modules followed a five phase “script” (Dillenbourg & Jermann, 2007). Phase 1 was a synchronous lab activity focused on teaching the identified skills and/or collecting data. In most instances this meant that students were introduced to the research question and worked together to answer that question, while, notably, the identified decision-making task was foregrounded. Working through the components of the scientific method together in groups acted as a scaffold for the particular element students needed to explore themselves. For phase 2, students were asked to write a draft of the paper section being targeted by that module. To assist with the completion of this task, they were provided with scaffolds that included standards and criteria as well as models of quality performance. Materials included: reviews that they completed in the synchronous lab, videos of particular methods where appropriate (necessary for online labs), descriptions of the goals of that written section and how they related to the scientific method, a detailed grading rubric which would be used to assess their work, and a highquality student submission from similar student work in previous semesters which was annotated to identify strengths and weaknesses. In phase 3, students submitted their draft section using OCLaRE. As described earlier, the objective of this phase was to have students consider a coherent scientific report of the entire process that links the storyline of the pre-written sections to the student-written section. OCLaRE inserted their draft section of the paper into a full high-quality student report submitted in a previous semester, and allowed students to view the entire paper in proper publication format. For phase 4, students were asked to complete a reflection assignment. They considered their own submission, as well as examples of the pertinent paper section of varying quality, all relative to the full publication describing the entire scientific process obtained from OCLaRE and the particular criteria required to properly complete the specific section. Lastly, phase 5, students completed the final draft of the section of the paper and submitted.

Discussion and relevance

The conceptual progression approach to IBL instruction was conducted within the context of a larger three-year study on the mechanisms and value of inquiry-based learning, and data from the semesters are still being processed and analyzed to attempt to answer larger research questions. To date, generally speaking, the results of this case study are encouraging for our practitioner-researcher team. Notably, student artifacts achieved standards consistent with high level quality at the introductory college level.

Given the nature of this practitioner-researcher project, it is important to note that the different stakeholders view the results differently. The course instructor (first author) is most interested in the results of the final module, which required students to undertake and make decisions throughout the entire scientific process, each of which would impact downstream decisions and have consequences on the final product. Thus, while the total of our IBL intervention could be perceived as simply providing an algorithm to follow of the scientific method, students could not have produced the high-quality papers submitted for the open-ended final module simply by following a recipe. Rather, the outcome could potentially be better perceived as having provided the students with an iterative set of decision-making practices, focused initially on each step of the process separately, but which students were ultimately able to compile together successfully, possibly due to our emphasis throughout of viewing each step within the context of the whole. Meanwhile, the researchers are curious and skeptical, currently examining the results of each module and which scaffolds were taken up and which were not. In particular, one focus for further investigation is the role played by OCLaRE. Those data are yet to be examined closely to identify how the task of reading through a full scientific article in the “complete-a-journal” activity mediated the understanding of the experimental process, as a whole.

In summary, from the data collected and analyzed to date, it appears that providing students with the agency to make decisions for all steps of the scientific process, with the exception of formulating a research question, is challenging and requires the design of additional scaffolds. That said, results of a post-semester survey indicate that, while the final assignment was extremely challenging, student confidence in having been prepared to meet that challenge was high. In the view of our instructor (first author), the students did indeed display their ability to meet the challenge, assessed by the quality of their final lab reports. In addition, most students displayed acceptable to impressive levels of competency for every stage of the scientific process and outcome, evaluated by a grading rubric designed for a typical biology course. Thus, from a practitioner’s perspective, this approach to IBL can be deemed a success, and could serve as a model for other biology instructors with first year undergraduate students. From a researcher perspective, this case study, of what we are calling a “conceptual progression” IBL model, provides insights into the process of designing and scaffolding for students’ autonomy and the release of agency.

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Data-Informed Course Improvement: The Application of Learning Engineering in the Classroom

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Abstract: Learning Engineering is a practice and process that can be used by any teacher in the classroom to apply the learning sciences in their instructional design, while collecting and analyzing data to determine the effectiveness of their interventions. This practice-oriented paper reports on three examples of the learning engineering approach applied to course improvements in higher education to address self-regulated learning, social presence, and interleaving.

Introduction

Learning engineering can be intimidating for the typical classroom teacher. The word “learning” is familiar, but the word “engineering” may be misunderstood or may make an educator feel unqualified to explore this approach. Much of the literature on learning engineering describes large teams engaged in a project (Dede et al., 2018), scaling up learning solutions (Saxberg, 2017), or utilizing the approach by educational software developers (Goodell, 2022). However, the good news for teachers is that the learning engineering process and practice can be applied on a smaller scale in the individual classroom by any teacher, at any level, and in any subject area, who wants to improve learning outcomes for her or his students. By applying the learning sciences to our instruction, planning for collection and use of data, and understanding our learners and the effect of a unique context, we can make our classrooms more effective, equitable, and enjoyable. These are the processes involved in learning engineering, and teachers may find this systematic approach to be attainable and beneficial. In this paper, I will provide a brief overview of learning engineering and then share how I have used this approach in my own classes with promising results.

Learning engineering

The IEEE industry consortium on learning engineering (ICICLE) defines learning engineering as “a process and practice that applies the learning sciences using human-centered engineering design methodologies and data-informed decision making to support learners and their development” (Goodell, 2022, p. 10.). While learning engineering teams do exist in some organizations and there are increasingly more job postings for the role of learning engineer (V. R. Lee, 2022), this approach can be used at a smaller scale. All that is required is an understanding of the learning sciences, familiarity with some engineering principles, and a willingness to be adaptable in your instruction based on the data from your learners to iterate improvements.

The science of learning can be helpful to instructors who are using evidence-based practices in their teaching to help them understand why these practices are effective and in what circumstances (Daniel, 2012; McMurtrie, 2022). One critique of the science of learning is that the studies are often too controlled, conducted in a lab setting or with strict controls in a classroom environment (Daniel & Chew, 2013). The learning sciences have brought principles to educators such as the role of prior knowledge, skills, and beliefs; desirable difficulties; error management; feedback; active learning; retrieval practice; spacing and interleaving; metacognition; self-regulated learning; multimedia principles; and problem solving (Benassi et al., 2014). While learning sciences researchers often apply theory in practice in ways that encompass the whole learner (V. R. Lee, 2022), learning engineering allows us to examine these concepts in a specific context with a unique group of learners to understand the limits and applicability of these phenomena.

Barr et al. explained that “engineering is the application of creativity and science to solve problems, and learning engineering is the application of the learning sciences to creatively solve problems for learners and learning” (in Goodell, 2022, p. 131). They noted several principles of engineering that can be applied to designing solutions to learning challenges, including addressing specific problems, end users who are intended to benefit from the solution, testability, maintainability, integrity, well-defined external integration, ethics, and management (p. 131). Learning engineers use systems thinking to explore modular design, constraints and tolerances, operating conditions, trade-off analysis, and feedback loops. Engineers and research scientists often use data differently: while the learning sciences are often focused on group means, learning engineers probe outliers and individual cases to explore boundary conditions (Goodell, 2022).

Use cases

I teach at an institution that serves nontraditional learners in distance education. My students often have not been in a classroom for many years, have negative past experiences with school, have work and caretaking responsibilities outside of classes, and often face other life stressors that place them at risk for not completing a course. In order to address these challenges, I turned to the learning sciences. I now provide three use cases from several semesters of an introductory computer applications class illustrating how I have utilized learning engineering in my practice as an educator. Each of these consists of the core components of learning engineering: a learning problem or challenge, the design of a solution that applies the learning sciences, implementation with data collection, and investigation with data analysis, including iterating improved designs (Goodell, 2022).

Self-regulated learning

Learning challenge. Traditional face-to-face classes often provide the on demand supports and structures that regulate student learning, but these can be absent in online learning unless intentionally designed, requiring students to regulate their own learning. First generation students have significantly lower levels of self-regulated learning skills (Williams & Hellman, 2004), and participating in online learning does not necessarily improve these skills (Barnard-Brak et al., 2010). Deficits in self-regulated learning skills can negatively impact distance learners (Bol & Garner, 2011), especially adults (K. Lee et al., 2019). I have seen this in my own learners.

Design solution. Pintich's (2004) model of self-regulated learning includes four phases (plan, monitor, control, and reflect) and four areas (cognitive, affective, behavior, context). Using this framework, I included a section in my course syllabi with tips for success that included questions students can ask themselves to regulate their learning, such as, "How long will it take me to complete this assignment?" and "How can I make this assignment meaningful to me?" I modeled task analysis for students by showing them how I would plan out my week if I were taking this class, including learning tasks in addition to completion of assigned and graded work. I displayed a sample weekly routine in calendar format with tasks spread out over the course of the week to encourage spaced practice (Dunlosky et al., 2013) with estimated times for each task so that students could plan within their busy schedules. I created separate Google Docs for each student that included four reflection questions they would complete weekly as an exit ticket. The document included a table with one question in each column and a new student response in a row for each week of the semester. Students were instructed to reflect on their learning experiences but not to spend more than five minutes on the task. The questions were:

1. What did I learn or what questions do I have? (cognitive)
2. How do I feel about my learning experiences this week and why is what I learned important to me? (affective)
3. What did I do that helped me succeed or what should I do differently? (behavior)
4. What was helpful about the structure of the class or the way I interacted with others? (context)

Data collection and analysis. By explaining the purpose and benefits of completing the optional learning tasks, such as practice quizzes and studying, as well as helping students to map them out into their schedule, I did see an increase in the number of students who completed those tasks. When not all students were completing the exit tickets, I assigned five percent of the final grade to completion and began tagging students immediately who did not complete it. This led to more than 90% compliance over the course of the semester with this short weekly assignment, an increase from prior semesters. Every week, I was able to see what each individual student found important and where they were confused, what strategies they were using for learning, and where I might make improvements to the course. By responding to student reflections with the commenting tool, I was able to tag them with resources and suggestions or ask questions for clarification on issues or suggestions. Students could reply to these comments from their email, which often led to ongoing conversations in the document throughout the semester. Students often provided excellent suggestions in their exit tickets for small changes I could make in class to improve their learning, such as providing assignments for multi-week modules in a calendar format instead of just a checklist. Whenever I try a new technique, I now ask for feedback from students in their exit ticket.

Social presence

Learning challenge. Social presence of any kind online can be defined as "the degree of feeling emotionally connected to another intellectual entity through computer mediated communication" (Sung & Mayer, 2012, pp. 1738–1739). Indicators of social presence can be affective (expressions of emotions or mood), interactive (acknowledgement of another), and cohesive (things that build or sustain group cohesion) (Rourke et al., 1999). Adult learners find teaching presence to be essential for their learning and seek deep interactions with content rather than surface learning, with peer interactions a bonus (Angelaki & Mavroidis, 2013; Ke, 2010). Mayer (2014) suggested that this connection helps to foster deeper processing during learning.

While the exit tickets had helped me to develop relationships with each individual student, I found that students in my synchronous online classes were reluctant to communicate with each other or speak up in front of the whole class. Teacher immediacy behaviors have been shown to have a positive impact on learner emotions and learning gains (Ge et al., 2019; Liu, 2021), while emotions (Plass & Kalyuga, 2019) and social connections are integral to the learning process (National Academies of Sciences, Engineering, and Medicine, 2018). To address the social distance and emotional connection in my classes, I looked for strategies that would help students to develop learning relationships with me and each other.

Design solution. One strategy I implemented was an opportunity for bonding in the first class meeting. I presented to the students my commitments to them: share tips for being a successful student, be patient with explaining the same thing in many ways, care about you and your experience in this class, make class meetings worthwhile, help you meet your learning goals, and appreciate your efforts. I then split the class into breakout rooms to introduce themselves to a smaller group, asking them to make commitments to each other. I followed this up with other teacher immediacy behaviors throughout the semester, such as referring to students by name, using a more informal and relaxed meeting platform (www.kumospace.com), using "we" and "our" language, narrating my thinking as I worked through problems, using cute praise memes in assignment feedback, and having informal conversations with students at the beginning of class.

Data collection and analysis. Students often commented in the weekly exit tickets described above how much they enjoyed playing review games together and working with a partner on an assignment because they were able to help each other and explain concepts in a different way. This was a marked change to the comments I had seen in earlier semesters where students rarely referenced one another. By setting aside approximately an hour per course each week to review exit tickets, I was able to maximize my personal connection with each individual student. The inclusion of other teacher immediacy behavior strategies and the frequent partner and small group work appeared to make the students more at ease as evidenced by comments in the weekly exit tickets, more students turning on their cameras during course meetings, more interactivity in the course chat, and more engagement and small talk during small group work. In future iterations, I will make these strategies explicit to the students and ask them to reflect on the impact to their learning experience.

Interleaving

Learning challenge. One thing that often frustrated me when teaching a computer applications class was that students frequently forgot content from the beginning of the semester by the time we reviewed for the exam. The curriculum consisted of a module on Windows, three modules each of Word, PowerPoint, and Excel, and a short module on databases. After learning about interleaving, and it occurred to me that it might be possible to switch up my coverage of the curriculum to help address this learning challenge. Interleaving is the act of mixing together study of multiple related topics rather than learning individual topics one at a time (Birnbaum et al., 2013).

Design solution. In the next semester, I planned to rotate the applications each week, rather than teaching them in a block. In the introduction to the course, I told the students about this approach and that I hoped it would help them to see the connections between all of the Office applications while mitigating the forgetting that often happens. I planned to examine the quality of assignment submissions, quiz scores, and comments from students in weekly exit tickets.

Data collection and analysis. An analysis of the data revealed a clear improvement in the quality of assignments that were submitted and a slight increase in weekly quiz scores. Students became more focused on the commonalities between the Office applications, such as the structure of the window, the tools on the ribbon, and using features like SmartArt and image editing. When reviewing for the final exam, students had retained more information on features of Word because they had utilized the program every three weeks throughout the semester, rather than in only three weeks at the beginning of the semester.

Conclusion

Using evidence-informed strategies in the classroom can be beneficial to learners, but the use of learning engineering has taught me the value of using evidence-*generating* strategies to understand my students, their learning experiences, and their learning outcomes. In this practice-oriented paper, I described three scenarios of course redesign in my classes where I used the learning engineering approach: I identified a learning challenge, applied the learning sciences to an instructional solution, collected data, and analyzed the data for evidence of effectiveness of the new strategy. In most cases, I made small changes to iterate the design throughout the semester based on the student data. While the emerging field of learning engineering primarily focuses on developing learning solutions on a larger scale, this process and practice can be utilized by any educator to improve learning experiences for their students.

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Designing a Modern Apprentice Program for a Digital Era

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Abstract: Policymakers, education institutions, businesses, and workforce development providers increasingly promote apprenticeship programs to address professional skilling needs. Yet, many of these programs act as recruiting pipeline strategies and fail to consider the learning experiences. While traditional models of apprenticeship offer a foundation for these programs, a revival that considers the many differences between traditional craft programs and modern ones is needed. Through a practitioner-led research and design project with the world's largest professional services firm's apprenticeship program, this study marries lessons learned with learning sciences research to position a Pedagogy of Modern Apprenticeship.

The case for modern apprenticeship program design

Globally, apprenticeships are on the rise, and they are no longer just for trades but are increasingly popular to skill workers for professional and technical roles. Policymakers and workforce development providers see apprenticeships as essential to address economic mobility, and Fortune 500 businesses are increasingly establishing apprenticeship programs. Analysis indicates an opportunity to expand this model to new occupations, including many in which employers require a bachelor's degree (Fuller & Sigelman, 2017., Federal Reserve Bank, 2019). This global trend has a stronghold in Europe and a recent policy revival in the US, where the Biden Administration stated that "Apprenticeships can change lives" (The White House, 2022).

While a renewed focus on apprenticeship is promising, traditional programs focus on developing narrow skills deeply embedded into specific contexts. And some function as a recruitment pipeline more than a learning experience. This may be because they leverage historical models of craft apprenticeships, which have been effective for centuries. Yet, as modern apprenticeship programs scale globally, involve multiple "master apprentices" to learn from, and include an increasingly digitalized work environment, it is time to adjust the design to address the needs of the adaptive and transferable skills required in the Future of Work.

This paper focuses on the in-progress implementation of a large-scale modern apprenticeship program at the world's largest professional services firm, Accenture. It discusses the company's journey of investing in apprenticeships as a talent pipeline and community impact initiative, prioritizing apprentice learning and ongoing career opportunities. It outlines how a joint team from Accenture and Harvard's Next Level Lab engage in a practitioner-led research approach to create a Pedagogy of Modern Apprenticeship.

Practitioner led research and iterative design of an archetypal program

We decided to use Accenture's North America Apprenticeship Program as an archetype of a modern apprenticeship program as a place to study, test and implement. The apprenticeship program was established from Accenture's collaboration with City Colleges of Chicago, Illinois, US, to inform the community college's information technology curriculum. Out of that relationship, Accenture brought on its first cohort of 5 apprentices into its internal technology team. Since launching the apprenticeship program in North America in 2016, Accenture has onboarded over 2,000 apprentices across 40 cities. These apprentices specialize in one of many tracks ranging from cybersecurity, digital transformation, and data science.

Under the company's US Corporate Citizenship program, the initiative focused on the company's goals to help bridge the opportunity gap via hiring from nonprofit organizations and community colleges. In 2017, the program expanded to two additional pilot cities and the following year to each city in which the company launched an innovation hub, tying the company's investment in innovation with job growth in local communities. Localized organic growth continued alongside expanding to new cities, adding role tracks into predominantly client-delivery roles, and ongoing iteration on the program's learning and employee experiences.

Building on the success of the early cohorts and Accenture's broader skills development strategy, the program has been integrated into Accenture's talent strategy. After growing and evolving steadily from the first cohort of five apprentices, in fiscal 2022, Accenture set and exceeded its goal for apprentices to make up 20% of North America entry-level hiring and extended the goal to fiscal 2023. Since the initial cohort, the design of the program continues to mature in several ways, including expanding to over ten learning and career tracks that foster learning by doing, creating more formal supporting roles (experienced others), embedding opportunities for self-assessment, choice, and reflection, while staying committed to apprentices being fully immersed in the organizational culture, processes, and structure.

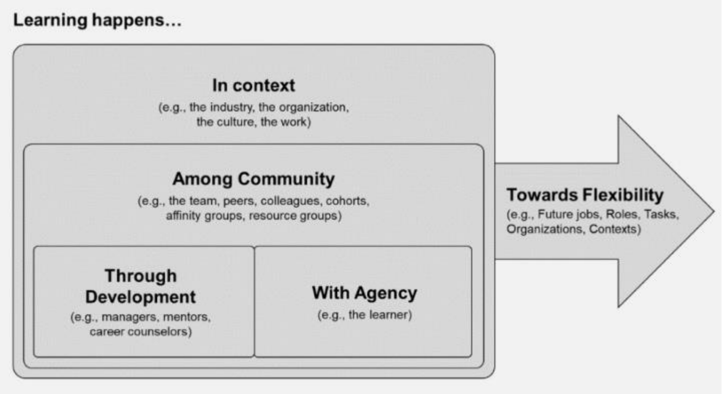
Apprentices are paid with benefits through the full-time, year-long earn-and-learn model. The minimum requirement is a high school degree or equivalent. Apprentices have a demonstrated interest in the role for which they apprentice, with a selection process focused on potential. The program includes, on average, 240 hours of structured technical and professional skills learning and 2000 hours of on-the-job learning.

Since 2016, the program has continuously evolved in response to participant feedback, advances in research about learning in situated environments, and a desire to move towards a program that prioritizes the learning experience of the apprentices over purely the recruitment pipeline potential. Interestingly, a chi-squared analysis of our participant and retention data suggests that starting year in the program and program conversion are strongly associated (X-squared = 2062.8, df = 24, p-value < 2.2e-16). Participants who enrolled in the program in recent years were much more likely to convert to an ongoing position than those who started in the program's earlier years. Once converted, program graduates typically have significantly higher retention than industry averages (LinkedIn Data Insights, 2022).

The pedagogy of modern apprenticeship

Drawing upon six years of lessons learned, participant interviews, case analysis, and an extensive literature review of research in the learning sciences, we describe five key features of how learning happens in Modern Apprenticeships. Each builds upon the research of how people learn (figure 1) and amplifies what is working about traditional craft apprenticeships while positioning additive features. For each feature, we ground in theory why this feature is important, define the feature, highlight some of the design of Accenture's apprenticeship program, including implementation details, and share abstracted learning for wider implementation.

Figure 1
The Pedagogy of Modern Apprenticeship



Learning in context

The context in which people learn is crucial to how they learn (Greeno & Engeström 2014). Apprenticeships are a long-held way to help people learn in the physical context they will apply it (Collins & Greeno, 2010). However, modern work is changing what it means to work in context to include physical and digital spaces, multi-geographic cultures, and international practices. Therefore, how programs are designed for context needs to evolve. Learning in context refers to the circumstances of a digital ecosystem that inform when and how an individual engages with digital tools to learn and do global work, cross-industry and adjusts quickly to changing demand and pressures.

The company's goal for the program is to embed apprentice roles into project teams doing real work; 93% are roles supporting client work. The Accenture apprentice learns in context through a specific learning and career track, working on project teams in which they learn from and contribute work alongside experienced others. Examples of projects that apprentices work on include user acceptance testing, creating training materials, and crafting relationship maps for large global teams. In addition, all digital tools are made accessible, including equipment, digital worker toolkit, virtual meeting cadences, and knowledge pathways (e.g., Google Cloud, AWS App Dev, Splunk, Salesforce) to enable learning and project-based work.

The apprentice program is structured such that an apprentice typically contributes to client projects for 10 of the 12-month program. Apprentices join teams with a specific role and appointed supervisors. Apprentices may be staffed on multiple projects through the program. Roles are built into its talent planning process with the goal of 20% of entry-level hiring. Planning cascades to business group and project team staffing.

Learning among community

Many programs recognize networking and community as important. However, most see it as secondary to learning core skills and often center the community around the apprentice cohort rather than other workers the apprentices are situated within. Yet, a lot of what people learn is through observation of experienced others and participation in a community of practice (Brown & Duguid, 1991). To develop the nomenclature (Toulmin, 1999) and tricks of the trade, learners need opportunities for peripheral participation (Lave & Wenger 1991). Learning among community refers to the relationships between apprentices, their cohort, support system, and the organization.

In the Accenture model, there is equal emphasis on the apprentice community of support and inclusion in the company-wide community. Apprentice-specific structures include apprentice cohorts that start the program together, a Success Toolkit specific to the apprentice experience, a Microsoft Teams site and channel to connect with others in the apprentice community in any location, program-wide monthly apprentice community calls, office hours with HR, and on-going touchpoints with 'Local Apprentice Champions.'

Apprentices are encouraged to engage beyond the apprentice community with programs that include non-apprentice employees. Eighty-six percent of apprentices in the most recent program survey report feeling engaged with their business unit beyond the program, indicating that the overwhelming majority felt included in the wider Accenture community. This is in response to intentional efforts; for example, apprentices are offered opportunities to lead parts of local office meetings, join Employee Resource Groups, engage in town hall sessions with their location, industry, practice, etc., and participate in company volunteering programs. Digital tools further drive connection by removing physical barriers and giving access to local, national, and global experiences. The multiple layers of community enable scale alongside localized context and personalization.

Learning through development

The master and apprentice structure is a hallmark of traditional apprenticeships. Experienced Others are essential to supporting learning from novice to expert for specific skills (Vygotsky, 1978; Bronfenbrenner, 1979; Collins, 2005). However, the master and apprentice relationship has changed dramatically from traditional apprenticeship programs. For one, today, a learner often has many "experienced others" from whom they are learning. Furthermore, since they often did not graduate through traditional apprentice-craftsman-master models, many "experienced others" are less practiced in the skills needed to perform the role.

Learning through development refers to the actions taken by multiple experienced others to intentionally develop the apprentice throughout their experience, and the program emphasis on preparing the experienced others to do so. In craft apprenticeships, the experienced other is considered capable of guiding the learner based on deep knowledge of a topic and process, having learned through apprenticeship themselves. In the digital context, being an expert alone does not qualify the experienced other to support apprentice growth. A modern apprenticeship includes the intentional development of experienced others to support the apprentice.

In Accenture's model, five experienced others interact in formalized roles with the apprentice. The model includes a peer mentor, project supervisor, people lead, apprentice champion, and human resources partner. Each experienced other are provided training on the mechanisms and goals of the program, expectations of their role in the apprentice experience, coaching skills, and a structure for working with each apprentice.

Learning towards flexibility

Teaching skills deeply embedded in a specific job context can make it harder to transfer them to other performance environments. This works well when apprenticeships focus on craft expertise that was narrow and situated. However, apprentices in modern programs need to be empowered to transfer learning across contexts and roles (Lobato, 2012). They need framing to presuppose knowledge can be transferred to different contexts and novel problems (Engle, Lam, Meyer, & Nix 2012.). Learning towards flexibility refers to the awareness of the diverse use of skills and knowledge across contexts or to novel problems.

Accenture realized that to be successful, apprentices need to take past experience and learnings from formal and informal training and apply it across different roles, varying projects, and divergent client contexts. Apprentices work with experienced others to complete their internal resumes, including identifying transferrable skills from past work, such as customer experience, data analysis, and risk management skills from work in a restaurant. On each new project, apprentices bring forward existing skills, often into a new context, such as industry, and layer on new skills specific to work at hand.

Throughout the program, apprentices are given time to reflect explicitly on this question and seek input from their experienced others. During these reflections, apprentices often hear from experienced others how their learning can apply to other areas of interest, priority areas for the business, and in the external market; this reinforces the importance of flexibility for their continued success.

Learning with agency

A shift from traditional to modern apprenticeship programs is that they must prioritize enabling agentic behavior from learners (Nolen, Horn & Ward, 2015). In times past, obedience has been valued above agentic behaviors. However, modern apprenticeship programs prepare workers for professional roles in a digital era. To thrive in this context, construct new knowledge, develop expertise, and know when to apply it, learners need to be agentive by combining these three factors – the learning environment, the experienced others, and the apprentice (Grotzer, Gonzalez, & Forshaw. 2021 & Duckworth, et al. 2009). Learning with agency refers to the combined role of the learning environment, experienced others, and apprentice to prioritize agentic behavior from motivated and self-efficacious learners (Nolen, Horn & Ward, 2015., Bandura, 1994).

Accenture actively seeks individuals with that proclivity in the hiring process and emphasizes this skill by offering self-advocacy training modules. Once in the program, apprentices can influence how they get involved, within and beyond their project assignment, and have the flexibility to seek learning opportunities that align with their goals. In addition, experienced others give feedback, and prompt reflection.

Agency in apprentices' on-the-job learning is also critical. In the most recent program participant survey, 74% reported feeling empowered to own the work assigned in month three and 87% in month 10, indicating a high and increasing sense of control as the program progresses. Safety and risk tolerance is supported by establishing clear guidelines for escalating issues with the apprentice and experienced others, normalizing asking for help, and regular feedback.

Next steps

As we continue working together in our practitioner-led context, our work is evolving more towards a Design-Based Implementation Research approach where we will leverage our joint focus on this work to inform the iterative design of the Pedagogy of Modern Apprenticeship and how each feature manifests in the development and deployment of the Accenture North America Apprenticeship Program.

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Debugging Debugging Instruction: A Research-Practice Partnership in K-8 Computer Science Education

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Abstract: Through a collaboration between a Minnesota-based CS education non-profit, learning scientists, and elementary and middle-school CS educators, we are collaborating to envision new ways to support students with the frequent impasses they experience when writing code. In this paper, we describe how we worked toward recognizing problems of practice, built on prior interaction analyses of classroom discourse, assembled a team of CS educators, developed (and critiqued) our shared language around debugging, articulated our rationale for particular learning designs, and calibrated our approach. We hope this paper serves as one concrete and generative example of how to use classroom-based interaction analyses as points of departure for empowering teacher-driven pedagogical imaginings.

Introduction

This paper provides a snapshot of an emerging research-practice partnership (RPP) between Code Savvy, a non-profit computer-science (CS) education organization (represented by Andrea Wilson Vasquez), Minnesota CS educators, and learning scientists studying debugging (David DeLiema, Jeff Bye, Megan Goeke). Our ongoing RPP centers CS educators in the discovery and specification of problems of practice and pedagogical approaches that draw inspiration from a previously underemphasized dynamic in debugging education: students and teachers select, modify, and discuss debugging pathways among many valid possibilities, including when noticing problems, positioning causes, and pursuing fixes (DeLiema et al., 2021).

Practitioner context: Code savvy and experience with debugging pedagogy

Our RPP is rooted in the work of Code Savvy, who has recognized that CS education is severely under-supported in Minnesota. Across the U.S., there is increasing demand for and interest in CS skills; but in Minnesota, where most of the people born in-state stay for their adult lives, there is a particular need to increase support for local development of a CS-informed community. Currently, Minnesota has no state standards regarding CS, and only 21% of Minnesota high schools offer any CS courses, placing Minnesota last of all 50 states in CS offerings (Code.org et al., 2022). Where CS is offered, these teachers tend to be the only CS educators in their school, district, or in some cases, geographic region. Unlike more common subjects, CS teachers in Minnesota cannot turn to their immediate teacher network for CS education support. Code Savvy was established in 2013 to address the specific, intersecting concerns in Minnesota CS education: lack of curricular guidance, isolation of CS teachers, and lack of access to CS educational opportunities, which collectively increase risk of inequitable CS experiences for Minnesota's young people. Driven by the goal of expanding equitable and engaging CS education, Code Savvy supports a network of CS educators across Minnesota ranging from full-time high school CS teachers to elementary teachers integrating CS into existing curriculum through a variety of professional development (PD) opportunities. The PD community serves as a support system for Minnesota's CS educators, acting as a place to articulate why to teach CS, how to teach CS, and how to navigate administrative structures. Currently 625 teachers strong, Code Savvy - with sustained leadership from Andrea between 2015 and 2023 - is uniquely positioned to both understand the needs and priorities of Minnesota's CS educators and to support dissemination of critical CS education findings.

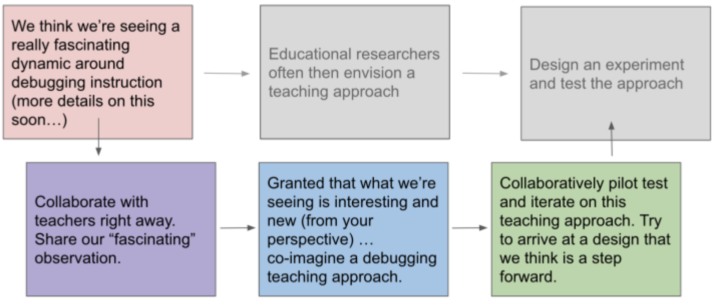
Andrea's personal experience across 10 years invested in CS education is that debugging receives the least attention in PD sessions with CS educators. Debugging, which roughly speaking is the process of noticing problems, searching for causes, and implementing fixes, is an essential and common part of programming teaching and learning (McCauley et al., 2010), and a practice that is often backgrounded in formal CS education spaces (Perscheid et al., 2017). When she started teaching at a high school makerspace, Andrea had to develop techniques for teaching students how to learn from debugging, and recognized that supporting students to develop strong debugging skills was an essential part of the classroom's culture of belonging – as all students will experience moments of impasse during coding. Knowing that in Minnesota we have limited chances to engage students with CS, it is our ethical responsibility to ensure that when students are in our CS classrooms, they are fully supported and included. Generating practical support for teaching debugging is directly related to expanding equitable and engaging CS education.

RPP origin story

Debugging was equally a topic of interest among our RPP's learning scientists. Attending to the existing debugging research literature (e.g., Fields et al., 2021) and using interaction analyses (e.g., Jordan & Henderson, 1995) of teacher-student discourse during debugging in naturalistics classroom settings, our earlier work had led to a framework that emphasized the open-ended process of teachers and students altering, foregrounding, and explicitly discussing different debugging pathways (DeLiema et al., 2021). That is, in many debugging situations, teachers and students have a wide range of pathways they can take through noticing problems, implicating causes, and pursuing fixes. For ease of reference, we refer to this as the debugging pathways framework. Andrea invited the learning sciences team to share the debugging pathways framework with the Code Savvy CS educator cohort she was leading, and we repeated this process annually over three years. Each time, we were struck by the CS educators' expansive reflections on debugging in ways that far-extended the framework and how it could inform pedagogy. Inspired by educational research that decenters research priorities and foregrounds participants' goals (e.g., Bang & Vossoughi, 2016), we pursued grant funding (see Acknowledgments section) and started to work together on a plan to turn these short sessions with Code Savvy cohorts into a sustained collaboration. We pursued this collaboration for several reasons: (a) debugging has persisted as a problem of practice both for teachers and educational researchers across several decades; (b) the pedagogical horizon opened up by the debugging pathways framework was vast and our team felt it was essential to center teachers' perspectives on where to take pedagogical designs; (c) our partner teachers were interested in investing time reflecting on debugging pedagogy; and (d) in our earlier Code Savvy sessions, teachers had both expressed interest in thinking with the debugging pathways framework and developed ideas about pedagogy that they signaled would be new to their classrooms and worth pursuing.

Moving into our RPP work, we held researchers' humility to educator expertise as a core value. Figure 1 is a screenshot of a flow chart we used to communicate this value and process to the CS educators in our RPP. We anchored this value in four additional design choices. First, in part to stave off too-early ideological convergence (e.g., Philip et al., 2017), we framed the debugging pathways framework as a draft fully open to revision. Second, we emphasized opportunities for educators to look at video data of programming classrooms and offer their own insights. While a rich tradition of video-viewing exists for teacher professional development (e.g., Sherin & van Es, 2005), we diverged from those efforts in that we did not have an intended learning goal or valued way of noticing classroom experiences in these data sessions. Third, we made concerted efforts to center teacher voice. All workshops prioritized time for our RPP leadership team to listen to the discussion and reflections of our CS educator collaborators. Fourth, we held back from quickly centering a specific problem of practice. That is, we viewed the debugging pathways framework as a provocation to both find new problems of practice and spark novel pedagogical approaches.

Figure 1
Framing in color our collaborative work in the RPP, contrasted with "top-down" research paths in gray.



We think we're seeing a really fascinating dynamic around debugging instruction (more details on this soon…)

Educational researchers often then envision a teaching approach

Design an experiment and test the approach

Collaborate with teachers right away. Share our "fascinating" observation.

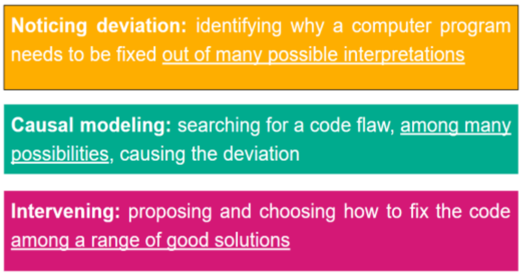
Granted that what we're seeing is interesting and new (from your perspective) … co-imagine a debugging teaching approach.

Collaboratively pilot test and iterate on this teaching approach. Try to arrive at a design that we think is a step forward.

Workshop design

Our approach to workshop design reflects the tradition of participatory design-based research (Bang & Vossoughi, 2016), in which researchers develop pedagogical approaches in close collaboration with teachers, paying attention to problems of practice centered by educators, power dynamics within the team, and design solutions proposed by the educators, through iterative stages of implementation, data collection, and analysis. The workshops were designed as a year-long series with 5-7 CS teachers working with different aged students. Most of the teachers who ended up joining had found out about the RPP because they had checked a box on a short survey expressing their interest in hearing about research opportunities following our earlier Code Savvy PD workshops. The remaining teachers knew Andrea through her CS education network. All teachers received stipends for their time in the workshops. In the first session, David and Jeff planned to introduce Figure 1 (above), make space to talk about the overarching goals of the RPP, and share the debugging pathways framework (see Figure 2 for a simplified version), which they had developed with Vijay Marupudi. This was meant to provide a perspective, language, and empirical focus on debugging that we hoped would unsettle the typical backgrounding of debugging in professional learning communities and provide a provocation for discussion about debugging pedagogy. In this way, the prior interaction analyses and framework (DeLiema et al., 2021) served as a point of departure for inquiry, not a pedagogical prescription. In sessions 2-4, we planned for our teacher collaborators to look at video data of students debugging, interpret the video, and discuss ideas for approaching scaffolding of student debugging. During these later sessions, we planned to have our RPP leadership team collaborate with the teachers to develop and iteratively revise conjecture maps: visual devices that provide an argument around a theory of design, short-term processes observable in the classroom, and valued long-term outcomes (Sandoval, 2014). This approach drew on prior work involving collaborative conjecture mapping in CS education (e.g., Lee et al., 2022). We planned to invite the teachers to pilot approaches in their own classrooms, documenting the results and their own reflections in iterations to the conjecture maps. After piloting, the entire RPP would have two additional sessions to consolidate the classroom pilots into a single unified conjecture map.

Figure 2
Debugging Pathways Framework



Noticing deviation: identifying why a computer program needs to be fixed out of many possible interpretations

Causal modeling: searching for a code flaw, among many possibilities, causing the deviation

Intervening: proposing and choosing how to fix the code among a range of good solutions

Implementation

Alongside 4 middle school CS educators and 1 first-grade CS educator, we have completed the first 4 workshop sessions and will soon begin classroom pilot work. In this reflection, we focus on two shifts in our process that took place during implementation and that are critical to the work of our RPP. First, we had intended to share the debugging pathways framework as a draft and then shift to envisioning pedagogical approaches. However, as the CS educators in our RPP reflected on the framework and applied this lens in video data sessions, the conversation kept returning to the framework as educators argued about its meaning and potential. In these arguments, CS educators critiqued both the focal terms in the framework (e.g., "my students would look at me sideways" if we used the word "deviation" in the classroom) and assumptions about the linear flow between these steps, even while embracing the notion that debugging in the framework was considerably more open-ended than traditional debugging models conveyed. To welcome this critique, David noted at the beginning of each workshop that we had put the "fascinating" interaction analysis observations from research in scare quotes in order to understand what the educators in our RPP made of these open-ended debugging dynamics. This shift pointed to fundamental questions about how to position interaction analysis in RPPs to stoke conversation while ensuring they are still treated as flexible representations in need of fine-tuning.

Second, we changed the structure of the fourth workshop from a group conversation to individual conversations with each CS educator. We had noticed that the framework sparked a wide range of learning design proposals, but the collaborative workshops did not provide enough space for each educator to unpack these imaginings; instead, discussions during group conversations leaned into contrasts between specific learning design proposals and contexts (e.g., noticing that an exercise wouldn't work in a particular classroom). In short, the substantial heterogeneity in learning design proposals left little space for deeper commonalities to be noticed and named in the moment. Shifting both our process and our goal, we moved toward individual conversations with CS educators to allow for each educator to articulate their thoughts in greater depth, without needing to connect to others' ideas in the moment. We introduced the conjecture map representation in each of these individual sessions and gave time to each educator to start assembling a process-based argument for why a particular debugging pedagogy might work and toward what ends.

Current results

We held a collaborative data session among the RPP leadership team following these individual meetings, with each leader 'representing' the conjecture map from one educator. We examined commonalities across disparate maps to glean a common pedagogical vision. Instead of arriving at a shared pedagogical approach (e.g., specific tools, curricula, pedagogical moves), we recognized shared lenses guiding specific designs. Megan further refined these notes into 4 lenses that stretched across all educators' unique pedagogical visions around debugging. (1) *Nonlinearity* captured how debugging involves engagement with – but not necessarily sequential progression between – the 3 framework steps. (2) *Future orientation* focused on making space to connect a current debugging solution to potential future codes and bugs. (3) *Community of support* addressed classroom teachers and students as a debugging support team. (4) *Multiplicity* focused on celebrating multiple, heterogeneous approaches to debugging. Our next step is to discuss these themes as a full RPP team, allow each educator space to assess whether their approach is captured by all 4 lenses (and what may be missing), and then consider what purchase they provide for refining each educator's unique pedagogy before classroom pilots.

Conclusion

Our RPP has embraced a process of flexibility and balance. Our approach has taken seriously a problem of practice noticed by a CS education non-profit and responded to a re-framing of debugging from learning sciences scholarship. At the same time, we made space to critique that prior research (including our own) and allow for considerably more individual expression of debugging pedagogies, even while we have worked to glean common lenses across these unique conjectures. As we work together to envision expansive forms of supporting debugging, we are committed to continuing to level the power between our non-profit leaders, learning scientists, and CS educators, working toward a common, ambitious vision for supporting students that makes possible individual forms of pedagogical expression and fully embraces the expertise of educators.

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Amalgamation of Narrative Discourse and Maker-Spaces as a Tool for Critical Pedagogy

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Abstract: We run a contextual and cultural maker-spaces in two villages of Uttar Pradesh. The vision of the maker spaces is to have a discourse around critical pedagogy as envisioned by Paulo Freire : social justice, student empowerment, co-construction of knowledge, and critical thinking. In the village, the 12-16 yr old learners study in affordable private schools after completing their elementary education from government school which wasn’t the case earlier. Families are engaged in agriculture, young boys migrate at the age of 10-12 years to West India. Girls are generally married at the age of 13-14 years. This vicious cycle of marriage, birth and livelihood doesn’t allow the mindset to change. In this paper, we will explore how in the above context narrative discourse when integrated with the maker-spaces acted as a tool for critical pedagogy.

Design and implementation

Looking at the context of Ramdwari, the possibilities of change seemed very few and extremely far. There is monotony around with the same routine year after year which led us to question — What’s to be done? We thought of narrative discourse pedagogy as students seemed to be excited by stories. Therefore, we thought of bringing powerful ideas which are similar in nature. With these stories, we felt that the students and community members would see some hope through the change that has happened in similar communities in different geographies. But, to get inspired is not the only thing. One has to think a little deeper into it. One has to identify the problem in their context, have the courage to challenge the status quo, discuss alternatives and find a solution.

To perform prototyping of ideas, we set up contextual and cultural maker spaces in which contextual objects could be repurposed, re-imagined, altered, added or modified so as to bring some ideas in action for social transformation and a positive cultural change.

In this particular project we started with the narrative discourse based on the story ‘cycle par sawaar auratein ’(translation — women riding bicycles). The story is about cycling as a women’s movement in rural Tamil Nadu, an article published in People Archives of Rural India. The whole phenomenon was the brainchild of the popular former district collector, Sheela Rani Chunkath. Her idea in 1991 was to train female activists so that literacy would reach women in the interior. She also included mobility as a part of the literacy drive. This flowed from the fact that a lack of mobility among women played a big role in undermining their confidence.

The story was chosen because girls ’freedom in the Ramdwari community was frowned upon. The girls ’ were not allowed to go and study outside their village after completing grade 8 from a government school. From the story, discussions erupted around gender inequalities as boys were allowed to go outside the village. From the discussion it moved to various problems or issues faced by the children everyday that are there in the community which gave us generative themes to work in the maker-space. Another point which got discussed was around the role of a bicycle as an emancipatory tool.

This led to a question that -- can bicycles act as a tool for social change other than providing access for mobility? To explore this question and deep-dive into generative themes we as facilitators designed sessions under three domains -- looking closely, exploring contextual objects, finding solutions.Even the simplest objects reflect the culture and more importantly the context (social and physical) in which they were created as well as the contexts in which they continue to be used. A close observation of these everyday objects not only sparks students ’curiosity but leads to increasingly complex thinking.

In the first session, the students were asked to observe a bicycle and draw its systems and subsystems. In this exercise, the students analyzed the various parts, its purpose and the correlation between them. The students drew detailed sketches of the bicycle and started co-relating various sub-parts based on speed, safety, comfort, etc. They also figured English alphabets while observing the shapes of parts or sub-parts. The students observed the minutest details, one of them being the study of why the front sprocket is bigger and the sprocket in the rear wheel is small?

When the students were observing the parts and subparts, one question emerged whether any of the subsystems can be used as a system in itself or a part of a different system. Further exploration emerged and we moved to doing take-apart the bicycles. Students have to dismantle an old cycle in 1.5 hours and then assemble it back in the next 1.5 hours in teams of 4. Proper tools like hammer, screwdriver, wrench, and spanner were arranged. This activity has been done after previous sessions on cycle where we had a lot of discussions and observations around the cycle. But then learning can be enhanced when we use our hands rather than ears. Multiple science concepts are covered in a cycle like force, transmission of force, work energy, speed, momentum, circular motion, friction, energy, center of mass, moment of inertia, torque, stability, spring, mass distribution, etc. As a single cycle can be used to explain so much of science, why not open it and understand the details of it.

Initially we thought that since the cycles are old and have lots of rust on nuts and bolts, the dismantling part would be tougher and once it is done, the students will assemble it back in half of the time. But we were wrong. They learnt more about mechanisms and observed little details during the assembling part of the task.

This is because while dismantling they were in a hurry or chip off the parts which were not coming easily and hence those distorted parts caused a lot of troubles. Some parts require special tools and such jobs can be only done by them. Hence normal tools took a lot of time.

The other factor is that the assembling process demands more focus from the students. For example - both the wheels of the cycle are very different from each other. But the general image is that a wheel is a wheel. 2 out of 4 groups put the front wheel to the rear side and when they had to put the chain on it, they realised their mistake and dismantled it once again. Then the students explored the mechanism of chain sprocket, brake by paper and locally available materials. This exploration led to a discussion around tools and objects in the community which use similar mechanisms or in certain cases the parts of the bicycle.

To converge both the things — generative themes and the explorations done on the bicycle as a contextual tool, the students were divided into different groups according to their interest, issue that they wanted to work on.

In each group, the students researched on their problem at hand and ideated solutions around them using the various mechanisms of the bicycle. Thereafter they did prototyping on one idea selected by them. Some of the ideas are:

- Group One thought that cutting grass/weeds on the agricultural field is always a problem. Therefore the group thought that if she attached a sharp blade from the front hub of the bicycle then she and others could easily cut the small and medium size grass/weeds by manoeuvring the handlebars of the bicycle. This will take less time and less effort and would cut the grass from the roots easily.
- Group Two has made a model to cut the grass/fodder with an attached bicycle. The same structure is available which runs on electricity but since there is an erratic supply of electricity in the village, the student thought of making a design which can work with bicycles. The grass/fodder which after cutting can be given to livestock as food for their nutrition.
- Group three attached a wiper through the front part of the wheel. During rains when the drains overflow, it becomes very difficult to ride the bicycle on swampy roads. Through this innovation when you are riding the bicycle, the sludge and the mud on the road could be moved to the sides of the road allowing movement on the bicycle. This could also prevent accidents due to balancing issues.
- Group four made a bicycle-enabled handpump in which instead of a handle the pump rod is attached with the crank of the bicycle. When one pedals, the crank moves which in-turn helps in moving the piston rod. When the piston rod moves up and down it helps in taking water out from the outlet thereby reducing the time and effort.
- Group five thought of attaching an umbrella on the top of a bicycle and a plastic sheet at the back so that the girls of Ramdwari could attend school during rainy days. The umbrella covered their body and the plastic sheet covered their bags.

Figure 1

The students taking-apart the parts of the bicycle (Right); The students have made a bicycle-enabled fodder cutting machine (Left)

After multiple rounds of talks and testing in the community, two of the projects were finally made and put to use for the community. The two projects were bicycle-enabled fodder cutting machine and an umbrella on a bicycle.

Cycle as an object offered a tactile experience for students, which challenged them to observe and conceptualise their thinking. While the teacher facilitates the session, the students construct meaning for themselves through their interactions with each other centred around the object (Hannan et al. 2013).

The problems students came across after the narrative discourse pedagogy did not only restrict to problems of their individual lives but also the problems faced in their communities for an extremely long period of time. This exercise enabled them to challenge the status quo, put some ideas together and test them for its workability in the maker-space. Therefore, maker-spaces and narrative pedagogy act as an outstanding tool for critical pedagogy.

Reflections

What we have experienced in these years working with the community and children is that narrative discourse pedagogy is deep rooted in critical pedagogy which critiques the dominant knowledge within curriculum. It critically examines inequalities in society and focuses on tools to develop critical consciousness, agency and empowerment through a problem posing approach in a learning context.

Bruner had mentioned that narratives are fundamental to human learning and act as a meaning-making tool with great pedagogical potential. The narrative discourse supports the identification of a contextual object through which students started to deep-dive as well as nurture the abilities around questioning and challenging the status quo among the community. The explorations in the maker-space supported the meaning-making process. As the narrative pedagogy built the reasoning skills among the students, the maker-spaces hold the power of perspective taking while devising solutions for the problems. This amalgamated approach led to high-level thinking that is central to making which is geared towards social transformation.

The narrative discourse as the starting point also changes the trajectory from the focus on finished product to the process of making. The process of design follows a linear structure, starting with ideas and ending in a re-presented material form; this is why the students in two groups initially struggled to align their approaches with creative collaboration. This changed through a playful, exploratory approach to the materials, take apart and mechanism exploration. Thus this amalgamation also emphasises the social, multi-sensory and affective aspects of exploring materials.

The process in the maker-space led to interactions among students which generated a lot of stories emphasising the rhetorical power of storytelling. In this case, ‘cycle par sawaar aurtein ’story illustrated how narrative could be used to make sense of questioning the status quo and connecting solutions for real world problems. Purposefully eliciting narratives from students that are related to problems closer to their worlds would likely resonate more powerfully, fostering a sense of ownership and identities among children as problem solvers.

In this sense, although situated at a micro level of interaction, this study also look sup-stream to connect to maker-spaces and stories based on notions of empowerment and participation in cultural change.

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Becoming CORE: The Story of a Community-Based Informal STEM Program

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Abstract: The Community Outreach, Retention, and Engagement (CORE) program is a community-based, informal STEM program designed for multicultural students and families in the Twin Cities area. We aim to build a more inclusive STEM field systemically, and our goal is for students to engage in STEM long-term through pursuing their own STEM pathway. We designed a culturally-relevant and holistic program, and we implement our programming with the FACE of CORE – *F*amily engagement, *A*cademic support and social-emotional learning, *C*ollege and career readiness, and *E*xposure to the STEM ecosystem through hands-on experiences. In less than two years, we have used systems of reflection and feedback to increase our participation and improve the quality of our programming, both of which positively impact CORE students and families.

Introduction

The Community Outreach, Retention, and Engagement (CORE) program is a community-based, informal STEM program housed within the Office for Equity and Diversity at the University of Minnesota. The CORE program provides free high-quality STEM programming for multicultural students and families in the Twin Cities area. Students join CORE in middle school and continue until the end of high school with the cohort model. Our goal for this paper is to tell the story of how we *became CORE* within our first two years by building on the structure and goals of previous versions of our program, adapting the model to meet our current needs, and embodying the newest version of the program to successfully serve our students and families. The process of *becoming CORE* began in spring 2021, when Audrey Breland was hired as the Program Director and immediately started bringing the program model to life. She built relationships with local schools, recruited students from partner schools, and connected with university faculty to provide STEM programming, all of which propelled us into a successful first year of programming in 2021-2022.

Our second year (2022-2023) of programming was facilitated by seven members of Team CORE. CORE is led by our program director and supported by the leadership team (Seth Thompson and Keisha Varma). CORE is enacted on-the-ground by four graduate assistants (Marisa Peczuh, Delina Brown-Jackson, Nawal Maxamed, and Otiti Mayo), each of whom take responsibility for one primary area of programming – STEM engagements, event logistics and CORE Crew, family communication, and media and marketing, respectively. Our program serves 126 students in grades 6-9 of diverse races and ethnicities – 95 Black, African, or African American; 11 Asian or Asian American; 7 Hispanic or Latino/a; 1 American Indian or Alaskan Native; 9 white; and 3 families who elected not to respond. In our two years as a team, we have continued to build from our program's foundation, reflected on our first and second years, and improved in our programming. We have aligned our objectives, design, and implementation, and we aim to share our model and best practices with others working in informal STEM settings.

Objectives

The overarching objective of CORE is to shift the culture of STEM at a systems-level to be more equitable and inclusive for multicultural students and families. Although our program welcomes all students, our program is designed for multicultural students. We consider students who identify as African American, Hispanic/Latino, Asian American and Pacific Islander, Native American, Hmong, Somali, and/or multiracial as multicultural. We focus on multicultural students because they are woefully underrepresented in STEM fields (National Center for Science and Engineering Statistics, 2021), not for lack of interest in pursuing STEM, but because of the historical practices that have systematically excluded these students (McGee, 2020). Our objective is to reimagine how STEM fields themselves, which have been white-normed over centuries of development (McGee, 2020), can serve the needs of an increasingly diverse population (Honey et al., 2020). Our first system of focus is at the university level. We collaborate with many STEM faculty and departments within our programming, and we work with these groups to reimagine how STEM at the university can further engage in the community and be culturally relevant. Ultimately, we aim to create a more equitable university STEM ecosystem through these partnerships.

At the program level, we have two further objectives. As an informal STEM program, our goal is to promote students' retention and engagement in STEM to contribute to a more diverse STEM field in the future. Specifically, we aim for students to graduate from high school, matriculate, and be retained in college in a STEM or STEM-adjacent field, and develop STEM career aspirations (Chen, 2013; Chittum et al., 2017). Within this objective, there are many possible pathways, such as choosing a STEM field, type of college (two- or four-year), and career. We empower students and families with information, opportunities, support, and agency to meet their individual goals within the general discipline of STEM.

Design

The CORE program is designed to move beyond a single focus on STEM by creating STEM experiences that are community-based, culturally relevant, and holistic. We collaborate with school principals, STEM educators, and family liaisons to learn about our partners' and families' needs, and we adapt our program accordingly. We are culturally relevant by valuing and integrating aspects of students' cultures into our programming (National Academies of Sciences, Engineering, and Medicine, 2015; Simpkins et al., 2017). We take a holistic approach by acknowledging that students' participation in STEM goes beyond interest in STEM to include other aspects of students' lives socially and emotionally (National Academies of Sciences, Engineering, and Medicine, 2015). Then, we work with STEM partners (e.g., faculty, departments, institutes) across the university to provide scaffolded STEM programming over seven years through our COREXperience model, which was developed by our program director to reflect the longitudinal experiences of CORE students. We recruit students in grades 6-8 to begin as COREXplorers, where students are exposed to a wide range of STEM majors and fields to foster interest. As students continue to participate in CORE, they become CORE Scholars in grades 9-12, where they narrow their interests and receive more intentional opportunities for college preparation and career readiness. Throughout this time, all students participate in hands-on STEM engagements, career pathways exploration, mentorship, and social-emotional learning. The design of our program promotes continuous exposure to new STEM experiences while also allowing students to develop individual passions.

Implementation

The FACE of CORE

While CORE generally aims to implement community-based STEM programming, our program director created the FACE of CORE to represent the pillars of our programming and focus our implementation – *F*amily engagement, *A*cademic support and social-emotional learning, *C*ollege and career readiness, and *E*xposure to the STEM ecosystem through hands-on experiences. First, we intentionally include families in our programming as key contributors in students' lives and participation in STEM (Sha et al., 2016). Our definition of family is broad, and we encourage students to bring important adult figures to events if their parents are unable to attend. For example, many of our students are accompanied by their school's family liaison. During events, students participate in activities alongside their family members, allowing them to learn and grow together. Our family engagement is culturally-relevant. We communicate in multiple modalities (i.e., text and email) and languages (i.e., Somali and English) when necessary. We also send a monthly newsletter to share additional information about CORE, review past and upcoming events, and provide conversation starters.

Second, CORE focuses on academic support and social-emotional learning in two main ways. We recruit undergraduate and graduate students to our CORE Crew, who serve as mentors to our CORE students (Afghani et al., 2013), in both paid and volunteer capacities. These students provide hands-on support at events, assist with STEM activities, and talk with students and families about their experiences. We also foster social-emotional learning through intentional programming to build students' self-efficacy, resilience and perseverance, goal setting, and positive identity within STEM (Jagers et al., 2019). Students have learned about stories of challenge and success (Lin-Siegler et al., 2016) as experienced by scientists of color, and students participated in an activity where they made a collage about their lives in ten years – a time when they will likely be obtaining their first higher education degree and considering career pathways.

Third, we offer college preparation and career readiness information for students and families. CORE Crew members share about their college and STEM experiences through Lunch and Learn Panels or Mentor Mingling at our events. These are powerful opportunities for students to learn about real student stories as well as gain access to informal mentoring. Undergraduate students are also likely to benefit from these experiences, such as developing life skills (Afghani et al., 2013). We also ask our STEM partners (to be discussed in the next paragraph) to illustrate their STEM stories by sharing about their personal and professional pathways from high school to their current role. This provides students with additional vocabulary and knowledge about the steps necessary to reach their STEM-related goals.

Finally, we provide students exposure to STEM at the university through engaging and hands-on learning experiences (National Academies of Sciences, Engineering, and Medicine, 2015). We have created a coordinated STEM ecosystem, composed of CORE collaborations and partnerships with existing STEM programs, to deliver an unparalleled scope of STEM programming for CORE students. We developed a K-12 STEM Opportunity Repository to document all STEM departments, institutes, outreach efforts, student groups, and more at the university to further connect this ecosystem. We have embraced that CORE is an asset to other STEM programs at the university, and we make new partnerships by reaching out to groups from the repository, describing our "asks," and offering partners "takeaways" that will contribute to their goals. Through meetings with these partners, we build strong, grassroots collaborations and plan for ways that the STEM partners can facilitate STEM engagements at our events. When working with STEM partners for a specific event, we provide feedback pre- and post-event based on our experiences, which provides them with the confidence to facilitate high-quality programming for our students and families. Therefore, CORE acts as a liaison to ensure that multicultural students and families know about the university's STEM programs and are supported in identifying, enrolling, and fully participating in them, whether at CORE events or beyond. This model avoids creating another set of exploration experiences for students in a saturated STEM ecosystem at the university. Instead, we focus on coordinating and enhancing the programming that already exists by crossing boundaries and building bridges. By partnering with these existing programs, CORE can focus on investing additional resources into academic support, social-emotional learning, and college and career readiness.

CORE programming

CORE's Family Engagement Programming implements the FACE of CORE through monthly events, including Fall and Spring Kickoffs, Saturday Scholars, Individual Growth Plan (IGP) conferences, and field trips. First, our Kickoff Events are like STEM fairs, where students and families visit booths and participate in various STEM activities. Second, Saturday Scholars are our signature events for four hours on two Saturday mornings each semester. Students participate in STEM activities, social-emotional learning lessons, and Lunch and Learn sessions, providing a holistic experience throughout the day. IGP conferences are individual meetings between students and the program staff to check-in, discuss personal strengths and weaknesses, and create intentional college and career plans. We also facilitate at least one field trip a year, where students are able to experience STEM outside of a classroom setting. Our typical programming occurs on campus, and during field trips, students are able to experience STEM in new settings off campus. In an effort to make the program accessible and culturally relevant, not only are these events free, we also provide meals, parking vouchers, and transportation. We have also implemented the CORE Roadshow as an effort for CORE to reach a greater number of students in the Twin Cities and to continue bridging schools and the university. During the CORE Roadshow, CORE plans STEM engagement opportunities with partner schools, and CORE STEM partners visit the schools in ways that meet each school's individual needs.

Lessons learned

In less than two years of programming, CORE has enhanced our programming in a number of ways. We have learned from the success of our program and also remain flexible for continuous opportunities for improvement. We use internal and external feedback to adjust our programming to further *become CORE* and meet the needs of our students and families. First, as a team, we debrief every event using a DNA Analysis, where we describe our *D*istinguishing practices, *N*eeds, and *A*ction steps. This routine allows us to share successes and challenges during our events, and we are able to make practice-based decisions at a fast pace to implement enhanced practices at subsequent events. Second, we use feedback from our students and families via sCORE Cards. Our sCORE Cards include questions about what students learned and enjoyed about the event, and families can rank their experiences from 1-5 on the FACE of CORE. With these responses, we are able to better understand the experiences of our students and families and adapt to programming according to their feedback.

Using these systems for improvement, we have found that our greatest success and challenge is the growth of the program, particularly in the number of students and families. First, we have realized the difficulties of coordinating events for a large group of people, but we have been able to think of creative logistical solutions (i.e., having rotating stations) and implement specific practices with STEM partners (i.e., meeting more frequently) to position STEM engagements for success. Second, providing individualized support for students requires significant time and effort. Therefore, we have shifted our focus to creating differentiated and personalized experiences, particularly for students in grades 10-12, beyond STEM via "More CORE." Students in each of these cohorts will be paired with Team CORE and CORE Crew members that will remain consistent throughout the year, allowing for a more relationship-based approach. Additionally, we will design a curriculum focused on *A*cademic support, social-emotional learning, *C*ollege preparation, and career readiness to prepare students in achieving their individual goals.

Relevance for others

We have highlighted many aspects of CORE's unique approach, and we believe certain components of the model could be useful for practitioners providing informal STEM programming for multicultural students and families. First, our partnership model, both at the local and university level, is one in which other programs could adopt. We have worked collaboratively with partner schools to meet their needs and improve our programming, which ultimately supports students across settings (National Academies of Sciences, Engineering, and Medicine, 2015). We have also bridged existing resources at the university, which allows for collaboration across the university and exposes students to a wide range of experiences. Second, we redefine STEM at both systems and local levels. We are changing the culture of STEM at the university by focusing on cultural relevance and inclusion, rather than simply recruitment. We have also developed a STEM program that is holistic by acknowledging students' academic, social, and emotional needs to ultimately support their long-term pathways in college and careers.

Our purpose in writing this paper was to describe how we have *become CORE* in two years of programming. Our objectives and design have served as a foundation, and we have implemented adaptable practices to meet the needs of our partners and best serve our students. We look forward to serving many more multicultural students and families in our loca area and supporting them in participating in a more equitable and inclusive STEM field in the future.

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The Makerspace as a Catalyst for Community Building and Innovative Pedagogies Beyond Stem

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Abstract: The presence of makerspaces, that have been implemented with the idea of advancing science education in a city in Northeastern Brazil, have also catalyzed new connections between teachers, and integration of other disciplines into the makerspaces while spreading innovative pedagogies in lessons beyond STEM disciplines. The goal of this paper is to illustrate the development of a collaboration process between a makerspace and a Portuguese teacher who co-designed a learning sequence related to text types such as narrative, descriptive, expository and argumentative writing, for students to learn, in the makerspace, with their hands-on and minds-in. This paper also highlights the challenges of implementation as well as the takeaways and learnings from this process, that most of all helped teachers realize the potential of co-designing and using new spaces and resources to create environments where learning goals are achieved while maker- and student-centered learning is present.

Introduction / objectives

An integrated effort to design new science standards, implement makerspaces and a professional development program for makerspace and science teachers to promote more practice-based science teaching and learning has been taking place, for the last 5 years, in a city in the Northeast of Brazil (Fernandez, Haegele, Blikstein, 2020). In this context, makerspace teachers and the makerspaces themselves are also becoming a catalyst for school community interaction and innovation in teaching practices beyond STEM disciplines. This paper describes the development process of a learning sequence focused on text types such as narrative, descriptive, expository and argumentative, that was co-designed by the makerspace teacher, the Portuguese teacher and a group of researchers who were working on the implementation of the new science standards within this city's school network. In 9th grade, students approach several communication situations with a more critical stance, and in dialogue with a wider audience, therefore at this stage, the curricular units in writing focus on text types related to action in the public realm, with emphasis on journalistic, opinion, investigative and descriptive writing. The issue of the reliability of information and the proliferation of fake news also has significant relevance in the Portuguese curriculum in this grade (Base Nacional Comum Curricular, 2022). The presence of the makerspace in the school aroused students' interest, and the Portuguese teacher suggested a collaboration with the makerspace teachers to design a new curricular unit related to these text types. Initially, all the Portuguese teacher had envisioned was the possibility of the use of the makerspace for students to engage in research on the internet using the laptops. As soon as the Portuguese teacher approached the makerspace teacher, she organized a meeting, with the researchers as well, to brainstorm possibilities for a hands-on and minds-in learning experience related to text types and writing. As the conversation evolved, so did a co-design process for a whole learning sequence of 6 lessons that aimed at achieving the Portuguese learning goals, while also introducing the students to the makerspace's tools and their creative potential.

In Brazil, the cost per student in public schools is still much below the average of developed countries, approximately US$3800/year as opposed to US$ 8600/year in other countries. (Nova Escola, 2018) In this context, little investments are made in professional development, infrastructure, and teacher salaries. Therefore, few opportunities for co-design, for the implementation of innovative pedagogies and access to digital resources and tools are present. A collaboration as the one described here is not commonplace, which makes it very meaningful, as a case that may spark interest and inspire other educators. The goal of this paper is to illustrate the development of this collaboration between the makerspace and the Portuguese teachers, detail the sequence that was co-designed, and highlight the challenges, as well as the learnings in the process.

Design

The design of this learning sequence on text types began with the curiosity of students about the new makerspace that prompted the Portuguese teacher to approach the makerspace teacher and propose a collaboration. The study of text types and genres arises from the need for communication and sociocultural activities. In Portuguese writing classes it is important to work with students on text types, as it helps in the construction of reading and writing knowledge. Seeking to improve the Portuguese lessons within the skills proposed in the Brazilian national standards (BNCC) the idea was to design a sequence for 9th graders, on this subject, using the makerspace. It was something new for all involved, nonetheless, the makerspace teacher, the Portuguese teacher and the researchers all began to think of a sequence that would engage students with their hands-on and minds-in using the space and resources of the makerspace. It took a few conversations for the Portuguese teacher to realize the goal was to create a learning experience that went beyond using the space for research on laptops, and that students would actually be able to use their hands to interact with and build artifacts that would help them think about and make sense (Papert and Harel, 1991) of the different text types being studied. The design process started with the briefing by the Portuguese teacher to the makerspace teacher and researchers on the main goals and learning expectations for 9th graders related to text types. Through a backward design process (Wiggins & McTighe, 2008), the team began thinking of possibilities where students would engage in a maker-centered experience that could also scaffold the writing of specific pieces in class, after the sessions in the makerspace.

The redesign of traditional classes to a model focused on teaching practices that have principles such as "hands-on" and "minds-in", learning through investigation and the student as the main author in the construction of their own knowledge is not an easy task. The makerspace teacher, in this context, was essential in this process, researching and studying ways to meet the objectives of the Portuguese teacher, within this new teaching perspective and curating materials and kits that would be used throughout the unit. The design of the sequence included 6 lessons, 4 of which happened in the school's makerspace and 2 in class where students engaged in writing activities. The text types explored in this sequence included Narrative, Expository, Descriptive and Argumentative writing. The strategies designed into the learning sequence to explore these different writing genres in the makerspace were:

- The Circle of Inventions, which is a practice that involves reading, making and the sharing of new narratives (Ricci P., Lederman K. S. and Junqueira R. 2019), which was used for the exploration of narratives in the form of chronicles.
- The Parts, Purposes and Complexities thinking routine (Clapp, Ross, Tishman 2017) which was used for students to explore the makerspace, as well as learn about descriptive text types as they wrote a descriptive text about different tools and equipment in the makerspace.
- An unplugged coding lesson, where students had to "program" the teacher to spread butter on a piece of bread, followed by a discussion about expository texts that have to be objective, clear, and logical such as an algorithm, or a recipe.
- The creation of an invitation to all of the school highlighting the benefits of learning in the makerspace, after the thinking routine Making Meaning (Ritchart and Church, 2020) on learning in the makerspace, as a way to practice argumentative writing.

The sequence includes discussion, reflection, instruction and writing after all the hands-on sessions, making sure, throughout the unit students have their hands-on, but also their minds-in the learning process and goals.

Implementation

The implementation of the sequence happened with two different grade 9 groups throughout 6 sessions of 2 hours.

Session 1 - The first session of the sequence, which took place in the makerspace, began with a brief presentation about the makerspace and was followed by a Circle of Inventions to spark a discussion and thinking about Narratives. In this practice students participated in a read aloud of the chronicle "Assalto" by Carlos Drumond de Andrade. Then, engaged in a making moment, prompted to create an artifact that could help them narrate an episode from their lives, that was significant to them, and that contained, as a thread, a misunderstanding, an aspect that was present in the chronicle they had read. In groups, students shared stories and began creating new collective narratives inspired by their own experiences as they "thought" with their hands and created an artifact, such as a prop or a model related to the narrative they thought about. Students used craft materials and simple circuits for this activity. By the end of the session students shared their artifacts and new narratives. The Portuguese teacher listened and asked the students questions about what they noticed, if they saw any connections between the chronicle and the narratives that emerged. She finalized the session formalizing an explanation on Narratives as a text type.

Session 2 - Students also created a Padlet with the images of the artifacts, summaries of the narratives and a reflection about the activity, which was used in class, as inspiration for the writing of a short chronicle. Throughout the sessions, both teachers took notes, made observations and documented the activity. Debriefing the experience, it was surprising for the Portuguese teacher how engaged the students were, even after the making moment, when time came for the reflection, formalization and writing, all students, even the ones who normally are disruptive and not involved were participative. The possibility of bringing their stories to life, concretely, through the creation of an artifact, helped connect students to each other, to themselves and to the subject in a way that brought a sense of confidence, belonging, autonomy and the meaningfulness to the proposed activity (Bondie & Zusho, 2018) which, translated into motivation and engagement.

Session 3 - Once again in the makerspace, students explored different tools and equipment such as Gogo Boards (a low-cost physical programming board), the laser cutter and the 3D printer. Students, organized for group work (Cohen and Lotan, 2017), engaged in a thinking routine called Parts, Purposes and Complexities where all aspects of the object in question had to be explored, in this case the equipment in the makerspace. They first looked closely at all the different parts of the object and wrote them down, then discussed their purposes and finally thought about how these parts and purposes connect to each other. The makerspace teacher then heard their descriptions and spoke a bit about these objects and their potential for learning and creating. The Portuguese teacher used these descriptions of the objects in the makerspace to introduce the topic of descriptive text types.

Session 4 - The strategy used to work on expository text, was a typical unplugged coding activity used to teach about algorithms. As the makerspace is a realm where digital tools are used as creative resources, coding is an important language to be learned, and it was an interesting way to talk about how computers follow instructions while also tackling the topic of expository text, that have to be logical, objective and clear. Students were supposed to give detailed instructions, to the teacher to spread butter on a piece of bread. After a lot of laughter, students finally realized the importance of giving very precise, step by step instructions to the teacher in order to get the results they wanted. This playful activity was a preamble to a presentation by the Portuguese teacher on the expository text types, as well as an introduction to algorithms by the makerspace teacher.

Session 5 - Students came back to the makerspace to reflect upon the experiences and learning they had there. For this the teachers proposed an activity named Making Meaning (Ritchart and Church, 2020), where they had to collectively think, write and connect different ideas, in a mind map format, about learning in the makerspace.

Figure 1

Students during the activities in the makerspace, and writings derived from the hands-on experiences.

Session 6 - These mind maps were used in the final session to help students write a text inviting different teachers and students to use the makerspace. In this piece they used argumentative writing to highlight the benefits and challenges of learning in this space. The sequence was finalized by the Portuguese teacher summarizing their experience and highlighting the aspects of text types planned for the sequence.

Takeaways and learnings

The development, implementation and reflections about this integration between makerspace teacher, Portuguese teacher and researchers, that lead to the development of the textual typologies sequence described above, illustrate how, when an open stance for cooperation as well as time are available for co-planning, new ways of thinking, teaching, learning, and engaging students in the makerspace are possible in fields beyond STEM. This experience points to the need for co-planning time and openness to explore learning possibilities in makerspaces with hands-on and minds-in in all curricular subject areas. The students' engagement throughout the process brought to light the potential of group work, innovative approaches and possibilities of integration between subjects through the work in the makerspace. The integration of the makerspace with writing lessons, enabled a clear perception of the connection between them, as well as led the Portuguese teacher to look beyond the traditional pedagogical practices already used, and realize the construction of knowledge related to language could also take many new forms. The Circles of Inventions, the unplugged algorithm activity, and the parts, purposes, and complexities thinking routine were strategies that allowed for an exploration of the makerspace, of some of its materials and tools while also reaching the Portuguese teacher's objective: to make students able to differentiate and practice writing different text types. Through the strategies used, we observed greater engagement of students, including those with more difficulty in concentration and discipline, which leads us to think that adopting hands-on and minds-in methodologies may increase student participation, in this case, allowing for a wider number of students to be active and participative and also generating learning related to collaboration, making, articulating ideas, telling stories and writing.

Despite having been a successful experience, building interdisciplinary learning experiences within the conceptions proposed by a makerspace is not a simple task. A significant challenge was to find methodological strategies that allowed for the goals of the Portuguese teacher to be achieved while also proposing mindful "hands on" activities. Time for co-planning between the makerspace teacher, the Portuguese teacher and the researchers was sparse and a significant part had to be done asynchronously which demands organization, commitment and a willingness for compromise between the team for the final decisions to be made in time for the implementation. Another point for thought and evaluation is the distribution of time within the proposed activities, as students still have difficulty performing some activities in the makerspace as these are not part of what they usually develop on a daily basis. It would be fruitful for students to have more time in the makerspace to gain more hands-on repertoire. Last but not least, the perception that the makerspace can be a catalyst for innovative pedagogies to spread through the school grew amongst teachers who also realized the need for a team, a community of practice to be collectively engaged in the thinking and planning of such integrations.

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Meaningful Hands-On Professional Learning for Teachers: Building up a Constructionist Practice Through Circles of Inventions

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Abstract: Professional learning for in-service teachers, so necessary for education, can be a challenge for teachers in public schools in Brazil with lack of time and resources. Proposing innovative maker-centered learning may be complex for many homeroom teachers who have never, themselves, experienced a maker-centered classroom. In this paper, we share the design of a workshop to introduce constructionist learning to educators, that is planned around the Circles of Inventions framework, that is easily adapted to different contexts, while bringing up the value of experience itself and metacognition to the professional learning process.

Introduction / objectives

Professional learning for in-service teachers is an ongoing need for education practices to be reviewed, reflected upon and for best practices and research findings to enter classrooms and affect the learning of students. Organizing meaningful and profound professional learning experiences for in-service teachers, however, in the context of Brazilian public schools, is a significant challenge for school leaders and teachers with very limited time available to learn, work and plan together. For the last 5 years, the authors have implemented numerous learning experiences using a framework named Circles of Inventions (Ricci P., Lederman K. S. and Junqueira R. 2019) - which includes reading, making, reflecting and the sharing of new narratives and thoughts - with students in public schools and in other educational settings, as well as with educators, in Brazil and abroad. This framework has allowed for interesting professional learning processes related to Constructionism, through 2 hour workshops, that are accessible and profound as they enable teachers to: 1. immerse themselves as students, 2. think with their hands, 3. have their voices heard, 4. connect to other practitioners in a meaningful way, 5. make connections to their own curriculums and 6. work in groups in an equitable way. This paper intends to illustrate the design and implementation of this workshop in different contexts and highlight the challenges and learnings from these implementations to spark further discussion on how this framework may be used in diverse professional learning settings with multiple different learning outcomes intended.

Design

In order to foster a constructionist learning experience, where something meaningful, shareable and thought provoking is created (Papert, 1991), among teachers who are not necessarily familiar with maker centered learning practices, we came up with a variety of Circles of Inventions workshops which bring up the value of experience itself and allow for a metacognitive experience for teachers to think about their learning as well as of their teaching. For each group of teachers and each singular occasion, we chose specific texts capable of catalyzing a creative process, reflection and the articulation and sharing of new ideas. Elements that are aligned with constructionism and the 4 P´s described by Resnick - Projects, Peers, Passion and Play. (Resnick, 2020)

The Circles of Invention are made up of three distinct moments: First, the **Circle of Reading** where a story functions as an immersion into a common territory of meanings which could be interpreted as a “microworld” to foster tinkering. This microworld may be interpreted as a safe place, a leverage for the child’s personal ideas to emerge, and subsequently the tinkering itself becomes a microworld for new narratives to emerge and for the learning of story building and storytelling. This cycle could be related to Edwards’ functional view on microworlds, where learners are expected to experiment, manipulate objects, engage in open-ended explorations as well as receive and interpret feedback, iterate and create new objects, solutions and challenges (Edwards, 1995. P. 144).

Second, the **Circle of Making/Tinkering** is not a moment to represent one’s understanding of the story, but a time and space to tinker, think with one’s hands about the questions raised by the educator. These prompts, must be carefully crafted to spark a possibility of inquiry and a creative process, individually or collectively. Third, the **Circle of Narratives**: a fundamental part of the framework where participants have the space and time to share their inventions and stories. From the thinking with these artifacts created, which connects to the concept of objects to think with (Papert, 1991) of constructionism, new narratives and thoughts emerge for the issues in question, as well as space is made for the participants to express themselves, be heard and also listen to peers. (Ricci P., Lederman K. S. and Junqueira R. 2019)

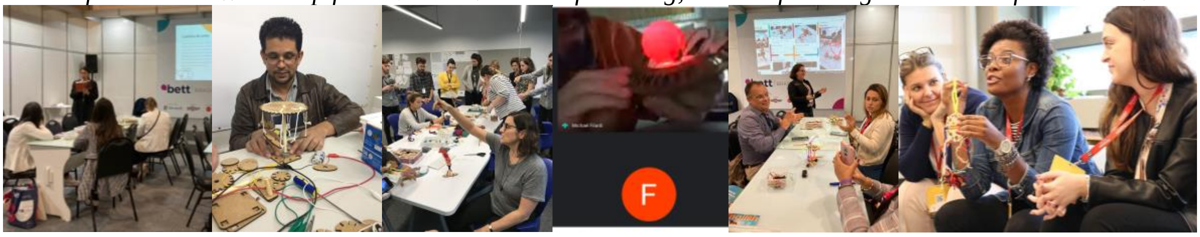
These professional learning workshops were designed to allow for equitable access into the learning experience, with low floors, high ceilings and wide walls (Resnick, 2020) and to fit in the busy schedules of public school teachers, both in urban and rural areas. The design of the workshop, carefully adapted to each context, also worked in educational congresses and conferences both in Brazil and abroad. Making visible the learning in the workshop is of utmost importance in this design, therefore in all workshops a digital sharable mural was used for the sharing of the participant´s artifacts, narratives, ideas and reflections derived from the workshop. The discussion and conclusions present in this paper were also informed by the evidence of learning made visible in these murals.

The design of the workshop comprises the following 6 moments. 1. Welcoming participants and introductions - creating a safe space for listening, thinking, making, sharing and reflecting. 2. The Circle of Reading - a carefully curated text is selected depending on the context and specific goals of the educators in the workshop, to spark thinking about a topic that leads the educators to reflect on their own and new educational practices. 3. In this stage of the workshop, the thinking routine Connect, Extend, Challenge (Ritchhart, Church, Morrison 2011) was adapted to provoke thinking about their own learning and teaching practices. In this adaptation, educators think about ways in which they connect to the text read, then extend their thinking through a group discussion related to their own practices and the ideas. 4. The third part of the thinking routine, Challenge, is transformed into a "making" challenge when the educators are invited to create an artifact to think with (Papert, 1991), to express an idea related to the previous discussion. This challenge, which becomes the Circle of Making/Tinkering, depending on the context, will be individual or in a group. During the Covid-19 pandemic, these productions were individual, but in in person workshops they tended to be as a group. 5. The sharing of this artifact with the group and the narratives that emerge are a vital part of the workshop. These narratives then feed the facilitators with information and insights for the final part of the learning experience, connecting everything to theory and practice. 6. The facilitators end the workshop sharing observations on the process, the artifacts and the reflections of the educators (students), making evident the big ideas and principles of Constructionist learning.

The design intends to be both a model for practices with students in diverse settings and disciplines, but also, and most of all, a lived constructionist learning experience that will spark thinking and possibilities for new meaningful and engaging approaches for teachers and students.

Figure 1

Circle of Inventions Workshop for educators. Circle of Reading, Circle of Making and Circle of Narratives.



Implementation

This workshop was implemented in at least 12 different educational contexts, such as urban and rural public schools, private schools, in an educational congress, in different conferences, as well as for research groups in universities in Brazil and abroad. The implementation described below will focus on one example of the workshop in an international conference with a multicultural group which we believe is representative of the experience. It is important to reiterate that in each context the reading offered and the provocation made were designed to be sensitive to the local audience, culture and specific workshop learning goals.

Soon after the lock down period was over, while teachers and students were beginning to go back to schools, we had a precious opportunity to design and deploy a Circle of Inventions with educators from around the world, during an online conference. For this event, we chose to read a poem by Maya Angelou, called Life Doesn't Frighten Me, celebrating the courage within each of us, while making fears visible. We chose this text believing that at that moment, the experience of fear was something really tangible for so many of us, something that connected people from different backgrounds and from where the participants can explore possibilities, tinker and build up meaningful and shareable "objects to think with" (Paert,1991).

For the challenge of making something meaningful, followed by the reading, we used another insightful Thinking Routine: "Imagine If" (Project Zero, Agency by Design, HGSE, 2018). We asked all the participants to answer, with their hands on, using materials available at their homes, the following proposition: Imagine If you could transform a childhood (or present) fear into something that puts you into action, makes you strong, and resilient. Build an artifact that could help you in this transformation.

Before the workshop, we shared with the participants a suggestion of materials that they could gather at home in order to tinker with during part of the meeting. When we have the chance to work with teachers in person, we use the Catalyst Kit, composed of sustainable items such as mdf pieces in organic and geometric shapes, pegs, rubber bands, pipe cleaners and also LEDS, motors and batteries, when and if possible we may also include robotic boards or programing apps into the activity. In online settings we ask participants for available things such as aluminum foil, any kind of wire, pieces of cardboard, tape and other possible reusable materials to be used.

An example of an artifact created by one of the participants was built upon his fear of spiders. We used a padlet to encourage them to post brief narratives about their inventions, and what this specific participant shared was: “I am frightened of spiders. I imagined if.... I can turn the spider's web into a colorful pattern with nature inspired flowers, petals etc. that becomes a bouquet.” As participants share their artifacts and stories, it is a moment for facilitators to document aspects of these descriptions that may translate into important principles behind Constructionism and may be used as references at the closing of the session. In this workshop, it was also very evident how these authentic narratives that are born from each one's tinkering moment bring the group closer together, creating a safe space for exploration of ideas, discussion of sensitive topics and the building of a sense of community. The way in which all artifacts and stories are valued in the discussion and may bring new insights into a topic also allow for voices that may be silenced in other contexts, to find welcoming space and be listened to.

The discussion propelled by the artifacts and narratives, allowed for the building of understanding of the relevance of the Circles of Inventions as a practice that can be used with students in different occasions and disciplines, and also made possible for facilitators to pinpoint the main ideas behind Constructionism such as learn by doing, technology as a construction tool, hard-fun, learning to learn, freedom to make mistakes and learn from them. The Circle of Inventions, its process and products also springboarded the possibility of tackling constructionist concepts such as, 1. microworlds as they became immersed in the shared meanings of the story, 2. body sintonicity, as their whole bodies became engaged in the tinkering and sharing processes 3. debugging, as obstacles were reached during the “making” process, when iterations and reviews were needed to reach a final shareable object. 4. transitory objects, as they reflect upon how much thinking happened with the objects they created 5. powerful ideas, as educators think about teaching and learning, which are big ideas, as they listen, make and share. As one participant put it, in the digital mural: *“I loved the way this experience was designed - very refreshing. The narrative itself helps one to reflect upon one's own personal experiences and then motivates one to create something that is personally relatable and yet also more universal.*”

Conclusion

Having an object constructed by themselves, to think with and tell stories with, was extremely powerful and relevant for educators to make their thoughts visible, in the most varied contexts, from a professional learning session in Brumadinho in the interior of Brazil to a session at Teachers´ College, Columbia University. The process of making and tinkering with different materials was very significant for participants to elaborate new narratives provoked by the Circle of Reading. After running Circle of Inventions for six years, we can say that the narratives participants come up with would not be the same without having this opportunity to think with their hands, and notice new meanings and angles not previously thought of as regards to a subject. In one occasion for example, after the reading of a text on sandcastles that get washed away by the ocean, a teacher mentioned she initially could only think of a hole, but after the tinkering moment she had created a kite and shared a story related to the possibilities of escape and movement created by these transformations.

Experiencing with their bodies a Circle of Invention from the beginning to the end, and not only hearing or reading about the framework and its fundamentals, is crucial for the whole understanding of how powerful this practice can be. We have observed that educators that have participated in the workshop, feel confident and keen on implementing this constructionist practice, the Circles of Invention, in their classroom. The participation in a workshop helps them realize that: 1. It is a low floor practice that does not demand much previous knowledge related to making skills 2. With wide walls, the Circle of Reading opens numerous possibilities for integration with the curriculum, for socioemotional learning, and for connections between students and teachers. 3. And has tall ceilings as each participant, or a group, has the chance of making something really significant, meaningful and sophisticated, connected to previous knowledge and experiences, also valuing different ways of thinking and knowing into the group

For teachers who are not familiar with teaching and learning maker practices, the Circle of Inventions may be a comfortable place from where to start. Another key point is that the hands-on process is not oriented to a product that works, but actually to something that carries meaningful ideas and even feelings, something that makes thinking visible and shareable. For those teachers who are more into technology, the Circle of Invention framework contributes to bring back the “meaning ingredient” that unfortunately many times happens to be missing in highly equipped makerspaces. The artifacts can be drafted and created digitally and then fabricated with the use of 3D printers and laser cutting machines. The feedbacks below, received after implementing this Professional Learning Workshop using the Circle of Inventions framework, encourages us to engage in discussions to improve and spread even more this practice among other educators, in Brazil and abroad:

> *“…I think Circles of Invention are a brilliant idea that is full of possibilities for improvisation. I believe that the structure is one that builds a much-needed bridge from STEAM to social emotional learning. ….I also believe that something different happens when you allow people to "think with their hands" and then reflect on the wisdom that they can see in what their hands have made real. ”* Susan Klimczak
>
> *“I think the most relevant aspect of this experience was to relate an abstract thought to a tridimensional object. Not only did the ideas give life to the object but also the object gave life to new ideas.”* Participant in workshop

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Rural Science Teachers Collaborative Design and Iterative Implementation of Three-Dimensional Lessons

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Abstract: Rural high school science teachers often work in isolation with fewer collaborative and professional learning opportunities. One opportunity they have missed is deep learning about and how to implement three-dimensional science lessons. To bridge the geographic isolation of these teachers and increase their capacity with three-dimensional science, we developed a novel professional learning model called Technology-Mediated Lesson Study (TMLS). This engages teachers in iterative, collaborative cycles of lesson design, teaching, observations via technology, and lesson redesign with a team of colleagues aimed at high-impact professional learning and enactment. This paper presents the program design and activities with science teachers who collaboratively design and implement lessons using the TMLS model.

Introduction

A major challenge for secondary science teachers in rural schools is isolation: being the only science teacher in the school or the only teacher of a particular subject. As a result, rural science teachers have fewer or no opportunities for meaningful collaboration, even though collaboration is a key characteristic of effective professional learning. When professional learning is up-to-date, ongoing, collaborative, practice-based, and connected to local contexts (Kennedy, 2016; Desimone, 2009; Penuel et al., 2007) it is more effective at changing teaching practice. Lesson Study is an established professional learning model that has shown success (Cheung & Wong, 2014; Kanellopoulou & Darra, 2019) in meeting teachers' professional learning needs by improving collaboration, helping them examine their practice, and enhancing student learning.

In one western state in the United States, rural schools are organized around four regional education service centers in which participating school districts collaborate to improve instruction in their region. These regional service centers provide professional development in broadly applicable categories such as educational technology but lack the resources to support science-specific professional learning and enactment. In this state, new secondary science standards are being implemented in the schools. These standards are built from the National Research Council's A Framework for K-12 Science Education (NRC, 2012) that established the foundation for the Next Generation Science Standards. The new state standards are similar, also using three-dimensional learning, combining science practices, crosscutting concepts, and disciplinary core ideas.

Many of the urban districts in the state are already training high school science teachers in three-dimensional science teaching, while most rural teachers have not received any training on the new standards. The program described here is designed to address the lack of professional learning opportunities for rural science teachers by using technology to bridge the geographic isolation they experience. Building from lesson study (Lewis & Hurd, 2011), we developed a novel professional learning model called Technology-Mediated Lesson Study (TMLS). TMLS engages teachers in iterative, collaborative cycles of lesson design, enactment, observation via technology, and lesson redesign with a team of colleagues from their region, resulting in high-impact professional learning and enactment. Improved science teaching in these regions will provide equitable access to high-quality science for all students who live in the rural regions of the state, many of whom are economically disadvantaged.

The purpose of this paper is to present the program and collaborative design and enactment using TMLS with rural science teachers. Initially, a small cohort of teachers engaged in collaborative codesign activities building shared capacity around the three-dimensional science standards, developing professional learning materials and experiences for other rural science teachers, and enactment of newly designed lessons through technology-mediated lesson study. This cohort of teachers then worked with more teachers to engage in building their capacity with three-dimensional science and the TMLS process.

Lesson study

Originating in Japan, lesson study is an instructional inquiry model that involves a group of educators organizing together under shared goals focused on student learning and co-creating lessons to meet those goals (Lewis & Hurd, 2011). Four essential teaching tasks—designing lessons, teaching, observing and analyzing student responses, and reflecting on implications for future lessons—are all foci of the lesson study process (McDougal, 2022). Lesson study slows down the lesson creation process, allowing teachers to concentrate on critical elements, such as the planning and reflection stage, to which they may not otherwise devote significant time. They are also given opportunities to observe another teacher's lesson—an opportunity that, for many teachers, is not frequently available. Watching someone else teach allows the observers to focus on student learning and misconceptions, which teachers can miss while teaching due to divided focus across an entire class. This close observation can help the teachers think about the design process and how to improve the lesson so misconceptions can be addressed. The repeated steps of lesson study develop educators' knowledge and motivation for teaching and helps develop a robust professional learning community (Lewis & Hurd, 2011; Murata, 2011).

Technology-mediated lesson study

One of the practical difficulties of lesson study is accommodating teacher schedules so they can fully participate in a lesson study group (Choppin et al., 2020; Huang, 2020; Soto et al., 2019). For rural teachers it can be almost impossible to meet with other teachers in the same discipline as they are often at other schools a considerable distance away. Technology-Mediated Lesson Study (TMLS) utilizes technology resources to allow teachers to interact and learn together when not co-located. This interaction among remotely isolated teachers connects them with colleagues they otherwise would have no connection with, including those in other districts. In TMLS, teachers initially gather as a group, set a goal or purpose of the group; which might be learning something new about teaching and learning or new curriculum writing. They then collaboratively work on the aim of their group (e.g., writing a lesson plan). Taking turns, they implement in their classroom where they record the enactment and share it with their group. The implementing teacher reflects, and the other teachers comment on the enactment. Then they meet virtually where they discuss and revise, ready for the next teachers to implement with the updated materials.

Primary goals of the program

This program has three goals. First, principles: an innovative model for rural science teacher professional development via technology-mediated lesson study that supports translating professional learning into classroom practice through social support systems among rural teachers. Second, people: building expertise and capacity among the rural science teachers to support three-dimensional science teaching. Third, products: creating and disseminating high-quality three-dimensional science lesson plans aligned with the new state standards and the Next-Generation Science Standards that will be shared with teachers in the state and across the country.

Conceptual framework

The design and research activities of this work are built on an ecological model described by Sallis et al. (2008) for changing health behaviors and is applied to changing teaching practices to incorporate three-dimensional science teaching. Teachers choose instructional practices based on personal factors (e.g., attitudes, self-efficacy), social factors (e.g., peer, administrator, and student expectations), and contextual factors (e.g., physical, material, and time resources). The program targets personal factors by supporting rural science teachers' development of knowledge, self-efficacy, and positive attitudes about three-dimensional science teaching. Social factors via cohorts of subject-region teams provide a sense of community and support for the instructional changes needed for the new state standards.

Design and implementation activities

Design activities in this program are facilitated by the teachers and supported by the researchers. In the first year five researchers and four teachers, from the four rural regions of the state, met five times in-person in two-day workshops to learn more about three-dimensional science, design a three-dimensional lesson, implement the lesson, and engage in the technology-mediated lesson study process. In the beginning a shared knowledge of three-dimensional science was needed, and through different activities this shared understanding began to grow. Once a strong base of understanding was established, a lesson was designed. This collaborative process among the teachers required understanding of their different contexts within the rural settings. Some teachers were very geographically isolated, were the only science teacher at their school, or taught a variety of students with different needs, including academic and socio-economic challenges. This caused some complexities in the design of the lesson. This included, but was not limited to, selecting a phenomenon, finding the best examples to use in the lesson that would be understandable by all their students, and teacher preferences with the format of a lesson plan. The teachers knew that many areas of the lesson would be improved through the enactment and technology-mediated lesson study (TMLS) process.

Using TMLS, the teachers implemented their initial three-dimensional lesson plan. In this process, one teacher implemented the lesson and recorded it using a Swivl. After uploading the recording and providing some initial reflections on the enactment, the other teachers watched the recording and commented with questions, praise, and ideas for improvement. Then they meet as a group in Zoom to reflect and discuss the enactment and make changes to the lesson. Then, another teacher would implement the lesson and the whole process was repeated. After each of the teachers implemented the lesson a final design on the lesson was completed. The teachers assessed the lesson plan using the EQUIP rubric.

After the first year and small cohort of teachers, they collaborated with the researchers in designing a summer workshop for nine additional rural science teachers. This workshop introduced additional teachers to three-dimensional science and the TMLS process. The summer workshop was five days and in small groups, facilitated by the first cohort of teachers, a new science lesson was designed. In the first few months of the school year these three groups of teachers engaged in the TMLS process and iteratively redesigned and implemented their lessons. During the 2022-2023 school year, these teacher groups designed and implemented a total of four lessons per group (total of 12 lessons) aligned to three-dimensional science. Each group used the TMLS process as they refined their lesson plan.

What we have learned

We have learned that the teachers appreciate the process of collaborating together. Since the majority of them are quite isolated, they enjoy working together and focusing on three-dimensional science lessons (devoid of any school issues). It is pure design focused on the science. They enjoy the TMLS process because the technology provides a means for further collaboration and engagement together, but also because it has iteratively improved their lessons. They have improved their collaboration skills and made new connections. One teacher said, "It's so nice having other people…who have different strengths but then also different perspectives. They're going to notice things I don't notice. And it's so nice having a group that is very focused on creating content and not dealing with school drama. There's not external education problems. We're just creating content."

They have enjoyed observing each other teach. Many of these rural teachers do not have the opportunity to observe other science teachers as some are the only one in their building (or even district). They do not always like watching themselves teach, but they are learning from each other beyond the intent of this work. Many of the teachers expressed how surprised they were by how much they learned through the TMLS process. One teacher mentioned, "This has been the best professional development I've been involved in. Because of [other group members,] I can see the value in what we are doing. I can see the advantage of having three or four teachers in the same subject in a school." Another teacher said, "You go to a [professional development] meeting, they tell you what you're going to do and then you don't get the time to practice it, so you just kind of fall back into the same rhythm that you were in before. Whereas this [TMLS] model has been that they told us what was expected and then we had time to practice it. And then when it wasn't right, we had time to fix it and then have more time to fix it until it was to where we were happy."

They enjoy learning about and how to implement three-dimensional science. It is exciting for them to engage together, but more to observe changes in their students. They have observed engagement, motivation, and questioning/language changes with just one implementation of a three-dimensional science lesson. The large amount of time to collaboratively design and iteratively implement and redesign a lesson is worth the changes they see in their students. In changing about how they think about three-dimensional science now one teacher said, "The DCIs, the SEPs, and the CCs are now things that are conscious on my mind when I am planning a lesson; whether I implement every single one, every single lesson is another story. But they're in my mind, and I do my best to implement at least a couple of those things into each of the lessons I plan."

We have learned that group dynamics is a complex system and often is quite delicate too. Becoming close to each other, understanding each other, and learning how to work together are important elements to make the design and TMLS process successful. Each of the groups have been facilitated slightly differently by the first-year cohort teacher, but each group has made progress throughout the TMLS process. The program is an iterative process of learning and growing individually and as a group. Keeping our eyes on the purpose is important, that helps everyone remember their roles and responsibilities in the process.

What others can learn

Others can learn from our design and implementation activities. There are a lot of programs that target three-dimensional science, but not many focused in rural high school science teachers. Learning about who they are connected to and how to help them connect is important. We have learned that technology is a powerful tool that can be utilized in our favor. Technology can connect people and can be used for design and observation activities. With that, lesson study is a powerful tool for connecting teachers and designing and implementing lessons. Even teachers who are not isolated could find ways to use technology and technology-mediated lesson study in positive ways.

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